

the reference levels of indoor radon concentration were redefined: action level 400 Bq·m<sup>-3</sup> of indoor radon concentration for existing houses; guidance level 200 Bq·m<sup>-3</sup> of indoor radon concentration for new buildings; guidance level 1000 Bq·m<sup>-3</sup> of indoor radon concentration for workplaces.

In 2004, the new uniform method for radon risk classification of foundation soils was published and accepted (NEZNAL et al. 2004).

In 2005, the governmental rules for purchasing and supporting remediation activities, as well as the Decree of the State Office for Nuclear Safety on radiation protection (No. 499/2005) were modified. The investigation level of indoor radon concentration for workplaces was changed to 400 Bq·m<sup>-3</sup>.

In 2006, the last modification of the Czech National Standard CSN 73 0601 Protection of houses against radon from the soil appeared.

Basic principles of the current Czech radon programme can be summarized as follows:

(i) protective measures, that should not only reduce exposures to radon in new buildings (preventive measures), but also in existing dwellings (interventions; remedial measures);

(ii) legislation for regulation and control of all potential radon sources (radon from soil, building materials, water);

(iii) quality control system – the detailed assessment of radon in soils is an integral part of building permission, the planning authorities are responsible for their approvals, all producers and importers of building materials and all drinking water suppliers are controlled by inspectors of the State Office for Nuclear Safety;

(iv) surveying the situation – representative survey of radon occurrence in houses in the whole territory of the Czech Republic and targeted survey in dwellings with higher radon concentrations;

(v) improving the radon awareness of the public and all state authorities; informative materials;

(vi) assistance to people owning the houses with higher indoor radon levels, offer of a state financial support in special cases;

(vii) development of measurement techniques and of protective measures; support of the research.

### 3. Methods of measurement

In general, the measurement of soil gas radon concentration (= volume activity of radon in the soil air) is based on the detection of the radioactive decay effects of radon and its decay products. Since radon and its decay products are emitting alpha and/or beta particles as well as photons in principle the whole spectrum of detectors can be used for measurement in combination with a suitable sampling technique (URBAN and SCHMITZ 1993, HARLEY 1992).

If radon containing air is admitted to the electrical field the radiation from the decaying atoms ionizes the air. Just this effect represents the principle of ionization chambers: the charge carriers are accelerated to the electrodes of the

chamber and the resulting current is detected as a measure of the quantity of decayed radon atoms. Another detection method is based on special properties of scintillation materials [ZnS (Ag)]: the energy of alpha particles is converted into scintillation photons, which are registered in a photomultiplier tube. The ability of heavy ionizing radiation to create remaining changes in the structure of solids is used in solid state nuclear track detectors or thermoluminescent detectors.

As for the current situation in the Czech Republic, some methods are commonly used, even in a commercial practice. Other methods are used only rarely, namely for research purposes.

Depending on the resulting parameter there are three groups of measuring techniques:

(a) instantaneous measurement (grab sampling) resulting in an instantaneous value of soil gas radon concentration;

(b) integral measurement resulting in an average soil gas radon concentration related to a chosen measuring interval;

(c) continual measurement resulting generally in a sequence of average (or instantaneous) values of soil gas radon concentration.

#### 3.1. INSTANTANEOUS MEASUREMENTS

Instantaneous methods represent prevalent measuring techniques in the Czech Republic. They form a base for the assessment of radon index of building sites (NEZNAL et al. 2004). They consist of two steps: (i) collection of a soil gas sample, and (ii) determination of radon concentration in the collected soil gas sample.

##### 3.1.1. Soil gas sampling

The history of soil gas sampling system development is relatively long and a large spectrum of methods that are available for collection of soil gas samples have been described, starting from complicated systems such as packer-probe used by TANNER (1988), or a small-diameter probe used by REIMER (1990).

The observed spatial variability of soil gas radon concentration (see Chap. 3.1.3.) and a consequent need for a method that enables to collect a large number of soil gas samples in a short time period resulted in the proposal of a very simple sampling system, the description of which was published more than 15 years ago (NEZNAL et al. 1991).

The sampling system consists of a small-diameter hollow steel probe with a free, sharpened lower tip. The probe is pounded into the ground to a desired depth below the ground surface using a hammer. A punch wire is then inserted into the probe and the tip is moved a few centimeters lower using a hammer again. This action creates a cavity at the lower end of the probe. A cap containing a rubber stopper and a needle is placed on the open upper end of the probe. The soil gas is sucked and samples of a controlled volume are collected using a large-volume syringe (see Fig. 3-1).



Fig. 3-1. Soil gas sampling: (left) Inserting the sharpened tip into the lower end of the probe. (center) The sharp tip is moved a few centimetres lower – this action creates a cavity at the lower end of the probe. (right) Soil gas sample collection using a syringe.

The entire system must be perfectly sealed. The use of a sampling system that is not perfectly sealed, or that does not reach a sufficient level of underpressure to collect gas samples in soils of low permeability, may result in an underestimated soil gas radon concentration. Values of soil gas radon concentration smaller than  $1\text{ kBq} \cdot \text{m}^{-3}$  are usually excluded from the evaluation because of possible sampling error.

The internal volume of the cavity, which is created at the lower end of the sampling probe, must be large enough to enable the sample collection. The soil gas samples are collected from a depth about 1.0 m below the ground surface (the depth of 0.8 m below the ground surface is used in the Czech Republic). If the soil gas samples cannot be collected due to extremely low soil permeability, high groundwater saturation, or presence of shallow, solid rock layers, some modifications can be used. If the soil permeability is very low, the cavity at the lower end of the sampling probe can be enlarged by retracting the probe about 10–15 cm toward the surface. Sometimes (upper soil layers with higher permeability are not reached, the probe remains fixed in the soil, as well as contamination of the soil gas by atmospheric air can be avoided) the probe

can be retracted to 0.5 m below the surface, while maintaining the perfect sealing of the whole system. A similar approach is often used when the sampling layer is saturated with water. However, all deviations from the standard sampling depth should be reported.

The capacity of the soil as a source of radon is large enough to get a satisfactory reproducibility of measured soil gas radon concentration in repeatedly collected samples (see Fig. 3-2).

### 3.1.2. Determination of soil gas radon concentration

Radon concentrations of soil gas samples are measured using Lucas cells (scintillation method), or ionization chambers, i.e. the alpha particles emitted during the disintegrations of radon and its short-lived decay products are used for the detection of radon. The gradual decay of each atom of radon is accompanied by the emission of three alpha particles: disintegration of  $^{222}\text{Rn}$  – alpha particle energy of 5.5 MeV, disintegration of  $^{218}\text{Po}$  – 6.0 MeV, and disintegration of  $^{214}\text{Po}$  – 7.7 MeV. When the soil gas sample is introduced into a Lucas cell, or into a ionization chamber,

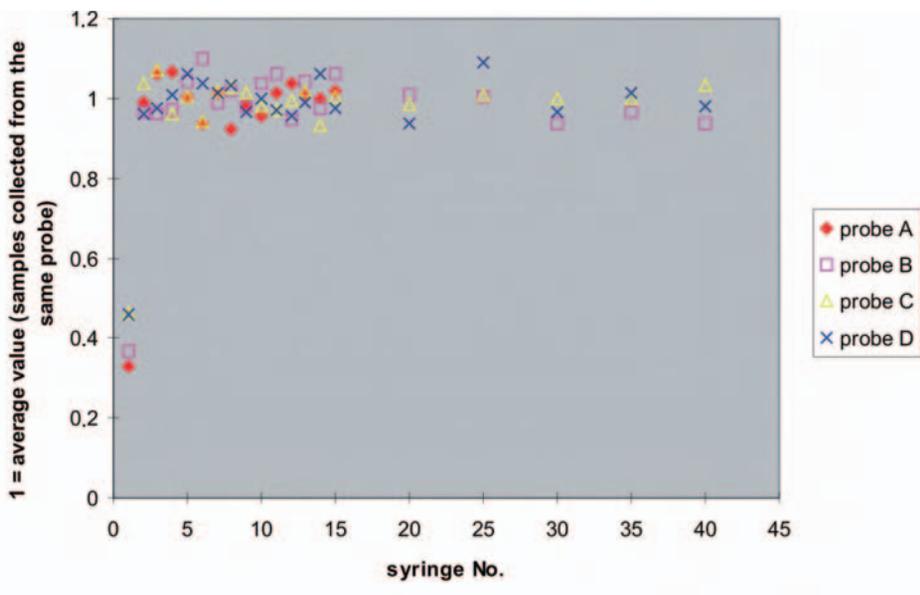


Fig. 3-2. Measurement of soil gas radon concentration in samples collected from the same probe (repeated sampling).

the average number of registered alpha particles significantly changes in time. At first, it increases rapidly due to the growing activity of radon decay products. The equilibrium is reached approx. 3 hours after the introduction of the soil gas sample into the detector, after that the average number of registered alpha particles decreases slowly.

The exact mathematical description of the relation between the registered number of pulses and the measured soil gas radon concentration is complicated. But it is achievable if some simplifying assumptions are accepted. If we suppose that (a) no short-lived radon decay products are present in the soil gas sample in the moment the sample is introduced into the detector, and (b) the detection efficiencies of the alpha particles with different energies are the same, we can express the relation between the detected number of pulses (counts) and the measured soil gas radon concentration by the following equation:

$$c = [N(t_v, t_r) - N_b(t_v)] / K \cdot R(t_v, t_r) \cdot V,$$

where

c	[Bq · m <sup>-3</sup> ]	is the radon concentration in soil gas (or in air) sample,
t <sub>v</sub>	[s]	is the time of counting,
t <sub>r</sub>	[s]	is the time delay between introducing the sample into the detector and the beginning of counting,
N(t <sub>v</sub> , t <sub>r</sub> )	[s <sup>-1</sup> ]	is the measured number of counts,
N <sub>b</sub> (t <sub>v</sub> )	[s <sup>-1</sup> ]	is the detector background corresponding to the time of counting,
K	[1]	is the average detection efficiency per one alpha particle,
R(t <sub>v</sub> , t <sub>r</sub> )	[1]	is the number of alpha particles, which will be emitted into the detector during the time interval from t <sub>r</sub> to t <sub>r</sub> + t <sub>v</sub> if the original introduced radon activity is 1 Bq,
V	[m <sup>3</sup> ]	is the volume of the soil gas (or air) sample.

The parameter R(t<sub>v</sub>, t<sub>r</sub>) can be determined using following equations:

(i) If t<sub>r</sub> > 180 min then

$$R(t_v, t_r) = 3 \cdot t_v \cdot \text{EXP}(-\lambda_1 \cdot t_r),$$

where

λ<sub>1</sub> [s<sup>-1</sup>] is the <sup>222</sup>Rn decay constant.

(ii) If t<sub>r</sub> ≤ 180 min then

$$R(t_v, t_r) = W_1 \cdot \text{EXP}(-\lambda_1 \cdot t_r) \cdot [1 - \text{EXP}(-\lambda_1 \cdot t_v)] - W_2 \cdot \text{EXP}(-\lambda_2 \cdot t_r) \cdot [1 - \text{EXP}(-\lambda_2 \cdot t_v)] + W_3 \cdot \text{EXP}(-\lambda_3 \cdot t_r) \cdot [1 - \text{EXP}(-\lambda_3 \cdot t_v)] - W_4 \cdot \text{EXP}(-\lambda_4 \cdot t_r) \cdot [1 - \text{EXP}(-\lambda_4 \cdot t_v)],$$

where

$$W_1 = (1/\lambda_1) + \{\lambda_2/[\lambda_1 \cdot (\lambda_2 - \lambda_1)]\} + \{\lambda_2 \cdot \lambda_3 \cdot \lambda_4/[\lambda_1 \cdot (\lambda_4 - \lambda_1) \cdot (\lambda_3 - \lambda_1) \cdot (\lambda_2 - \lambda_1)]\},$$

$$W_2 = [1/(\lambda_2 - \lambda_1)] + \{\lambda_3 \cdot \lambda_4/[(\lambda_4 - \lambda_2) \cdot (\lambda_3 - \lambda_2) \cdot (\lambda_2 - \lambda_1)]\},$$

$$W_3 = \lambda_2 \cdot \lambda_4/[(\lambda_4 - \lambda_3) \cdot (\lambda_3 - \lambda_2) \cdot (\lambda_3 - \lambda_1)],$$

$$W_4 = \lambda_2 \cdot \lambda_3/[(\lambda_4 - \lambda_3) \cdot (\lambda_4 - \lambda_2) \cdot (\lambda_4 - \lambda_1)],$$

and

λ <sub>1</sub>	[s <sup>-1</sup> ]	is the <sup>222</sup> Rn decay constant,
λ <sub>2</sub>	[s <sup>-1</sup> ]	is the <sup>218</sup> Po decay constant,
λ <sub>3</sub>	[s <sup>-1</sup> ]	is the <sup>214</sup> Pb decay constant,
λ <sub>4</sub>	[s <sup>-1</sup> ]	is the <sup>214</sup> Bi decay constant.

For λ<sub>1</sub> = 2.098 · 10<sup>-6</sup> s<sup>-1</sup>, λ<sub>2</sub> = 3.788 · 10<sup>-3</sup> s<sup>-1</sup>,

λ<sub>3</sub> = 4.311 · 10<sup>-4</sup> s<sup>-1</sup>, λ<sub>4</sub> = 5.864 · 10<sup>-4</sup> s<sup>-1</sup>:

W<sub>1</sub> = 1434180,

W<sub>2</sub> = 270.37,

W<sub>3</sub> = -9929.5,

W<sub>4</sub> = -5618.4.

Note: Under typical circumstances, the assumption (a) is fulfilled. The soil and the sampling system themselves play the role of a filter, which removes the radon progeny from the collected soil gas sample.

As can be seen in Fig. 3-3, the calculated (theoretical) values of R(t<sub>v</sub>, t<sub>r</sub>) are in a relatively good agreement with experimental values of R(t<sub>v</sub>, t<sub>r</sub>), which were obtained by repeated measurements of the same soil gas sample.

In practice, different measuring modes are used depending on the measurement purposes. In general, it is possible to start the counting in any moment after the transfer of the sample into the detector and to use the above mentioned equations, or it is possible to start the counting in a fixed time after the transfer of the sample and to calculate the value of the measured parameter using a calibration constant, which had been previously determined for the chosen time interval with a calibration source. Examples of measuring modes are presented in Chap. 4 (Instrumentation).

If the measurement starts shortly after the transfer of the sample into the detector the result may be influenced by the presence of thoron (<sup>220</sup>Th) in the soil gas. In this case, a repeated measurement of the same sample allows to estimate the thoron concentration in the soil gas.

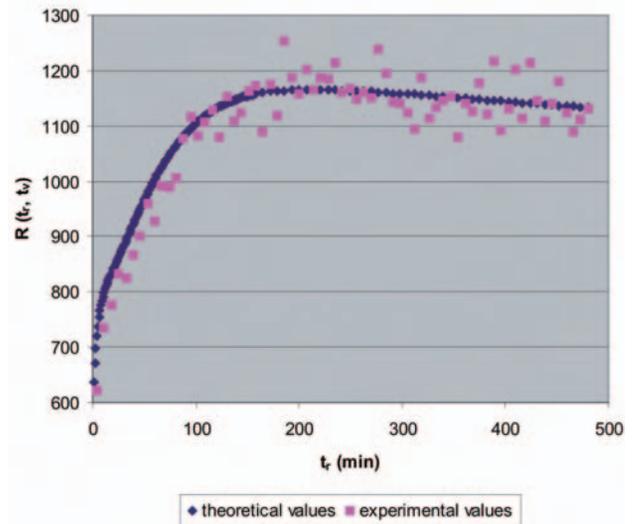


Fig. 3-3. Comparison of calculated (theoretical) values of R(t<sub>v</sub>, t<sub>r</sub>) and experimental values of R(t<sub>v</sub>, t<sub>r</sub>) obtained by repeated measurements of the same soil gas sample; t<sub>v</sub> = 400 s.

### 3.1.3. Observed variations

As the protection of new buildings against radon penetration from the ground in the Czech Republic is based on in-situ soil gas radon concentration measurements (see Chap. 6), possible influence of temporal variations of the measured parameter on the evaluation of results is very important. Several long-term research projects dealing with this problem have been carried out.

In 1990–1992, a 14-month observation of the soil gas radon concentration using two permanently installed probes at two test sites distanced several meters was performed (NEZNAL et al. 1992a). The geological structure was almost the same at both sites: sandstone weathering residuum covered by fine-grained sand with loamy admixtures. At site 1, the soil surface had been contaminated by natural radionuclides in the past. At site 1, the soil gas radon concentration values ranged from  $34.1 \text{ kBq}\cdot\text{m}^{-3}$  to  $91.8 \text{ kBq}\cdot\text{m}^{-3}$  (number of measurements: 270) with the arithmetic mean of  $60.2 \text{ kBq}\cdot\text{m}^{-3}$ , standard deviation (SD) of  $11.3 \text{ kBq}\cdot\text{m}^{-3}$  (SD/mean = 0.19). At site 2, following statistical parameters of the data set were obtained: range from  $3.0 \text{ kBq}\cdot\text{m}^{-3}$  to  $6.3 \text{ kBq}\cdot\text{m}^{-3}$  (number of measurements: 270), arithmetic mean =  $4.3 \text{ kBq}\cdot\text{m}^{-3}$ , SD =  $0.6 \text{ kBq}\cdot\text{m}^{-3}$ , SD/mean = 0.15. The general temporal pattern was represented by higher winter/spring and lower summer/autumn values, but seasonal variations were not so large. Short-term changes of radon concentrations at site 1 and at site 2 were often different, or even opposite. In 1992–1993, repeated soil gas sampling at five reference areas with different geological structure and soil permeability were performed (NEZNAL et al. 1995). Two different soil gas sampling methods were tested:

(a) “probes”, i.e. the standard sampling method using small-diameter probes (the probes were pounded into the ground anew every measuring day, i.e. the location of measuring points was not exactly constant.),

(b) “chambers”, i.e. the soil gas samples were collected from cylindrical chambers permanently installed in the soil.

Measurements were repeated nine times at 25 measuring points at each reference area, using both methods. Average values of soil gas radon were compared. Results may be summarized as follows: Only a weak relationship between average soil gas radon concentration and soil temperature, and between radon concentration and soil moisture was observed. It seemed to be different for different sampling methods. Different correlations coefficients were obtained at areas with different geological structure. It was concluded that observed temporal variations of soil gas radon concentrations often corresponded not only to real variations of the measured physical parameter, but also to fluctuations and errors connected with sampling and measuring techniques. The influence of changing meteorological conditions might not be as important as the influence of changing sampling depth, the influence of geological heterogeneities, and the influence of sampling and measuring errors. The highest values of average soil gas radon concentration obtained at any area during

a 1-y period were about two times the lowest ones (more exactly from 1.5 to 2.5).

In 1994–1995, measurements at the test site on the surface of the uranium mill tailings confirmed previous results (NEZNAL and PERNICKA 1996). Temporal variability of soil gas radon concentration expressed as the ratio (SD/mean) decreased with the depth below the surface: SD/mean was lower than 0.10 at the depths of 1.5 and 0.8 m, while it ranged from 0.13 to 0.25 at the depths from 0.5 to 0.3 m.

In 2000–2001, repeated measurements of soil gas radon concentrations at several test sites were performed. A satisfactory reproducibility of the evaluation based on in-situ soil gas radon concentration measurements was confirmed again. The sampling depth of 0.8 m represents a relatively good compromise between the required reduction of errors caused by the radon concentration variability and the required reduction of weather effects on the one side and the practicability of the method under field conditions on the other side. It is evident that all conclusions are valid for the geological and meteorological conditions that are typical for the Czech Republic, or maybe for Central Europe. The situation in other countries with a substantially different climate or geology may be different. In our experience, spatial variations of soil gas radon concentrations are more important than temporal ones. The soil gas radon concentrations may vary, often greatly, over a small distance. The occurrence of heterogeneities may indicate the presence of faults or tectonic zones (NEZNAL et al. 1991).

As the areas with a homogeneous geological structure and with a homogeneous soil gas radon concentration are rare, any evaluation based on a single measurement is almost worthless. Since 1991, at least 15 measurements of soil gas radon concentration are recommended when a building site for a single family house is evaluated (MATOLIN and PROKOP 1991). On the other hand, the occurrence of spatial variations represents a serious reason, why protection of a building should be based on the results of a building site characterization and not on large scale radon risk maps.

As for the changes of soil gas radon concentration with depth, a large research dealing with this topic was performed in 1993–1994 (NEZNAL et al. 1994b). Eight reference areas with various geological settings were chosen with respect to the characteristics of the underlying bedrock, origin, permeability and stratification of soil deposits, and depth and variability of groundwater level. Soil gas radon concentration as well as soil permeability were determined at depths of 0.3, 0.6, 0.9, 1.2 and 1.5 m. Fifteen measurements were made at each depth and at each reference area – average values were evaluated. Variability of radon concentration with depth was different at areas with different geological characteristics. Almost constant soil gas radon concentration was observed at areas with relatively homogeneous and highly permeable Quaternary fluvial sands covered by clayey loams, or in case of highly permeable eluvial deposits of Cretaceous sediments – sands covered by sandy loams. Insignificant increase of radon concentration with depth was measured at areas

with relatively homogeneous and medium permeable loess loam, while significant increase of radon concentration with depth was observed at areas with granodiorites characterized by extensive weathering and by high radon potential.

### 3.2. INTEGRAL AND CONTINUAL MEASUREMENTS

Different integral methods have been tested and used in the field of basic geophysical survey, namely in connection with the uranium prospecting: for example the alpha-card technique based on the measurement of the alpha activity of radon progeny deposited on the surface of a collector (unpublished reports of former Uranium Exploration Enterprise).

Also the track-etch detectors (TED/SSNTD) can be used not only for the determination of radon concentration in dwellings, but also for the measurement of average radon concentration in rocks, or in the soil gas. The method is based on the assessment of the alpha track density in a special film material, most often LR-115 (KODAK), or CR-39. If the alpha particle with a specific energy reaches the film, the transfer of energy causes a latent damage of the material. The film is then etched and the etching creates visible tracks.

As for the measurement of soil gas radon concentration at building sites, a special arrangement of track-etch detectors was proposed by TUREK et al. (1997). The CR-39 detectors were arranged into pairs with the active surface faced opposite one to another and with the narrow air gap between them. Two L-shaped metallic holders glued together using a double sided adhesive tape keep the detectors parallel at a properly chosen distance (0.5–7 mm). The soil gas containing radon comes between the detectors through the side opening. This arrangement serves to several purposes: (a) to define the rectangular air volume from which the alpha particles can be registered, (b) to control the detector response by changing the distance between the two parallel detectors, (c) to reduce the plate-out effect from outside, because the surface of the side opening is relatively small with respect to the detector surface, (d) to create thermally and electrically well conductive capsule for reducing humidity, condensation and electrostatic effect. The system has been tested in the field with good results, but it is not used in practice nowadays.

Integral methods decrease the influence of temporal variations of the measured parameter, because the response is summarized over a longer time interval (hours, days). On the other hand, the demandingness of integral methods is higher if they are compared with instantaneous measurements. And there are also other sources of errors. One of them was described by TANNER (1991): Passive detection of radon isotopes depends on diffusion of radon atoms from the sites of their generation to the location of the detecting or collecting device. Because some radon decays en route to a passive detector in soil, the radon concentration measured by the detector must be less than the concentrations in those soil pores where it is undiminished by diffusion

to the detector cavity. The true radon concentration may be significantly underestimated especially in moist soils, or when large detector cavities are used. As the soil moisture usually changes during a one-year cycle, a degree of underestimating may also change with time.

Continual monitors of soil gas radon concentration are based on two different approaches: (i) passive system based on a diffusion of the soil gas into the sensitive volume of the detector, and (ii) active ones, in which the soil gas is sucked from the soil continuously, or semi-continuously, and transferred into the detector. The passive systems are usually equipped by a semiconductor – silicon – detector (for example ALGADE – BARASOL; SARAD). A new active continual soil gas radon monitor with an ionization chamber is presented in Chap. 4.

At present, the continual methods are used only for research purposes in the Czech Republic.

### 3.3. INTERCOMPARISON MEASUREMENTS

Several international intercomparison measurements of soil gas radon concentration were organised in the past: Badgastein, Austria, 1991 (CLIFF et al. 1994), New York, U.S.A., 1995 (HUTTER and KNUTSON 1998), Praha, Czech Republic, 1996 (NEZNAL et al. 1997), Praha, Czech Republic, 2002 (NEZNAL et al. 2004a). It is obvious that from metrological point of view there are many serious problems connected with organizing any field intercomparison measurement of soil gas radon concentration and similar parameters, such as radon exhalation rate from the ground surface. The natural geological environment is almost never homogeneous. The soil gas radon concentration as well as the radon exhalation rate from the ground may vary, often very greatly, over a small distance, the variations of soil gas radon with depth are different under changing geological conditions. Field intercomparison measurements thus are not intended to be used as an intercalibration of methods and instruments. They are designed as an intercomparison of results obtained using different instruments and methods employed in the field in order to assess the ability to interrelate diverse measurements. Under these circumstances, values are not reported against a standard or reference measurement. Participants results are simply compared to each other, in order to obtain an indication of the collective precision of various measurements.

Geological conditions in a depth of soil gas sampling as well as conditions on the soil surface should be as homogeneous as possible at the test site. If these requirements are not fulfilled, a large variability of measurement results can be expected. On the other hand, any preliminary measurements should be limited at a chosen test site to avoid a situation that the upper soil layers will remind of a Swiss cheese.

Interesting results were obtained during a small intercomparison exercise in 2001 when the instantaneous, integral and continual methods were compared (NEZNAL et al. 2004b). It was concluded that the observed short-term temporal variations of soil gas radon concentration during

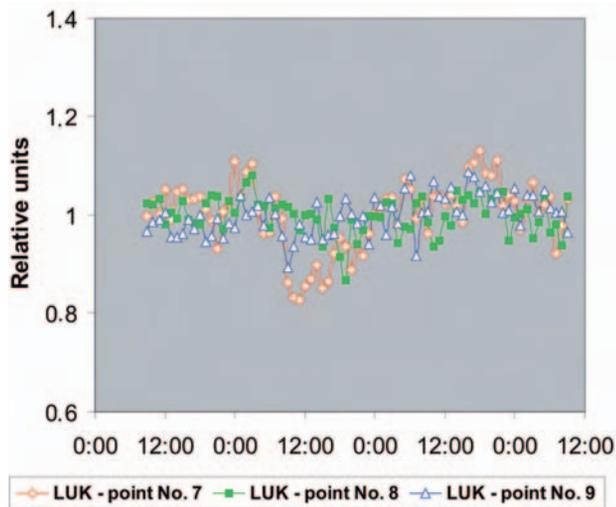


Fig. 3-4. Relative temporal variations of soil gas radon concentration – instantaneous methods; counting in the laboratory (devices LUK; measuring points No. 7–9).

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.

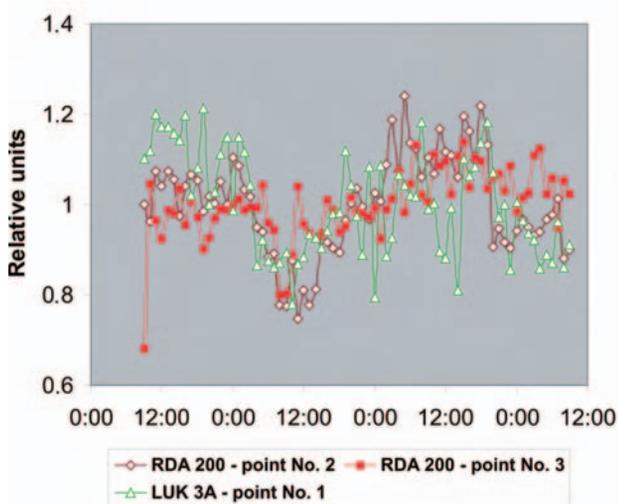


Fig. 3-5. Relative temporal variations of soil gas radon concentration – instantaneous methods; counting in the field (devices RDA 200, LUK 3A; measuring points No. 1–3).

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. There 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  $\text{kBq} \cdot \text{m}^{-3}$ , 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

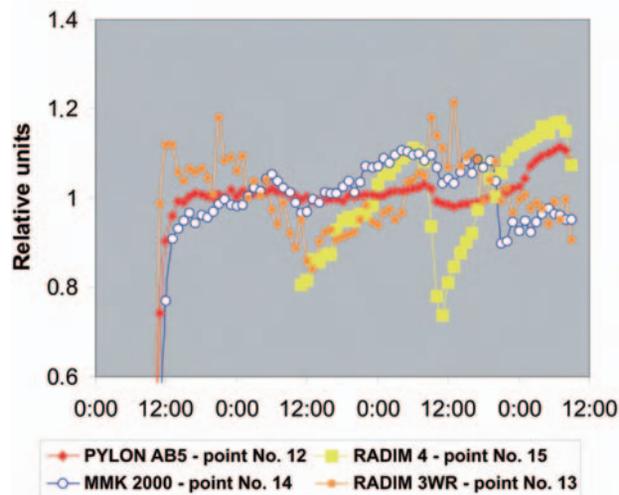


Fig. 3-6. Relative temporal variations of soil gas radon concentration – continual monitors (devices PYLON AB5, RADIM 4, MMK 2000, RADIM 3WR; measuring points No. 12–15).