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Relation of geological setting, soil-gas and indoor radon concentrations

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Abstract. Comparison of the results of soil-gas and indoor radon observations clearly show their dependence on geological-tectonic setting of the observation site. The paper presented deals with relations between the soil-gas and indoor radon concentrations and geological structure. It is evident that neotectonic faults are ideal pathways for movement and rising up radon emanations to the surface and, thus, to the dwellings. There, in case of permanent presence of high levels of the radon and its daughters´decay products may cause lung cancer of an inhabitants. The several cases abroad and in Slovakia are demonstrated.

Key words: geology, soil-gas, indoor, radon, concentrations

Introduction

The radioactive gas radon (^{222}Rn) and its daughters´decay products (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po and ^{210}Pb) represent 47 % of mean annual effective dose equivalent of radioactive irradiation of human being (UN, 1988). The ^{222}Rn is product of radioactive decay of ^{226}Ra. The source of the radon is uranium mineralisation in acide rocks-granites with pegmatite veins, acide volcanites-rhyolites, rhyodacites, dacites and their pyroclastics.

Due to its properties, the radon and its daughters´products may penetrate through geological medium from relatively great depths and on long distances from the source.

It is known from medical researches that high and long-term radon doses in dwellings have an impact on the excess incidence of lung cancer of their inhabitants. That is why radon problematics is widely studied all over the world.

Because indoor concentrations are dependent on the strength of the radon emanations source in geological basement, it is important to know the areas with the highest radon concentrations in soil gas, that is, those that have the potential for providing the greatest indoor radon concentrations that contribute directly to individual exposure. The geological data have to be used to estimate the relative emanation source strength, because soil types derived from underlying bedrock are a function of rock type and weathering. Follow-up soil-gas radon measurements provide a functional identity of the availability of radon and radon-movement potential. Both-geologic and soil-gas radon survey assessment-defines then areal boundary of the potential source of radon emanation. In simplest term, both the physical and chemical constitutions of the soil are important factors controlling local radon concentration. These parameters affect soil moisture, radium concentration, emanation and mobility.

The mobility is governed by permeability and the strength of the driving force, whether it is forced by flow or diffusion (Reimer, 1991).

Some case histories on geology-radon problem

Radon mapping in Luxembourg

The measurements of indoor concentrations in Luxembourg made before 1990 showed numerous dwillings with high values of „equivalent volume radon activity (EVRA)“, especially in the North. In order to detect houses with high radon levels, a campaign with long exposure-time solid state detectors started in 1990 and is still going on (Kies et al., 1994). About 110 800 houses were observed.

Despite of small surface of Grand-Duchy of Luxembourg, a great regional variability of indoor radon concentrations is noticed. The Eislek area in the North shows EVRA values substantially higher than in Gudland, in southern part of country. The reason of it is different geological structure of both regions. The Gudland is built by Mesozoic sequences with a thickness of some 1400 m which outcrop over 65 % of the country. Triassic and Lower to Middle Jurassic outcrop extensively where Tertiary has only small representations.

To the North the Eislek is a region of highly disturbed Paleozoic with extensive plateaus and deep, narrow valleys where metamorphic rocks of Eodevonian age are exposed. The Eislek is highly folded. In most lithologies rocks cleavage is developed. The faults are abundant here.

The results of 3-months indoor radon observations reflect different geological structure of both, Gudland and Eislek units. Gudland is characteristic by low radon levels (geometric mean 57 $Bq.m^{-3}$), while Eislek is typical by high levels (geometric mean 145 $Bq.m^{-3}$).

Percentage of houses with radon-gas concentrations above a fixed level is shown in Table 1.

These data show that the most important factor is the rock underlying the house. The local variability of indoor radon levels will be more detailed after survey based on radon-soil and soil gas permeability observations that are performed at present.

Table 1. Results of indoor radon observations in Grand-Duchy of Luxembourg.

Region	Number of houses	% of houses	% of houses >150 Bq.m^{-3}	% of houses >400 Bq.m^{-3}*	% of houses >800 Bq.m^{-3}
Luxembourg	110 800	100.0	16.2	3.7	0.8
Gudland	99 600	90.0	6.3	0.7	0.1
Eislek	11 200	10.0	40.1	10.7	2.5

*limit of EU

Radon in the Helsinki metro

The bedrock rocks of the Helsinki metro are granites and metamorphic complexes. Due to the fact that their uranium content is high and that the ground water contains high amounts of natural radioactive elements, mainly uranium and radon, the radon measurements in tunnel workings were started (Annanmäki & Oksanen, 1991). In the Helsinki metro the first radon measurements were made during excavation in 1972 and they showed that radon concentration of 2000 Bq.m^{-3} could be reached, if the ventilation was not working properly. Since 1975 regular measurements along the tunnel were made. The highest radon concentration measured was about 7000 Bq.m^{-3}, but normally the concentrations were lower than 500 Bq.m^{-3}. In most of places the concentration was lower than 200 Bq.m^{-3}. It has been estimated that the mean doses to the lungs of the workers are lower than 2 mSv/a and for typical passenger the dose is about 0.1 mSv/a.

Outline of natural radon occurrences on karstic terrains of Hungary

From 1978 the continuous radon observations were performed at about 150 sub and near-to-surface monitoring stations established in the most important karstic regions of Hungary (Csige et al., 1991). Most of the measuring sites were in cave air, infiltrated and inflowed waters of caves, karstic wells, springs and some in an observation shaft lowered the soil mantle above a cave.

The obtained time series of radon observations in cave air showed a great variety in the mean value (0.2-14 kBq.m^{-3}). However a periodical change of one year frequency and a long term variation manifested themselves as common and typical phenomena. In cave air summer maxima and winter minima were observed, their ratio falls in the range of 10-100.

The seasonal changes can be well explained by a simple air circulation model based on the assumption of periodically formed temperature gradient forced airflow of seasonally reversed direction through the fractured karstic strata. The results of soil gas measurements per-formed above a cave show radon maxima in winter and minima in summer (50.0 and 2.5 kBq.m^{-3} respectively). This observation supports the above mentioned model.

Soil gas radon observations in Frederick County, Maryland, USA

A study designed to test the geological-based and soil-gas techniques to estimate the Rn potential has been done in a/m region. This area was chosen for study because it represents a region of diverse geological setting. There are 3 physiographic provinces represented in the Frederick County with underlying rock types including the three major geological classifications of igneous, metamorphic and sedimentary.

The distribution of soil-gas Rn, measured in the depths of 0.75-1.0 m below terrain, varies throughout county and seems to be strongly related to the underlying geological unit or rock type, especially for high and low radon concentrations. In certain areas, such as the quartzite ridges in the western part, the soil-gas Rn concentrations are low. Other areas, such as metamorphic region in the southeast of the county have very high radon concentrations (Reimer, 1991). The overall radon soil-gas distribution and corresponding geological information correlates well with measured average indoor radon concentrations. In general, geological-based techniques seem to provide an excellent approach to estimate the Rn potential of an area.

Relationship between radon and geology in the south-west of England

In the south-west of England many homes have been found with high indoor radon concentrations. The high levels of radon in the dwellings are generally associated with parts of the region on or close to the areas of granite. The uraniferous granite is highly fractured and there are some major faults in the region. These offer a convenient pathway for the migration of radon originating in the bedrock. There may also be secondary uranium mineralisation within the fractures or faults generating higher levels of radon at the source (Varley & Flowers, 1991).

The concentration of radon in the soil gas has been measured at various geologically contrasting sites in the South-West. High levels of radon (up to several thousand Bq.m^{-3}) have been recorded over faults, whose position has been confirmed by other geophysical methods. Several houses haven been investigated too. It has been found that the measurement of soil-gas radon concentrations, used with geological data, has significant value as an indicator of high indoor radon levels.

Relations between neotectonics, soil-gas and indoor radon concentrations in Bratislava region, sw. Slovakia

The region of Bratislava Capital and its surroundings is tectonically highly disturbed. This (neo) tectonic setting creates excellent pathways for radon emanations rising up to the surface and, thus, to the dwellings. The area under study is built by Paleozoic granites and Mesozoic sedimentary complexes of Malé Karpaty Mts., by Neogene clayey-sandy sediments of Záhorská Nížina lowland

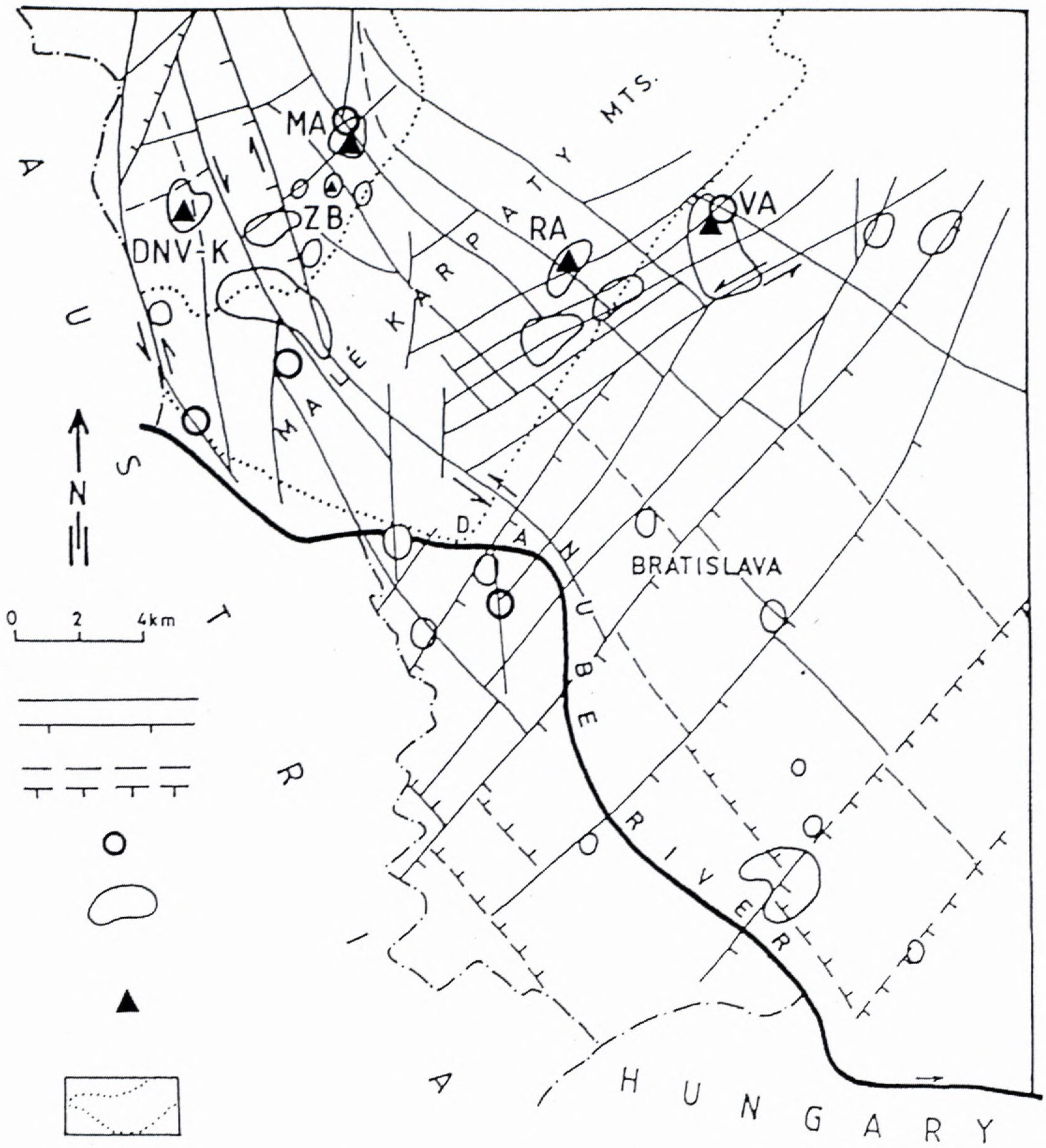

Fig. 1 Relation between neotectonics and radon risk in Bratislava region with location of indoor observations (J. Hricko, 1998).
1 – neotectonic and seismoactive fault expressive, 2 – neotectonic and seismoactive fault unexpressive, 3 – epicentre of the registered earthquake, 4 – area of high radon risk (in soil gasa of surficial layer), 5 – indoor radon observations (DNV-K: Devínska N. Ves – kolónia, ZB: Záhorská Bystrica, MA: Marianka, RA: Rača, VA: Vajnory, 6 – Malé Karpaty Mts. area.

and by Neogene and Quaternary sediments of Podunajská nížina lowland. The region is affected by tectonics of different ages and courses (Fig. 1). Some of the fault systems are seismo-active and still active (Hricko, 1998).

In frame of the multidisciplinary environmental project „Bratislava-environment, abiotic component" (Hricko, 1993) the Bratislava region was covered by regular soil-gas observations. The volume radon activity was determined in 0.80 m deep holes. The density of observations was 3 reference areas (each represented by 20 measuring stations at 20 x 20 m network) per 1 sq.km. The maps of radon risk prognosis on the scales of 1 : 25 000 and 1 : 50 000 are results of this radon survey. The 56.8 % of the area under study possess low radon risk, 37.6 % medium one and 5.6 % the high radon risk. The relationship between (neo) tectonic setting and distribution of areas with high radon risk is shown in Fig. 1. Follow-up indoor radon observations in dwellings lying at places with high radon risk of geological bedrock have manifested high radon levels. The indoor radon measurements have been performed in Devínska Nová Ves, Marianka, Rača and Vajnory localities. The values of equivalent volume radon activity (EVRA) from 6 months long observations have brought unfavourable results in some houses. The examples of the highest radon level: Marianka: 698.0 Bq.m^{-3}; Rača: 905.0 Bq.m^{-3}; Vajnory: 566.0 Bq.m^{-3} (Nikodemová et al. in Hricko, 1993). All these houses lie in high radon risk area and they are situated at neotectonic faults.

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For assessment of healthy risk of the inhabitants, the results of long-term measurements in 257 dwellings of Bratislava Capital have been used. The further dosemeters were placed to the flats lying in high radon risk, determined by soil-gas radon observations: 27 in Marianka and 48 in Devínska Nová Ves, Záhorská Bystrica, Rača and Vajnory villages. The assessment of healthy risk of the inhabitants concerning assumed deaths on lung cancer has brought following results: In Bratislava City, seven deaths on lung cancer per annum for 100 000 persons may be assumed, while in Marianka village twenty-eight (!) ones, caused by radon presence (Nikodémová et al. in Hricko, 1993).

Conclusions

The soil-gas and indoor radon observations done in different countries have brought evidence that there is a close relationship between geological-tectonic setting and radon levels in the bedrock gas and in the dwellings.

The most convenient pathways for rising up radon emanations to the surface and then to the dwellings are (neo) tectonic faults and fault systems.

The highest radon levels have been measured at dwelling, located in the areas with high values of the radon volume activity in soil gas of the bedrock surficial layer.

The permanent high level of radon and its daughters´products in dwellings may cause the lung cancer of their inhabitants.

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