INFLUENCE OF UNDERGROUND MINING ON THE GEOGENIC RADON POTENTIAL

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Abstract

Different aspects of the geogenic radon potential in a coal mining area in south-western Germany are discussed. Due to the rather low specific radium activities of rocks and soils varying between 10 and 70 Bq/kg a low geogenic radon potential can be expected. Radon concentrations in soil gas in abandoned mining areas are characterized by a lognormal distribution with a median value of 20 kBq/m^3. In the neighboring area with deep mining generally younger than two years, radon contents increase up to a median value of 38 kBq/m^3. The radon background in mining areas can be superimposed by an advective, structurally controlled component. Actually, narrow mining induced fracture zones constant in time and adjacent to the mining area often show radon peaks in soil gas four to five times higher than the background reaching values of more than 100 kBq/m^3. A positive correlation between methane and radon at methane degassing spots is probably caused by a CH_4 flow, which collects radon from the soil and carries it up to the surface. Indoor measurements in about 100 houses over a period of three months were conducted. The radon concentrations on ground floor are not influenced by the mining activities. In the basement, however, higher radon concentrations were detected. A time-dependent spatial shift of high indoor values following the direction of underground coal mining can be explained by the disturbance of the rock system strength in the subsurface leading to tectonic movements just above the recent mining area.

Key words: deep mining, geogenic radon potential, indoor radon, radon in soil gas

1 Introduction

The breakdown of drifts and crosscuts following underground coal mining leads to drastic disruptions at the surface known as subsidence. These movements change the fabric of the rocks generating sufficient pathways for an enhanced migration of soil gases in the subsurface. Therefore, mining regions are considered to be potentially radon affected areas (Lehmann et al., this volume; Wysocka et al., 1995). To find evidence for the expected influences of underground mining, detailed geologically based field measurements were carried out on the evaluation of the geogenic radon potential (Kemski, Klingel, Siehl, 1996a; fig. 1). Selected rock and soil samples have been analyzed by gamma spectrometry for their radium contents. Investigations along profile lines crossing zones of mining indurced tension and at methane degassing spots were used to estimate the existence and the extent of an additional advective component of the radon signal. Finally, possible effects of mining activities on radon concentrations in buildings were verified by an indoor survey.

2 Study area

The study area is situated in the southwestern part of Germany in the Saarland. Coal mining is the most important industry since the beginning of this century. The densely populated area has a size of approximately 6 km^2. Subsidence problems always occur after a new exploitation of coal bearing beds in the underground.

Conglomerates, sandstones, siltstones and shales with layers of hard-coal of Carboniferous age (Westfal) are the typical rocks in this area. In its eastern part they are covered by young terrace sediments of the Saar River, in the south by flat lying sedimentary rocks of Rotliegend (Permian) and Buntsandstein (Triassic) age. Two different types of soils can be differentiated in the investigated area. Eutric cambisols with a depth of less than 1 m and with high permeability are derived from sandstones and conglomerates. Soils developed from deeply weathered siltstones and shales can be classified as gleyic luvisols with low permeability.

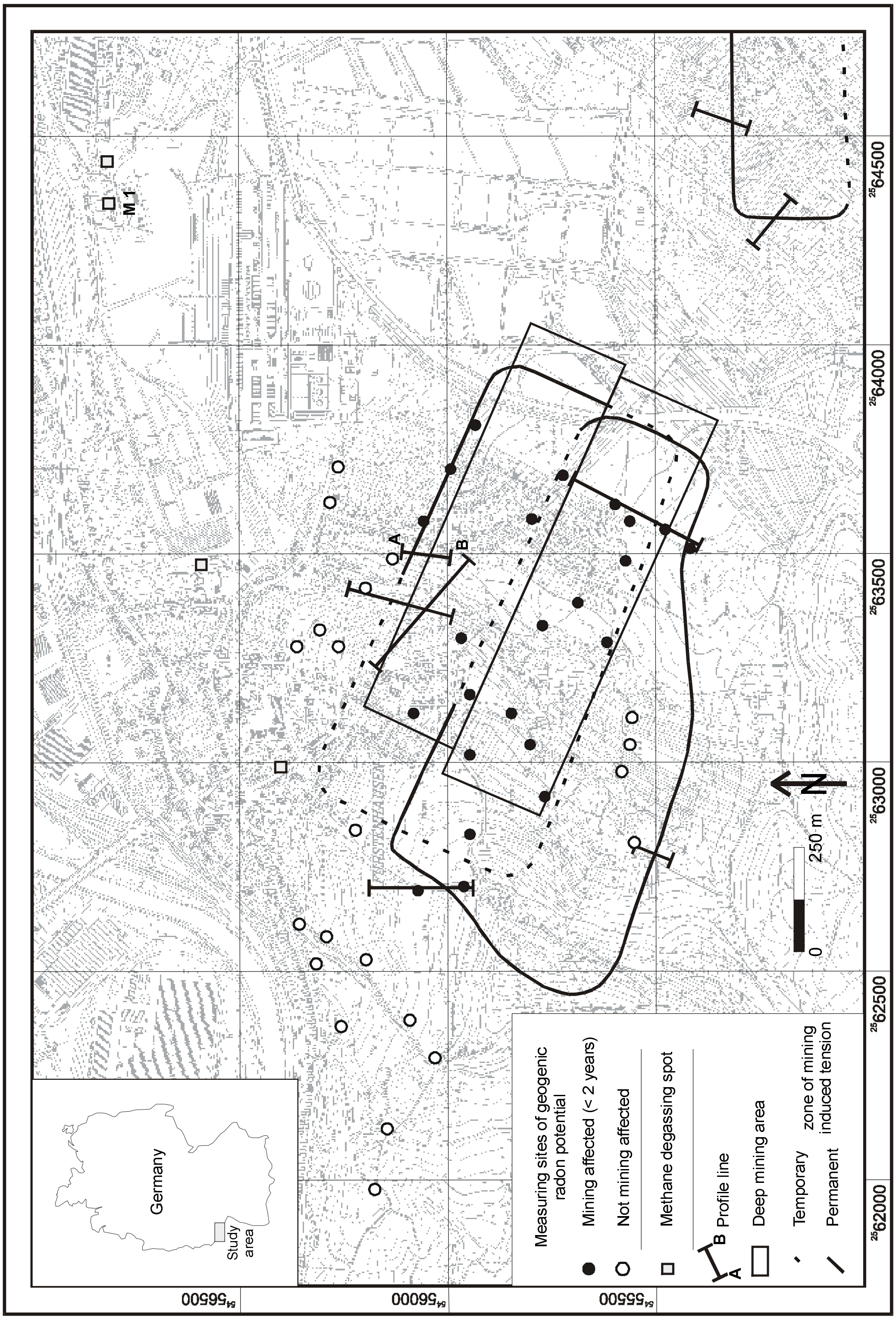

figure 1: Map of measuring sites in the study area

3 Measurement methods

Evaluation of the geogenic radon potential is based on a standardized procedure for radon measurements (Kemski, Klingel, Siehl, 1996a). An active spot measuring system with a scintillation counter and Lucas cells was used to measure radon concentrations in soil gas. At each measuring site, three boreholes of 1 m depth were drilled. After pumping 10 l of soil gas from the borehole to avoid contamination of atmospheric air, two gas samples of about 100 ml were taken at each site. The maximum radon value was used for evaluation. Gas permeability of the soils was ignored in this campaign, because it was generally lower than 10^{-14} m^2. All radon measurements were completed within four weeks under the same meteorological conditions, therefore seasonal variations in soil moisture and atmospheric pressure could be neglected.

Investigations at the profile lines and the methane degassing spots were conducted in a similiar way with the drilling of just one hole per measuring site. Methane was measured *in situ* by heat conductivity (AUER M 510).

4 Results

4.1 Radium in rocks and soils

Rocks and soils were examined for their specific radium activity to test for geochemical anomalies. Coals are characterized by very low radium contents, often below 10 Bq/kg. In all other rocks specific activities vary between 10 and 70 Bq/kg with a median value of 33 Bq/kg. These results fit very well to the known ranges of radium activities in other sedimentary rocks (Kemski, Klingel, Siehl, 1996b). Although weathering processes increase the content of resistant minerals with radionuclides in soils, the specific radium activities of the investigated soils are lower ranging between 20 and 30 Bq/kg with a median value of 26 Bq/kg. The deposition of loess as well as the leaching effects may have caused the decrease of radium activities. In soils with a low gas permeability radium is the only source for the diffusive component of radon in soil gas. Due to the rather low specific radium activities of rocks and soils a low geogenic radon potential can be expected.

4.2 The geogenic radon potential

Radon measurements at 44 sites have been performed in soils overlying Carboniferous rocks and in terrace sediments of the Saar river to evaluate the geogenic radon potential. Radon concentrations show a lognormal distribution, which is typical for such data. They range from 2 to 98 kBq/m^3 with a slightly increased median value of 27 kBq/m^3 compared to the known value of 21 kBq/m^3 for Carboniferous rocks in the Saarland (Kemski, Klingel, Siehl, 1996c). Data were summarized in two groups (fig. 2). Group 1 summarizes all locations, which have remained largely unaffected by the previous mining, as well as those, where the deep underground mining did not occur within the last two years. Group 2 encompasses all locations with recent mining activities (younger than two years). In the area unaffected by mining, the median value is 20 kBq/m^3, whereas in the mining area, the median value increases to 38 kBq/m^3. This difference can be contributed to the influence of mining. Especially, the subsidence following deep mining generate pathways for gas migration.

4.3 Zones of mining induced tension

As a consequence of mining activities, the rock system strength is disturbed leading to a roof break in the underground stopes. Tectonic movements in the overlying rocks are the most common feature. At the surface the area generated by mining subsidence forms a depression zone (fig. 3). This area is larger than in the actual underground mining area. The subsidence in the depression zone can be described as a long lasting dynamic process. The highest rate of subsidence at the surface reaching up to two centimeters per day occurs approximately two months after the mining of the respective area. One year after the beginning of the subsidence, 75 % of the movements have been accomplished, hence continuing for about two years after the end of mining. On a circular zone around the mining area – the zone of mining induced tension - the cracks and fissures remain open for longer time periods. It is not a single lineament, but a cluster of narrow linear elements with a lateral extension up to more than 50 meters.

Soil gas measurements of CO_2, radon or helium are well established as a tool for the mapping of faults or fracture zones. Gas peaks at the surface are situated above the outcrop of these

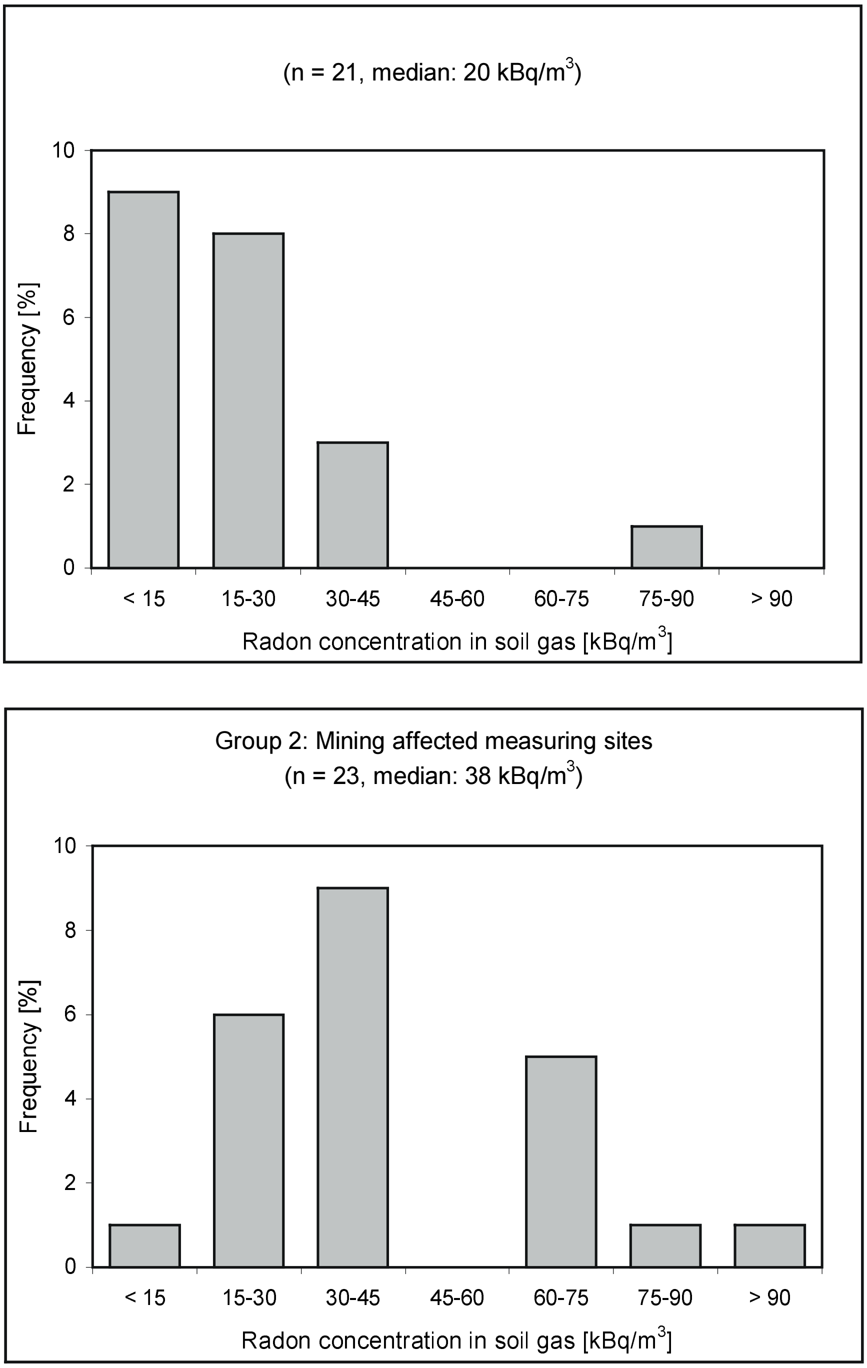

figure 2: Frequency distribution of radon concentration in soil gas

pathways indicating the structural controlled gas transport. The mining induced disruptions at the surface can be also detected with the application of this method. Therefore radon concentrations in soil gas were measured along several profile lines of 100 and 350 meters in lengths crossing the zone of mining induced tension. The influence of morphology, the type of soil, and the water content on the radon concentration could be neglected. For each line radon concentrations clearly above the local background of 10 to 20 kBq/m^3 were detected, reaching

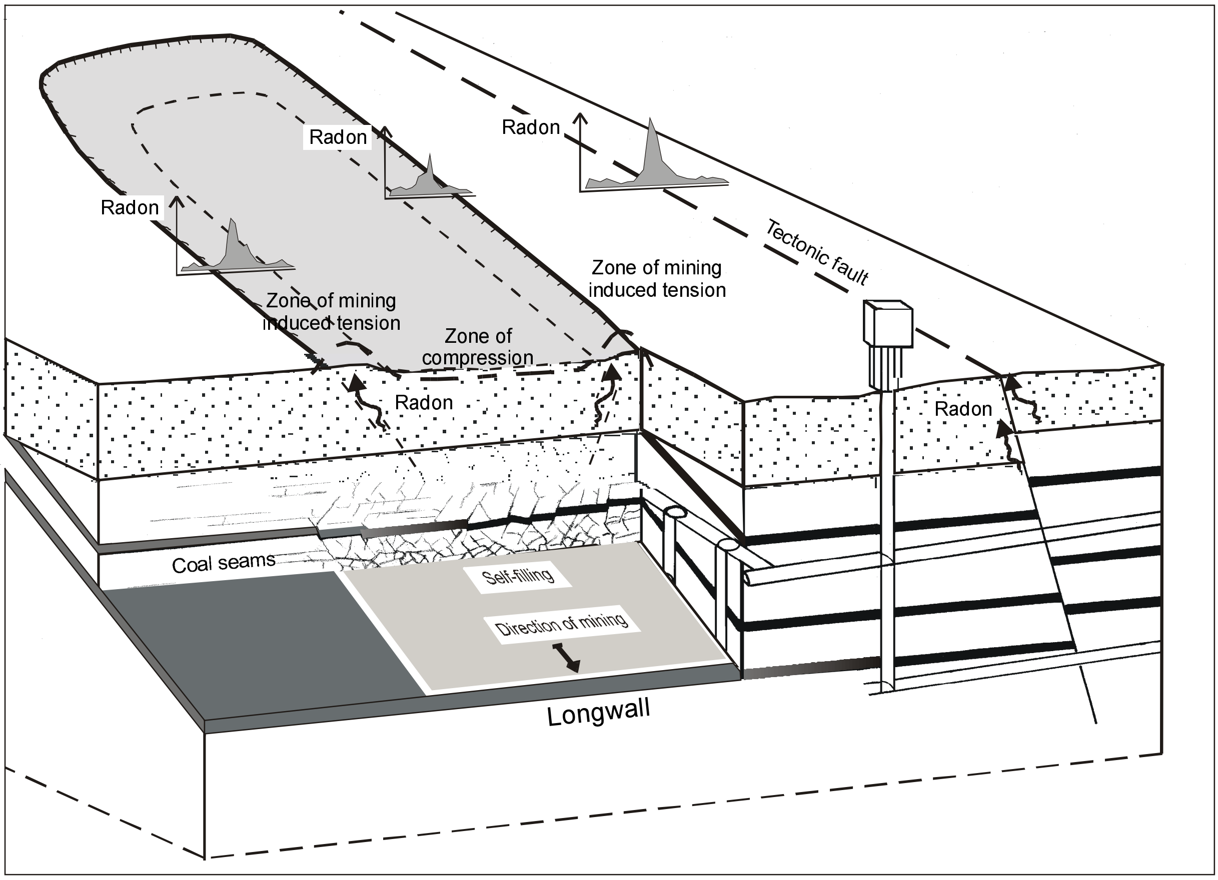

figure 3: Radon migration above deep mining affected areas and tectonic faults (modified after Palm, 1993)

from 40 kBq/m^3 (fig. 4) up to more than 100 kBq/m^3 in profile lines in the western part of the investigated area. The close relationship between the predicted zones of mining induced tension and the peak maxima indicates an advective component of the radon signal. Radon measurements at mining induced zones of tension, where mining activities have been finished more than five years ago, prove, that the position of the radon anomalies are constant over a longer period.

4.4 Methane and radon

Methane (CH_4) is generated, accumulated, and stored in the rocks during the process of formation of hard-coal. It can be released, if cavities and other pathways in the bedrock exist, enabling the gas to migrate to the surface. Therefore, methane can act as a carrier gas for

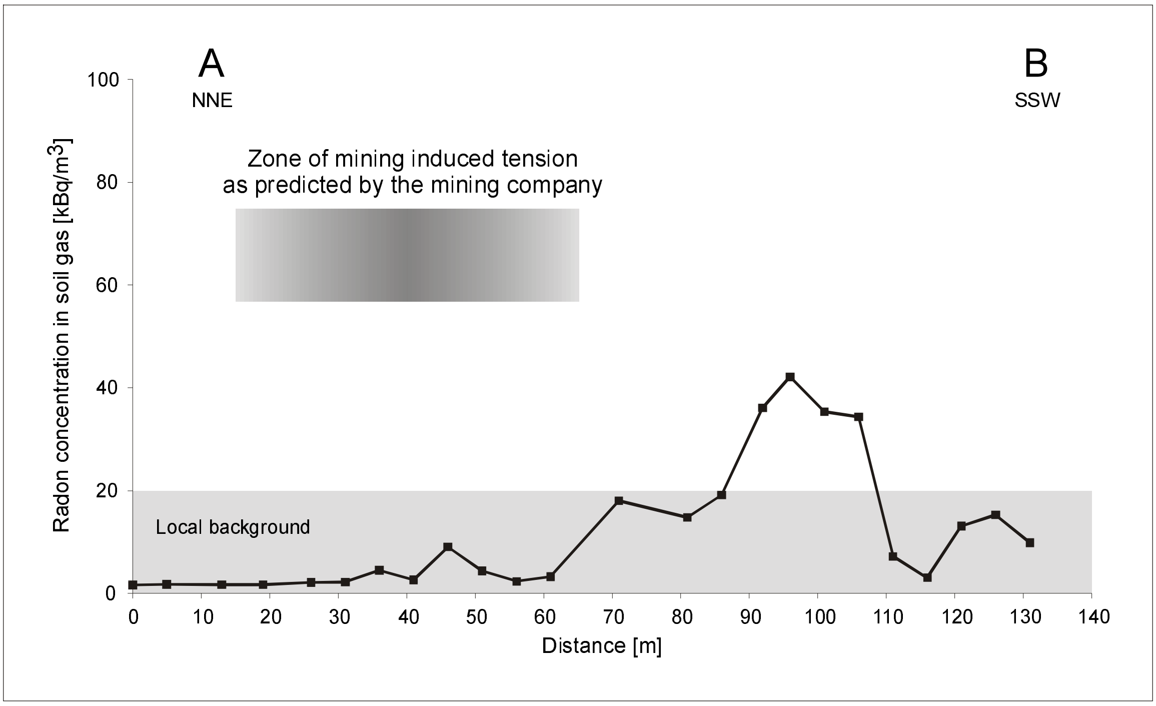

figure 4: Radon concentration in soil gas above a permanent zone of mining induced tension

radon. Extensive or spot degassing as well as degassing along lineaments can be observed. Usually methane exhalations vary in time depending on seasonal changes in soil moisture or atmospheric pressure. It is well known, that CH_4 degassing is rarely constant over long periods at the same spot and decreases with time (Kaltwang, 1990).

The field measurements were performed both for radon and methane in disturbed soils just below the surface of roads and other pavements in depths of about 30 cm. This very special sampling situation as well as the results cannot be compared to soil gas measurements used for the evaluation of the geogenic radon potential. As expected, dilution of radon by atmospheric influences in these shallow depths and the very low radionuclide contents of gravel and sand below roads and pavements reduce the radon background to 2 kBq/m^3.

Radon concentrations at four methane degassing spots are positively correlated with methane concentrations (fig. 5). Especially above 10 vol.% of methane this dependence becomes obvious, when radon concentrations are exceeding the background at least five times.

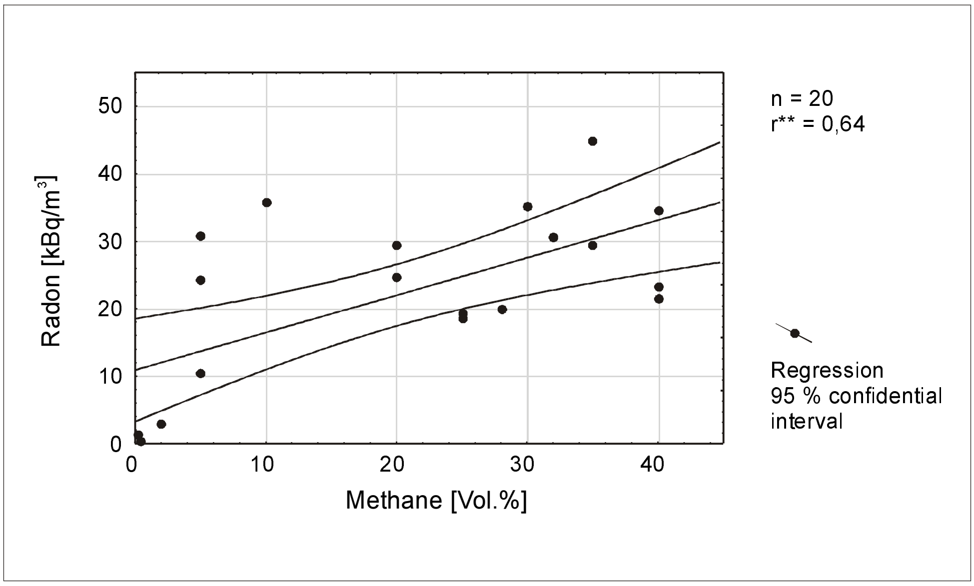

figure 5: Scatter diagram of radon and methane contents at a methane degassing spot (M 1)

4.5 Indoor measurements

Indoor measurements of radon concentrations were carried out in about 100 houses over a period of three months. In every building two solid-state nuclear track detectors (Macrofol) were installed in the transition in spring and in autumn: one detector in the basement and one in the living area on the ground floor. Two groups of house locations were selected for this study: half the number of buildings were in an area with mining activities younger than two years (case group), the other half in an area without recent mining activities (control group).

The median values of 47 Bq/m^3 (control group) respective 48 Bq/m^3 (case group) in the ground floor correspond closely to the German median value of 40 Bq/m^3 (fig. 6). It is far below the upper limit of the normal range of radon concentrations in buildings in Germany of 250 Bq/m^3 (SSK, 1994). Obviously, there is no difference between both groups. In the basements of the houses in the control group however, the median value of 60 Bq/m^3 is about 30 % below the median value of 85 Bq/m^3 in the case group (fig. 7; median value for basements in West-Germany: 52 Bq/m^3 (BMI, 1985)). Further results of a questionnaire show the influence of the building site and construction characteristics on the indoor radon values.

	control group	case group		control group	case group
	basement			ground floor	
n	37	61		40	58
min [Bq/m^3]	24	26		18	13
10 pc [Bq/m^3]	34	35		27	25
median [Bq/m^3]	60	85		47	48
90 pc [Bq/m^3]	109	164		102	122
max [Bq/m^3]	275	910		320	276

figure 6: Statistics of indoor radon concentration

Especially the existence of cracks and fissures in basement walls and floors as well as a lacking damp-proofing in the basement is correlated with increased indoor radon concentrations.

5 Discussion

Radon concentrations in soil gas in the investigated area are influenced by mining activites in the underground in different ways.

Radon contents in soil gas (median: 20 kBq/m^3) are generally low compared to other regions of Germany (Kemski et al., 1998). Nevertheless a clear spatial pattern of increased values is observed. In the mining affected area radon concentrations are significantly higher (median: 38 kBq/m^3). Strongly enhanced values up to more than 100 kBq/m^3 locally occur at the zones of mining induced tension. Both phenomena can be explained by mining induced tectonic movements in the subsurface. Time dependent changes in the fabric of rocks and soils increase the radon emanation rate. Additionally an advective, also structurally controlled migration is generated resulting in the radon peaks at the zones of mining induced tension.

Degassing of methane is positively correlated with radon concentrations in soil gas. Obviously, CH_4 acts as a carrier gas for radon. Because methane degassing into buildings leads to a hazard situation for their inhabitants, surveys to localize exhalation spots exist. In case of methane problems in houses extensive preventive ventilation procedures were initiated instantly. As a consequence, radon contents in these buildings are reduced to a negligible level.

The mining induced subsurface dislocations of rocks have a strong influence on the fabric of soils and rocks as well as on the foundations of buildings creating cracks in floors and walls. Therefore the radon transfer from the soil into the house may increase following the existing gradient between soil gas and indoor air. Consequently, the highest indoor radon concentrations were observed in the basement of houses in the case group. The spatial distribution of high indoor values vary in time. The comparison of indoor measurements from spring and from autumn show a shift of radon peaks from east to west with time, following the direction of deep mining.

6 Conclusions

The study shows evidence for a clear pattern of the radon concentrations in soil gas and in buildings influenced by mining activities. Increased indoor radon concentrations in the basements limited by the time of deep mining activities were measured. In living rooms, however, radon contents were generally below the upper limit of the normal range with just a few exceptions; measures to reduce indoor radon concentrations have not been recommended.

It has to be emphasized, that the radon concentrations in soil gas in this area are rather low compared to other regions in Germany. Therefore increased indoor radon contents in regions with higher soil gas concentrations and mining activities can be expected. Additionally, always local geological characteristics and specific building construction types have to be carefully considered and should be investigated in detail.

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