Acta Physica Universitatis Comenianae
Vol. XLVIII XLIX, Number 1&2 (2007 2008) 125-132

The Monitoring of the ^{222}Rn Activity Concentration in Borehole Water – Results from the First Year of Observation

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Abstract: In this paper the variations of the ^{222}Rn activity concentration in borehole water are discussed in comparison with water level changes, snow melting and precipitation. The three boreholes V-1 (10 m), V-2 (40 m) and V-3 (10 m) have been drilled in the Lower Triassic quartzite in the area of the Astronomical and Geophysical Observatory of Comenius University at Modra-Piesok (40 km NE of Bratislava). During the year 2006 the samples of water from all the boreholes were taken regularly and the analyses of ^{222}Rn activity concentration were performed. Simultaneously, the state of water level in the boreholes was measured. The variations of radon concentration in borehole water were studied in relation to the water level changes and the precipitation amount. In V-1 and V-3 boreholes the precipitation caused significant changes of water level and strongly affected the values of ^{222}Rn activity concentration in water in comparison to V-2 borehole. The highest values of radon concentration were determined in water from V-1 and V-2 boreholes. In V-3 borehole the radon concentration in water was low. Radon is probably transported into borehole water from the underlying granodiorite of Modra massif, but with different intensity in each borehole.
Key words: radon, borehole, water, precipitation.

1. Introduction

The natural radioactivity of water is determined by a content of dissolved solid and gaseous natural radionuclides, mainly by ^{40}K, ^{238}U, ^{234}U, ^{232}Th, ^{226}Ra and ^{222}Rn. ^{222}Rn is an inert radioactive gas produced by alpha decay of ^{226}Ra with a half-life of 3.82 days. Radon does not chemically react with its environment. It can only be engaged in physical mechanisms [1].

In rock environment the radon is transported mainly via connected cracks and fissures filled with underground water. Radon can be transported by this water to far larger distances than diffusion processes alone would permit.

The analyses of ^{222}Rn in water are performed mainly in the context of potable water, because of radon high solubility in water. Exposure to radon is associated with health risk. The most obvious pathways for exposure to radon are due to ingestion and inhalation of radon degassed from water in household appliances [2, 3].

Within the scope of natural radioactivity investigation in Slovak Republic the measurements of radon concentration in 5271 samples taken from underground and surface

Devoted to Prof. Pavel Povinec 65-th anniversary waters have been performed. The maps of natural water radioactivity have been constituted [4].

In the last years an increased attention is focused on the use of radon as a natural processes tracer. The possibility of radon monitoring in water for an earthquake and volcano prediction have been studied [5 8] and also in hydrological investigations [9].

The aim of our investigation is to study the variations of radon concentration in borehole water and borehole air in relation to the water level changes, the precipitation amount, atmospheric pressure and temperature. This information had to be known, if the results of radon measurements in borehole environment should be used for the monitoring of various geophysical and hydrological processes. Particularly, the results of the regular ^{222}Rn activity concentration monitoring in borehole water from one year of the observation are presented in this paper in the relation to precipitation amount and snow melting.

2. Methods

The water samples for the ^{222}Rn activity concentration analyses were collected from three boreholes situated at the area of Astronomical and Geophysical Observatory at Modra-Piesok (AGO Modra). The AGO Modra is situated approximately 40 km NE of Bratislava in the Little Carpathians Mts (Fig. 1). Regarding a radon risk, the Little Carpathians fall into the medium radon risk category [4].

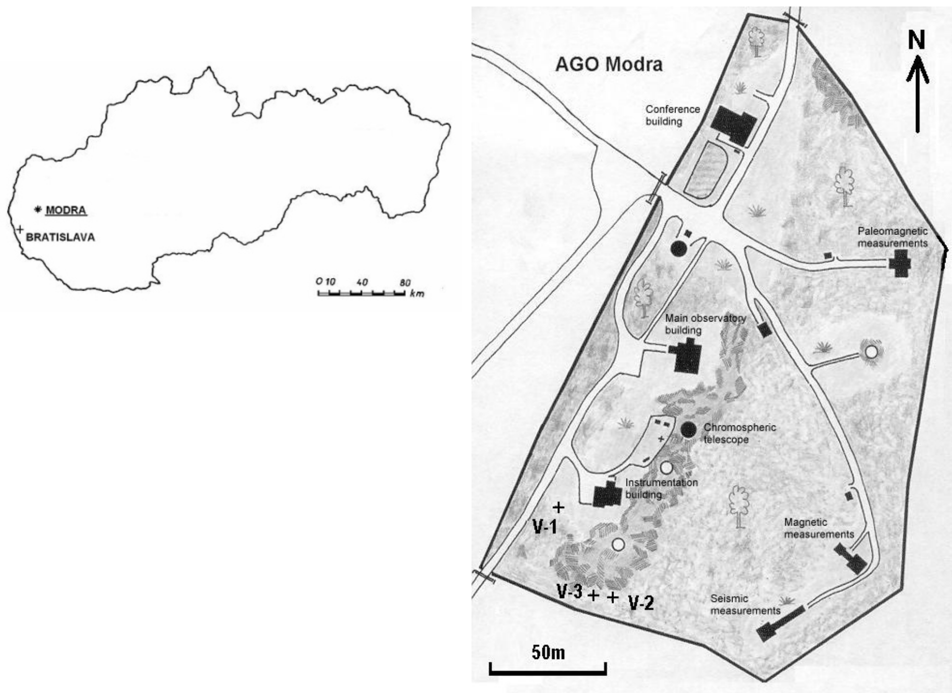

Fig. 1. Schematic map of Slovakia with marked measuring site Modra.

The boreholes V-1 (10 m), V-2 (40 m) and V-3 (10 m) are drilled in the Lower Triassic quartzite folded in the granodiorite of Modra massif [10, 11]. The inner diameter of these boreholes is 80 mm. They are cased with a PVC pipe with 10 % perforation along the whole length. Since 2003 the continual radon monitoring in borehole air have been performed in V-2 and V-3 boreholes by the alpha detector Barasol [12]. Nowadays the alpha detector is placed only in V-3 borehole at the depth of 3 m [13].

The water sampling was executed regularly by a plastic bottle with a volume of 200 ml three times a week during one year. Simultaneously, the water level state under the surface was measured in every borehole. The ^{222}Rn activity concentration in water was determined in the laboratory at the Department of Nuclear Physics and Biophysics at Faculty of Mathematics, Physics and Informatics of Comenius University in Bratislava. Radon included in a sample of 7 was transferred into a scintillation cell of Lucas type DS 401M [14]. After the radioactive equilibrium of radon with its daughter products was achieved, the radon counts were measured and the ^{222}Rn activity concentration in water was calculated.

The variations of radon concentration in water were studied in relation to appearance of the precipitation and snow cover. The meteorological data for our investigation were kindly provided by the staff of AGO Modra.

3. Results

Since January to December 2006 totally 296 samples of water were investigated from the boreholes at AGO Modra. The most samples (130) were collected from V-2 borehole, where water occurred during the whole year. From V-3 borehole 87 samples were gathered, because there was no water since the beginning of September. Only 79 water samples were collected from V-1 borehole. During our research the water level decreased under the bottom of this borehole for four times.

3.1. Water level

The influence of soaking precipitation water to the state of the water level and to the values of the ^{222}Rn activity concentration in water from both V-1 and V-3 boreholes was confirmed during the whole year of our investigation at AGO Modra.

Water originated by intensive precipitation with amount more than 20 mm per day. In this case the water was able to infiltrate through the soil and rock environment into the adequate depth to modify the original parameters of a borehole environment. The responses of both V-1 and V-3 boreholes to the precipitation were well discernible.

After the precipitation the water level in the boreholes started to rise. The growth of water level in V-1 was up to 3 m, while only up to 1 2 m in V-3 in comparison to the previous state. The observed increase of a water level was considerably faster than its decrease in both boreholes. The growth of the water level in V-3 was not so quick in comparison to V-1. In general, the values of the water level state in V-1 and V-3 boreholes were higher since January to June than in the summer months.

All three boreholes are situated in a forest environment in a slope of the hill, but V-1 is situated at a position roughly 9 m lower than V-3 and V-2 boreholes, which have been drilled at approximately the same level. During the intensive precipitation a certain amount of rainfall water is not able to soak into the soil and it drains away to the valley. This soaking water, together with precipitation, dropped directly to the surroundings of the V-1 borehole and caused the more intense rise of the water level in this borehole.

In the second decade of July the underground water level in V-1 was under the bottom of this borehole. Since the beginning of August water appeared in this borehole again, but within a month the water sank under the borehole bottom again. Due to a very low amount of precipitation in autumn there was no water until the half of December. Similarly, there was no water in V-3 borehole since September.

Since January to March 2006 the area of our research was permanently covered with snow layer up to 1 m. At the end of March the snow melted very rapidly and it completely disappeared during ten days. It resulted in a remarkable increase of the water level in all boreholes, about 3.5 m in V-1, the water level reached up to 0.8 m under the surface. In V-3, this rise was of the same rate as after the precipitation.

In comparison to V-1 and V-3, the situation in V-2 borehole was different. The water level in this borehole was situated considerably deeper (26.5 ± 1.5) m under the surface to be affected by precipitation. However, at the end of March, due to the snow melting accompanied with precipitation, the rapid rise of the water level in V-2 borehole up to 4 m was observed. It was stabilized later at the position about 2 m higher than in previous the months.

The seasonal changes of the water level were noticed. The highest water level was achieved after the snow melting and in the following spring months. During the summer the water level started to decrease and it reached its minimum in the winter months.

3.2. ^{222}Rn activity concentration

3.2.1. V-1 borehole

Immediately after the precipitation the ^{222}Rn activity concentration in borehole water in V-1 instantly decreased. Afterwards, the radon concentration started to rise. Reversely to the course of water level, the radon concentration in borehole water increased slowly, but its drop was very rapid (Fig. 2).

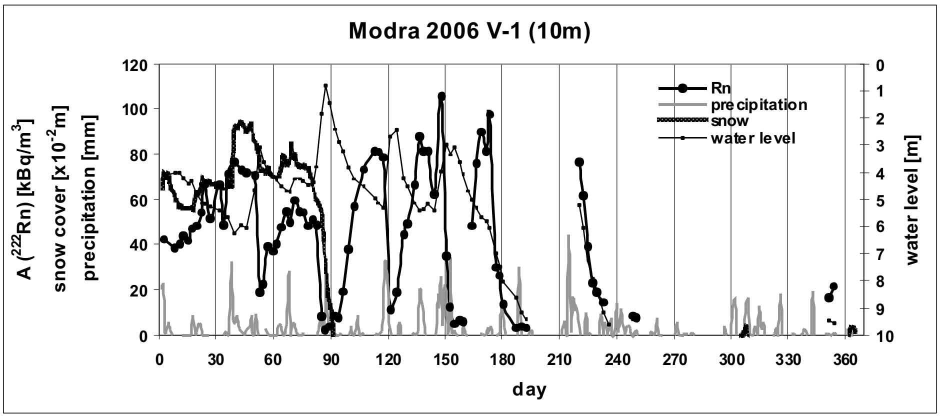

Fig. 2. The courses of ^{222}Rn activity concentration in borehole water and the state of water level in V-1 borehole in relation to the precipitation and snow cover.

The difference between the radon concentration in water before and after the precipitation was up to 70 80 kBq.m ^{3}. The maximal values of ^{222}Rn activity concentration reached about 100 kBq.m ^{3}.

As it follows from the data measured for V-1 borehole, the negative correlation between the state of water level and the values of ^{222}Rn activity concentration were calculated from January to June ($R^2 = 0.68$).

At the end of June the situation in V-1 changed. The intensive decrease of water level was observed, due to a warm and dry weather together with escalated evapotranspiration. At the same time also the values of ^{222}Rn activity concentration started to decrease.

3.2.2. V-2 borehole

The course of the ^{222}Rn activity concentration in the borehole water in V-2 was not affected by precipitation water in the same degree as it was observed in the case of V-1 and V-3 boreholes (Fig. 3).

The values of ^{222}Rn activity concentration in the borehole water in V-2 reached the highest values among all the investigated boreholes. Two significant peaks were observed. The first appeared at the beginning of snow melting in March. After the beginning of the snow melting the ^{222}Rn activity concentration in water started to increase. The following precipitation, together with proceeding melting, increased the water level and the radon concentration in borehole water decreased simultaneously.

The second and markedly higher peak was noticed in autumn. In the half of November the significant growth of the ^{222}Rn activity concentration was registered. During two days the radon concentration in water increased by a factor of two and it stayed at this level for approximately three weeks. In that time the values of the ^{222}Rn activity concentration reached the highest level during the whole year of our research. The values of ^{222}Rn activity concentration returned to the previous state at the end of the year.

The negative correlation ($R^2 = 0.55$) between the state of water level and radon concentration in the borehole water was confirmed after the snow melting in March (day 92) until the half of November (day 330), when the second peak appeared.

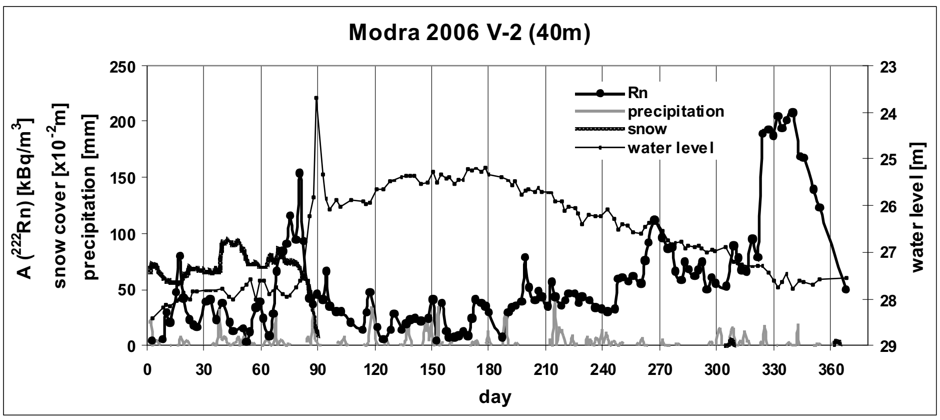

Fig. 3. The courses of the ^{222}Rn activity concentration in the borehole water and the state of water level in V-2 borehole in relation to the precipitation and snow cover.

3.2.3. V-3 borehole

The measured values of radon concentration in V-3 borehole were the lowest among all the investigated boreholes, they do not exceed 30 kBq.m ^{3}. Contrary to V-1, the radon concentration in V-3 borehole started to increase subsequently after the precipitation. The maximum of radon concentration was achieved for about two weeks or less. The growth of radon concentration was less considerable like in V-1, it was only about 10 20 kBq.m ^{3}. The reversion to the previous state arose after approximately 2 4 weeks (Fig. 4).

Until the snow melting at the end of March, the positive correlation between the state of water level and related values of ^{222}Rn activity concentration were observed ($R^2 = 0.67$).

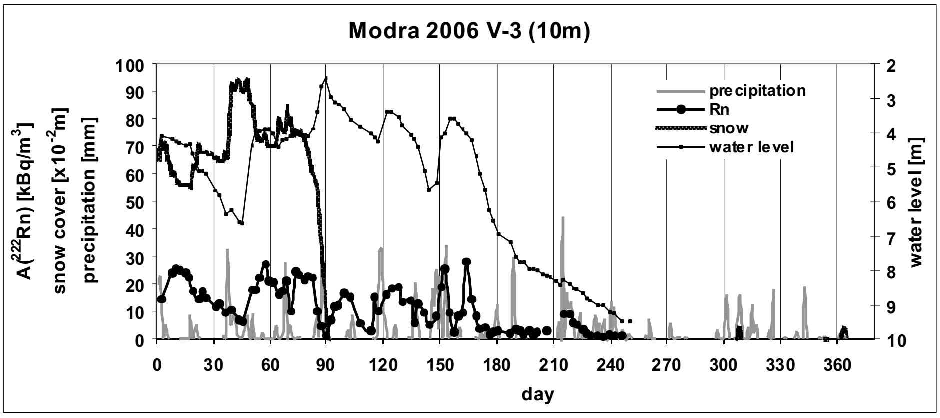

Fig. 4. The courses of ^{222}Rn activity concentration in borehole water and the state of water level in V-3 borehole in relation to the precipitation and snow cover.

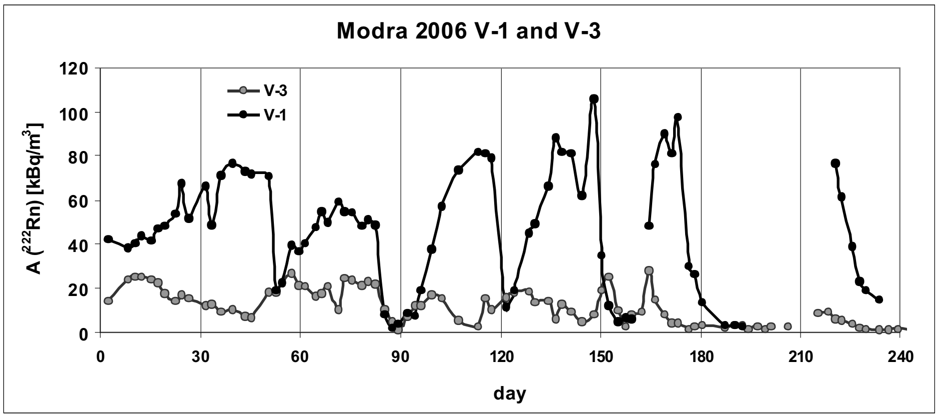

Fig. 5. The comparison of the courses of the ^{222}Rn activity concentration in the borehole water in V-1 and V-3 in comparison to the precipitation amount and snow cover.

After the rapid snow melting at the end of March the radon concentration in borehole water decreased together with increase of water level. In the following months the positive correlation appeared again (R^2 = 0.48).

Since June the values of ^{222}Rn activity concentration in borehole water in V-3 reached very low values. As a consequence of the low amount of precipitation the water level in this borehole started to decrease rapidly.

The increase of the radon concentration after the precipitation in July was not of the same range as in the previous months.

During the predominant part of the year the radon concentration changes in V-1 and V-3 boreholes appeared in approximately the same time (Fig. 5). In comparison to V-1, the growth of the radon concentration in V-3 borehole was less intensive and it lasted for a shorter time.

4. Conclusion

The significant water level changes together with the variations of the ^{222}Rn activity concentration in borehole water in V-1 and V-3 boreholes were confirmed. The increase of the water level was well discernible, if the precipitation amount was more than 20 mm per day.

After the snow melting the increase of water level was noticed in all the boreholes. The ^{222}Rn activity concentration in water decreased simultaneously.

The changes of the ^{222}Rn activity concentration in the borehole water in V-1 and V-3 boreholes occurred in approximately the same time. The radon concentration measured in V-3 was lower in comparison to V-1. Also the difference between the radon concentration before and after the precipitation was noticeably lower in V-3 than in V-1 borehole.

At the end of summer, the water level decreased under the borehole bottom in both mentioned boreholes, V-1 lost water as the first.

The negative correlation between the slow and long term changes of water level and related values of the ^{222}Rn activity concentration was observed in V-2 borehole.

Water occurred during the whole year of our research in V-2 borehole. The water level maintains at approximately (26.5 ± 1.5) m under the surface. Neither the water level nor the radon concentration changes caused by precipitation were observed in this borehole. However, the negative correlation between the slow long-term water level changes and the variation of radon concentration in water were noticed.

The ^{222}Rn activity concentration in water in V-2 was influenced by external parameters in the least degree among all the investigated boreholes. It suggests that radon concentration monitoring in water from this borehole could be used for the subsurface hydrological and geodynamical processes investigations in this locality.

Acknowledgements

This study was supported by Scientific Grant Agency of Ministry of Education of Slovak Republic (VEGA project 1/3046/06, 2/4042/24). The authors are indebted to the staff of the Modra AGO for provision of the precipitation data.

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