U sorbed in bitumenous layer) holds a record in the extreme measured soil gas radon concentration within the Czech Republic (1633.9 kBq . m^{-3} mean from 15 test probes and 3218 kBq . m^{-3} maximum value). Younger sedimentary formations have not brought any radon surprise in the surficial measurements (mean for Cretaceous sediments – sandstones and claystones 17.4 kBq . m^{-3}), however we must not forget the existence of synform uranium deposit Stráž pod Ralskem situated in the basal Cretaceous sediments in the depth of 200 m. The manifestations of inreased radon concentrations in this area are bound to local fault systems. Paleogene and Neogene sediments are far away from usual radon ranges in bedrock. The Tertiary neovolcanites have mean radon concentrations about 23 kB.m^{-3} with exclusion of phonolites, which exceed in certain cases 80 kBq . m^{-3}. However, due to the steep relief of phonolite cones, these areas are not usually settled and therefore together with a limited areal extent the phonolites do not represent and important radon prone areas.

Quaternary sediments can be considered as a special question (?problem?) in radon geology. First, the area covered by Quaternary sediments (calculated according to the geological maps 1 : 50 000 covers the area of 31 167 km^2, which is nearly one half of the Czech territory. Second, due to the historical reasons, nearly 57 % of municipalities are situated on the Quaternary sediments (mostly fluvial, along the watersheds). Third, the Quaternary sediments are usually allochthonous, formed by mixture of material transported from distance (non usually exactly determined) sources and represent also the geological environment with great inhomogeneities in permeability. Therefore, the attention should be given to radon risk assessment with respect to underlying rock types and considering the original sources of the sediments.

Carpathian belt

The Carpathian belt represents the youngest orogenic event (Palaeogene – Neogene) on the territory of the Czech Republic. Concentrically arranged nappes exhibit the pressure field from SE to NW and they are formed mostly by flysch sediments – sandstones, claystones, siltstones and conglomerates. This rocks' composition does not produce any radiometric and soil gas radon anomalies itself, but sligtly increased indoor radon concentrations can be observed in the dwellings situated in the tectonically disturbed zones along the nappes' fronts and deeper fault systems perpendicular to them. The Palaeogene and Neogene sediments exhibit the range of radon concentrations between 15 to 20 kBq . m^{-3}, gamma dose rate between 45–65 nGy . h^{-1}.

2. Brief history of Radon Programme in the Czech Republic

The first reference to negative health effects of radon appeared in the 16th century: Paracelsus described a specific "miners disease" that occurred in silver mines in Jáchymov (Joachimstahl) and Schneeberg. The symptoms and the development of the disease differed from those of tuberculosis. But as late as in 1951, Bale discovered the reason: inhalation of short-term radon decay products. The discovery was followed by first epidemiological studies, in the Czech Republic organized by Ševc et al. (1993). Other papers (Åkerblom and Wilson 1981, Åkerblom et al. 1984) described radon from bedrock as a main source of daughter products in dwellings.

In 1956, Hultquist observed high indoor radon concentrations in Sweden. In 80-ies, high indoor radon concentrations were observed also in Czech houses, at first in houses built from materials with higher content of ^{226}Ra (aerated concrete Poříčí and slag concrete – START houses).

The first governmental resolution about radon, as well as the first proposal of the uniform method for radon risk classification of foundation soils appeared in 1990 (Barnet et al. 1990). At the same time, the first radon risk maps of the territory of the Czech Republic at a scale 1 : 200 000 were published.

In 1991, the Decree of the Ministry of Health of the Czech Republic on the requirements for limiting radiation exposure due to radon and other natural radionuclides (No. 76/1991) was accepted. Two basic reference levels of indoor radon equivalent energy concentration (EEC) were defined: action level 200 Bq . m^{-3} of EEC for existing houses; guidance level 100 Bq . m^{-3} of EEC for new buildings. Preventive investigation levels for the content of ^{226}Ra in building materials and of ^{222}Rn in supplied water were also defined. In the same year, the governmental resolution No. 520 about purchase and remediation of START houses, and guidelines of the Ministry of Finance giving the rules for purchasing and supporting remediation activities were published. A complete set of uniform measurement methods has been available. Two years later, the governmental resolution No. 709 supporting the search for high radon houses and remediation in schools and action on water supplies was accepted.

In 1994, a modification of the origin proposal of the classification method for radon risk classification of foundation soils was published (Barnet 1994a, b).

In 1995, the competency in the field of radiation protection was transferred from the Ministry of Health to the State Office for Nuclear Safety by the Law No. 85/1995. The first version of the Czech National Standard CSN 73 0601 Protection of houses against radon from the soil was published.

In 1997, the Atomic Law (No. 18/1997) containing regulation and control of all possible radon sources and the Decree of the State Office for Nuclear Safety No. 184/1997 on requirements of radiation protection were accepted. The Czech National Standard CSN 73 0602 Protection of houses against radon and gamma radiation from building materials was published.

The year 1999 is the year of the acceptance of the governmental resolution No. 538 about radon programme.

In 2002, the Atomic Law was modified (No.13/2002) and the new Decree of the State Office for Nuclear Safety No. 307/2002 on radiation protection was accepted. Also the reference levels of indoor radon concentration were redefined: action level 400 Bq . m^{-3} of indoor radon concentration for existing houses; guidance level 200 Bq . m^{-3} of indoor radon concentration for new buildings; guidance level 1000 Bq . m^{-3} 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^{-3}.

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 owing 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 ionisizes 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 detecors.

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).