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Investigations of outbursts and tremors in Polish collieries with application of radon measurements

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Abstract. In the 80's and 90's of the last century some attempts were undertaken to apply specific radiometric methods to support the prediction of outbursts in collieries, located in Lower Silesian Coal Basin (LSCB) in south-western Poland. This idea was developed as an analogy to the application of radon changes in groundwater prior to earthquakes, and on this basis the hypothesis of variations of radon emanation from coal seams, preceding approaching outburst, was formulated. It has been stated, that a certain correlation between temporal and spatial variations of radon level and the level of outburst's hazard existed. Then, new investigations have been started in copper and coal mines with the hope to use radon as a tool for the prediction of another dynamic phenomena – tremors. In the case of these investigations, only weak evidences were found. In the last years the occurrence of outburst was noticed in the collieries of Upper Silesian Coal Basin (USCB). Therefore, we started observations of changes of radon concentration in gas, sampled from headings, driven in endangered coal seams. The goal of the research is an attempt to formulate "radon index of outburst hazard" to support other, routinely used, methods of the prediction of dangerous events. In this paper some results of investigations, done in collieries in LSCB and in copper mines are quoted to give the background for preliminary results of new research, ongoing in one of the coal mines in the Upper Silesia region.

Key words: radon • hazards • outbursts • tremors • coal mine

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Introduction

Outbursts of gas and rocks are one of the serious hazards, occurring in the underground mining. There were numerous examples of the large catastrophes in mines, caused by this phenomenon, with a lot of casualties among miners. According to Hargraves [2], the outburst is a sudden release of gas and coal from the freshly exposed coal face during exploitation of the seams or during driving accessing galleries in coal. Sizes of released coal particles are usually small, typically fine coal dust. The main reason of such events is the presence of very large amounts of gas (CO_2 or CH_4) absorbed in the coal. The release of the gas together with coal (the outburst) is caused by the perturbation of the dynamic equilibrium in the strata. It may be caused by the exploitation or other mining activities in seams, prone to outbursts, The release of gas under very high pressure is so sudden, that it may cause damage to the mining equipment and elements of support. If the methane is present in the mixture of released gases, an additional problem might be its inflammation or an explosion. Miners, working in the vicinity of the spot, are endangered – severe injuries or even fatalities might happen, due to suffocation, burns, etc.

The biggest incident of outburst in Poland happened in 1958 in Nowa Ruda Colliery in LSCB. During the event 750 000 m^3 of CO_2 as well as 5000 tons of coal were released, with five casualties among miners. In the 80's and 90's of the last century some attempts have been undertaken to apply specific radiometric methods to support the prediction of outbursts in collieries, located in LSCB [5–8]. For a long time, there was no such danger in the collieries of USCB, but it started to change lately. In November 2005 at a Zofiówka coal mine, an outburst occurred, with three miners killed and four others seriously injured. During this event 280 m^3 of coal was rejected into gallery from the heading, and within first 2 h after the outburst the total volume of released methane was assessed as at least 10 000 m^3. Since that time it has been stated, that such hazards were occurring in three collieries, located in the south-western part of the USCB. Additionally, there is also a risk of such phenomenon in the part of the salt seam of Kłodawa salt mine in Kłodawa, in northern Poland [14].

Another type of the hazard, linked very strongly to the mining activity, is called tremor. This is a quake, induced by underground exploitation of minerals. In Poland such events are significant and numerous in coal mines in Upper Silesia and copper mines in the Lubin region. It may cause damages in underground galleries, posing a threat for miners, leading sometimes to severe injures or even to casualties.

Therefore, the following questions appeared:

– Could be seen any correlation between geodynamic phenomena, like outbursts and tremors and changes of radon level in the strata?
– Can we use observations of radon concentration as a precursor of the forthcoming geodynamic events?

Results of measurements, done in the 1980's and 1990's were very promising. Therefore, it has been an inspiration for new investigations in coal mines aimed at the use of radon as a possible tool for the prediction of outbursts.

Radon level as the indicator of geodynamic events

It is a well known fact that changes of the intensity of radon and helium emission were observed prior and during seismic events [9, 10, 15]. Sudden changes of radon concentration in water in springs and wells have been observed many times before earthquakes. First time such results were described after the analysis of measurements done before the Tashkent Earthquake in 1966 by Kisin [4]. The possibility of the correlation between radon concentrations in waters, rocks and soil and forthcoming quakes were reported in many publications within last several decades [1, 3, 12, 13, 18].

In the case of investigations in underground mines, the main assumption was that the activity of radon, exhaling from the face of the galleries, may be related to the strain in the strata. It means, that measurements of radon level in the gas, sampled from the strata, could be possibly used as the indicator of outbursts or tremors. In the underground mine radon may relatively quickly diffuse into borehole, cracks or fissures and later be transported together with carrier gas into ventilation tracks to appear in the atmosphere of galleries. Advantages of using radon to monitor the changes of the strain in the strata are: its low adsorption coefficient on coal and radioactive properties enabling the detection its concentrations.

In this paper the preliminary results of new research, which is ongoing in one of the coal mines in the Upper Silesia region is presented. The presently performed investigations are done on the basis of the research performed in the past in Lower Silesian coal mines and in a copper mine, described below.

Methods

During investigations performed in the early 1980's in mines, located in LSCB, grab sampling measurements of radon ^{222}Rn were done with the application of Lucas cells. The use of this technique enables to measure radon concentration from few tens of becquerels per cubic meter. The radon level in the mine environment may change in the range from several bequerels until thousands of bequerels per cubic meter (Bq/m^3), therefore this method was suitable for measurements performed in heavy environmental conditions in mines [5]. In the headings of galleries prospecting boreholes were drilled in the coal seams, with the length from 3 to 6 m. Gas was sampled directly from boreholes into Lucas cells with the application of hand pump, the air was sucked through a silica gel to remove humidity from the sample.

For the radon monitoring in the gallery at the Zofiówka coal-mine in USCB, a very similar sampling technique has been applied, as described for LSCB collieries. Samples of gas were sucked into the Lucas cells from prospecting boreholes, drilled in the face of the gallery. The depth of gas sampling was 2 m, sampling was done several minutes after completing of the borehole, to avoid the dilution of the sample with air, ventilating the gallery. In the same time another sample of gas was taken from the reference borehole, drilled at a certain distance from the heading, in unperturbed zone. Measurements of radon concentration in the Lucas cells were done on the surface, 3 h after sampling to achieve the best sensitivity. The background count-rate for the Lucas cells was 1 count/min [cpm], and, therefore, the detection limit for radon (LLD) is relatively high – 25 Bq/m^3, when the counting time is 60 min.

Results and discussion

Results of investigations of outbursts in LSCB

Radon concentrations, measured in air, sampled from boreholes, drilled in the coal seam in the Thorez mine were within the range 20–700 Bq/m^3. The first conclusion was that during the advance of the gallery heading significant changes of radon concentration have been observed. It has been found that in periods with no outbursts radon level was low. Nonetheless, just before forthcoming outburst the decrease of radon concentration, close to zero, was usually measured, while after the event typically a sudden increase of radon concentration occurred (see Fig. 1). The driving of the gallery was leading to changes of the strain in the strata, simultaneously the pressure of the gas in pores

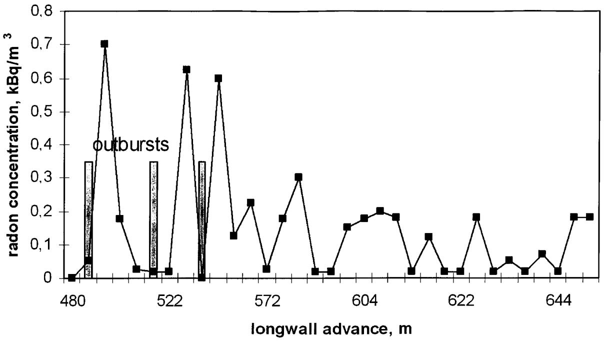

Fig. 1. Changes of radon concentration in coal seam in the Thorez Colliery.

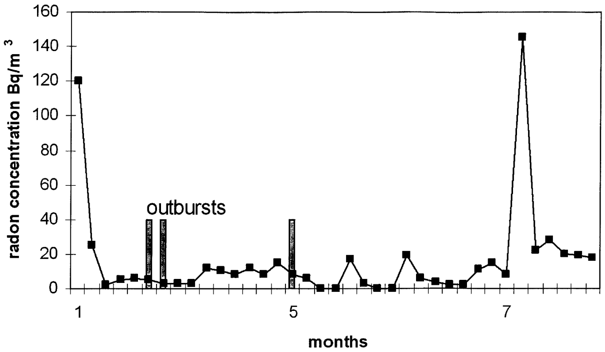

Fig. 2. Changes of radon concentrations in a copper mine.

varied in a wide range. Observed decrease of radon concentration before outbursts was probably caused by closure of fissure and cracks in the coal body in the proximity of the face as a result of high strata strain preceding outburst. After the outburst, the increase of radon concentration can be explained as a result of a decrease of gas pressure in the seams, the occurrence of numerous, freshly open cracks and fissures, enabling easy migration of radon.

The results of monitoring, done in the Thorez mine, were very promising and giving a hope for the possibility to create the "radon index for outburst prediction".

In a Nowa Ruda mine very unusual phenomenon has been observed – outburst occurred not in the coal seam, but in a sandstone layer. It was due to saturation of the rock with methane, transported previously from coal seams. Therefore, radon concentrations were measured in boreholes, made in the sandstone layer. In this case radon content was higher than those measured in the coal, reaching few kBq/m^3. And the pattern of radon changes before outbursts was different. At first, it was a significant decrease of the concentration, followed by a slight increase just before the gas release.

Results of investigations of tremors in a copper mine

For better understanding of possible links between changes of radon concentration in the strata and geodynamic phenomena in the rock body, investigations have started in one of the copper mines in Poland [17]. The main goal of this campaign was to check, whether there was any correlation of tremor occurrence and radon variations in the copper-bearing dolomite. The desired final output of the analysis might be the prediction index, based on radon measurements.

Part of the copper mine, characterized by a high seismic activity, located at the depth of 1000 m below the surface, was chosen for continuous monitoring of radon. Slightly inclined boreholes were drilled into the roof of several galleries in this zone, through dolomite with different porosity. In these boreholes heavy-duty radon probes were placed. Data of seismic activity, exploitation advance, application of anti-strain blasts, done in particular part of the mine, were collected. It has been found that despite a relatively small distance between boreholes, the results of monitoring were often very different. In one of the sampling points, the concentration of radon in the borehole was relatively low, varied in the range 2000–2700 Bq/m^3, and moreover it was too difficult to correlate these changes with seismic events. At the same time, pattern of radon changes in the borehole, located nearby, was clearly distinct. After very fast in-growth, the radon concentration reached a level of 40 000 Bq/m^3. Then, it has been followed by a decrease, the concentration being about 20 000 Bq/m^3 (Fig. 2). In this period two significant tremors occurred, with the energy release 10^4 J and 10^7 J, respectively. For the next three weeks, radon concentration was stable, and varied only slightly around a value of 20 000 Bq/m^3, then it started to raise again to a value of 30 000 Bq/m^3. During another two weeks, radon concentration was dropping down by a factor of two (to 15 000 Bq/m^3). And again two tremors were recorded within this time – with energy 10^6 J and 10^5 J.

This result was the outstanding one, therefore an analysis was performed to find out possible features of the borehole, distinguishing it so significantly. It has been found that the particular borehole was drilled through the zone of low density of dolomite with numerous cavities, with very specific physical properties. This type of rock is remarkably different in comparison with compacted dolomite, very common in the layers at that depth. It was probable that the specific parameters of the medium – low density dolomite – may lead to enhancing of the radon transport for long distances. On the other hand, the observed decrease of radon concentration, prior to tremors can be explained by closure of cracks and fissures as a result of an increase of the strain in the strata, resulting in the slow down of the radon transport.

In the other sampling sites we did not find correlations between the radon concentrations and tremors.

Preliminary results of investigations in outbursts prone zone in USCB

Radon monitoring in seams, prone to outburst, has started in March 2009 in one of the Upper Silesian hard coal mines. Measurements of radon were done for gas samples, taken from boreholes, drilled in freshly exposed coal face in driven gallery. These galleries are located in the coal seam 412/4 and 413/2, at a depth of about 830 m below the surface.

Mine service is responsible for routine measurements of outburst indexes such as intensity of methane de-sorption from coal, compactness of coal, production of coal drillings. The measured values of these indices

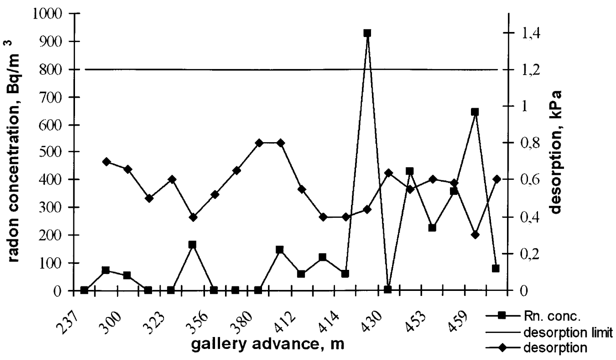

Fig. 3. Coal seam 413, gallery E-3, radon concentration vs. desorption index.

exceeded warning levels [16]. It has been stated that the gallery is drilled under the conditions of high outburst hazard. Very high intensity of methane de-sorption (> 1.2 kPa), also very high production of coal drillings during drilling (Zw = 20 dm^3/m) and additionally relatively low compactness of coal in this seam (f < 0.35), are resulting from a high strain in the strata, saturated with methane in the zone, adjacent to the gallery heading, and confirming the high hazard in this zone [16].

Results of measurements, performed up-to-date in the coal-mine showed that radon concentrations are low, in the range 25–950 Bq/m^3, for samples taken from boreholes in the gallery heading and below 150 Bq/m^3 for samples from the reference borehole.

Results of measurements performed at the Zofiówka coal mine are shown in Fig. 3. The curves of radon concentrations and desorption index are plotted. It can be seen that values of the desorption index were high, above the warning level. In the same period radon concentration was very low, below 100 Bq/m^3. Slight increase of radon level up to 150 Bq/m^3 at the end cannot be correlated with variations of the index value. In both cases no correlation has been found for radon concentration and methane concentration in the seam gas (Fig. 4).

Because routine measurements of hazard indices showed a high level of outburst potential, therefore special measures to decrease probability of the event have been undertaken. The method of anti-strain blasting and a special method of the exploitation with the use of explosives, to prevent uncontrolled release of gas from rock body was applied. For these reason, no geodynamic events occurred during the period of performed research, proving the effectiveness of applied mitigation measures.

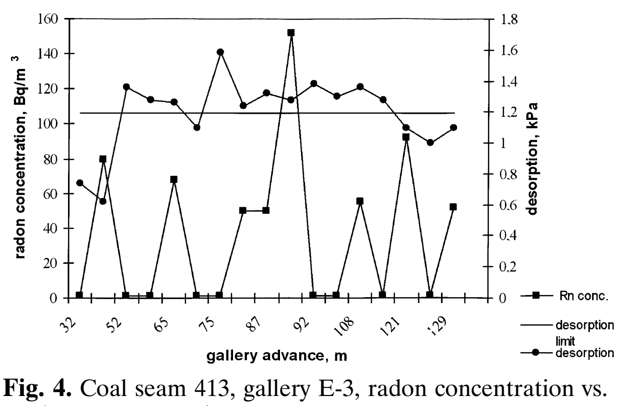

Fig. 4. Coal seam 413, gallery E-3, radon concentration vs. methane concentration.

Conclusions

Radon concentrations measured in the 1980's and 1990's in LSCB mines in coal seams, prone to outbursts, have shown ^{222}Rn variability in a wide range from several up to 10 000 Bq/m^3.

Typical pattern of radon behaviour was a significant decrease of the concentration before outburst and the definite increase of its level after the event. Due to repetition of this effect and good correlation with forthcoming outbursts, it was a great hope that the "radon index" for the prediction could be developed.

Very clear correlation between the radon changes and geodynamic phenomena (tremors) has been found after analyses of results from the examined copper mine. The significant decrease of radon level was seen, followed by a quick increase of the concentration after the event.

Till now, the results of preliminary investigations, which started in 2009 in the USCB coal mine, were not satisfactory. One of the reasons is that since the beginning until now no events of gas outburst were observed, despite the much greater level of permissible values of routinely used hazard indexes i.e. the intensity of gas de-sorption from coal and methane concentration in seam gas. The results of radon measurements were in the same period far below 1000 Bq/m^3. So far, no correlation has been found between all indices and radon variations.

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