Seasonal changes of radon concentration in the Niedźwiedzia Cave (SW Poland) (*)

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(ricevuto il 9 Giugno 1998; revisionato il 12 Febbraio 1999; approvato il 24 Febbraio 1999)

Summary. — The paper presents the results of measurements of average monthly radon concentrations obtained in the most beautiful Polish cave, the Niedźwiedzia Cave, between July 1995 and December 1996. 222 measurements were taken at 7 measurement points with the use of trace detectors LR-115 type II. Distinct seasonal fluctuation of the concentration was observed: the highest values (up to 3.60 kBq/m^3) were noted in summer (from April to September), while the lowest ones in winter (0.10 kBq/m^3, in January 1996). A sharp increase in the concentration in spring and a decrease in autumn are typical. The main factor controlling radon concentration changes in the air of the Niedźwiedzia Cave is the process of ventilation.

PACS 91.25.Ey – Interactions between exterior sources and interior properties.
PACS 91.65.Dt – Isotopic composition/chemistry.
PACS 92.60.Sz – Air quality and air pollution.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Karst systems, and caves in particular, are good "conductors" and reservoirs of radon, therefore research on radon occurrence in caves is carried out in many countries [1-9]. It is important for radon geochemistry studies, besides the knowledge of processes controlling accumulation and movement of radon helps to protect people working in caves open to visitors from exposure to high radon concentrations.

The authors undertook studies of radon concentration changes in this most beautiful and largest Polish cave accessible to tourists in 1994, and constant monitoring has been carried out since 1995.

(*) Paper presented at the "Fourth International Conference on Rare Gas Geochemistry", Rome, October 8-10, 1997.

2. – Description, location and geology

The Niedźwiedzia Cave is an underground tourist object, and due to its status of a nature reserve, also an object well isolated from the influence of the atmosphere by proper air gates. It consists of a system of corridors and chambers cut by the Kleśnica groundwaters into three levels. The lower level is not open to visitors and the upper one is very small in size. The middle level is accesible to visitors and this is where the research was carried out (fig. 1).

The Niedźwiedzia Cave in Kletno is situated within a marble lens surrounded by grey-green mica schists. These rocks belong to the so-called Stronie series — one of the major elements of the Lądek-Śnieżnik metamorphic massif (West Sudety, SW Poland) (fig. 2) [10-12].

Not far from the cave, in Kletno, an uranium mine was in operation from 1948 to 1953. The uranium mineralization, still found there, may lead to formation of considerable amounts of radon in its vicinity, in the crystalline rocks of the Lądek-Śnieżnik metamorphic massif. Radon may be also produced directly in the crystalline rocks, as they contain minerals with slight additions of uranium [13, 14]. The Śnieżnik gneisses of this area contain locally higher amount of uranium (up to

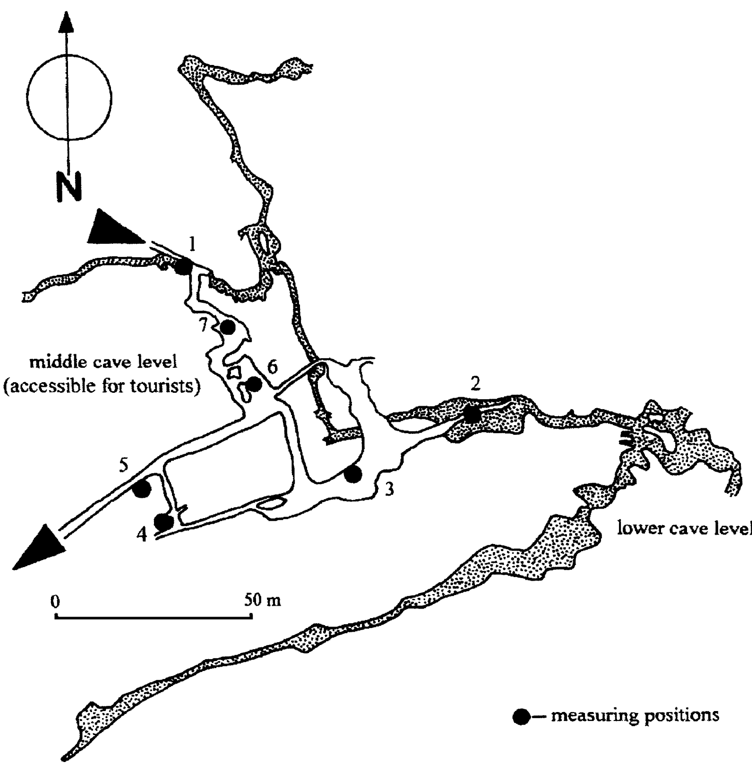

Fig. 1. – A sketch map of the Niedźwiedzia Cave in Kletno (after [15]) with measurement points of the average monthly radon concentrations in the air. 1 - Wielka Szczelina (Giant Crack), 2 - Zauek Kaskad (Cascades' Cul-de-sac), 3 - Sala Pałacowa (Palace Chamber), 4 - Korytarz Wodny (Water Corridor), 5 - Korytarz Człowieka Pierwotnego (Primitive Man's Corridor), 6 - Biwak (Bivouac), 7 - Sala Lwa (Lion's Chamber).

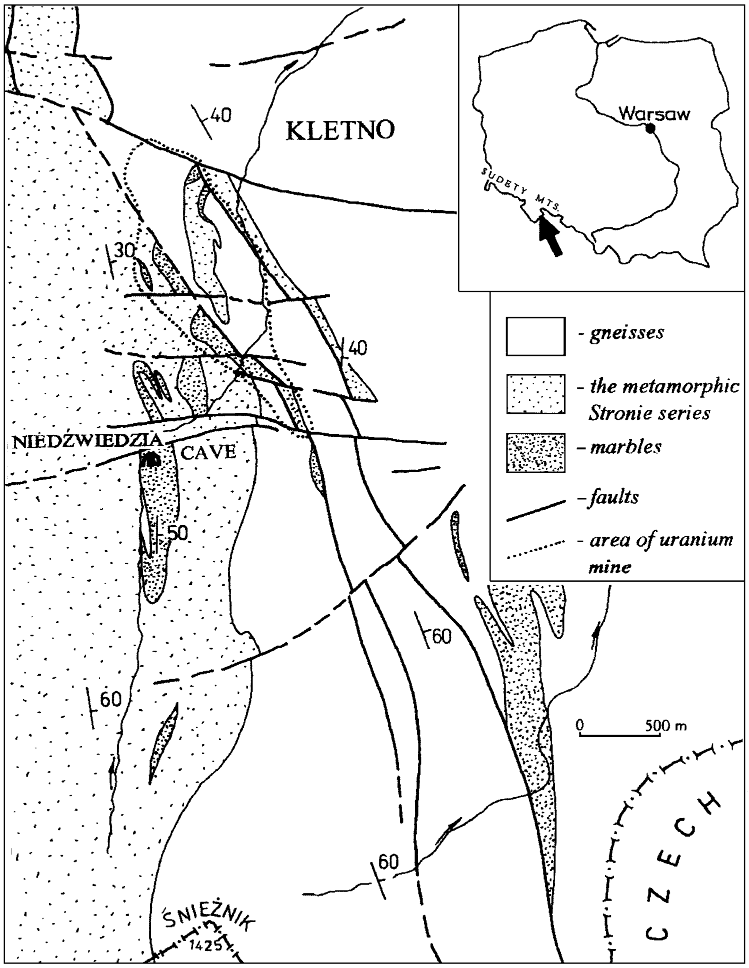

Fig. 2. – Geological sketch map of the vicinity of the Niedźwiedzia Cave in Kletno (after [10]).

approximately 11 g/t) [16]. Systems of faults and cracks existing in this area may facilitate radon migration towards the body of the marble lens in which the cave is situated.

3. – Method of investigation

Average monthly radon concentrations in the air were measured with the use of nuclear track detectors LR-115 type II installed in plastic containers with paper filters to prevent pollution or radon decay products, also emitting alpha-particles, from getting near the detector. They were exchanged once a month, and sent for chemical treatment and reading to the Laboratory of the Radiation Contaminations Department of the Institute of Occupational Medicine in Łódź.

4. – Seasonal and spatial changes of radon concentration

The origin of radon in the Niedźwiedzia Cave should be connected with its formation in crystalline rocks and migration via the fissure and fault network, where the emanation coefficient increases, into the cave's interior.

The regularities of radon accumulation in the Niedźwiedzia Cave were confirmed by researches carried out in 1970s and 1990s, also by the authors of this paper [17, 18]. The authors pointed out a considerable variability of radon concentration in each part of the Niedźwiedzia Cave. This phenomenon suggested a possibility of air circulation inside the cave and air exchange with the atmospheric air and the air of the lower level of the cave. This led to an experiment (currently under way) in which radon is used as a natural tracer of air circulation inside the cave. The results of these studies may contribute greatly to better recognition of the cave's microclimate.

Thus, it was necessary to measure radon concentrations in the Niedźwiedzia Cave throughout the whole year, to establish their changes, *i.e.*, extreme and average values, and to find out their causes.

A distinct seasonal variation of radon concentration was observed in the cave: considerably higher concentrations were registered in the warm period (from April to September, or even October) in comparison to the winter period. A sharp increase and a decrease in concentrations were identified in spring and autumn correspondingly (fig. 3). Two maxima were noted during the warmer period, *i.e.*: in May and August 1996, with average radon concentrations at 2.97 kBq/m^3 and 2.04 kBq/m^3, respectively. The lowest average value was measured in January 1996 at 0.27 kBq/m^3. The widest range of values was observed in the warmer (summer) period. The lowest radon

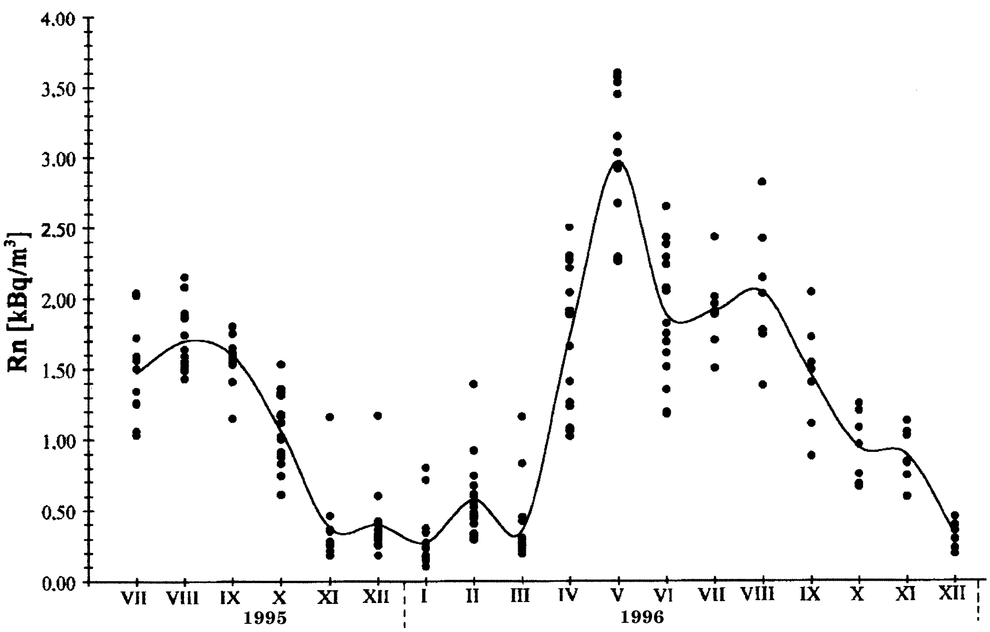

Fig. 3. – Average monthly radon concentrations in the air of the Niedźwiedzia Cave in 1995 and 1996. The line connects arithmetic averages from values obtained at all measurement points for individual months.

concentrations were noted in January 1996 at measurement point no. 5 (0.10 kBq/m^3), and the highest ones in May 1996 at measurement point no. 4 (3.60 kBq/m^3), while slightly lower concentrations were measured in the same month at measurement points no. 1 and 3 at 3.57 and 3.53 kBq/m^3, respectively.

The factor causing the seasonal variation in radon concentration in the Niedźwiedzia Cave may be the pattern of its natural ventilation. As it is inefficient due to the protection of the specific microclimate of the cave's interior, it is possible for the radon to accumulate with the air stagnating in the underground chambers and corridors. This phenomenon is caused by the almost constant (oscillating from 0.1 to 0.5 °C) temperature in the cave. Therefore, in this case average daily temperatures of the atmospheric air in its vicinity are important. When they are higher than the temperature inside the object, the colder (heavier) air stagnates and the radon emanating from the rocks stays inside the cave. Such a situation occurs from spring to autumn (during the warmer half-year). Then, the withheld air with a higher radon concentration does not leave the cave, which results in considerably higher radon concentrations than in the cooler half-year. In winter, the air from the cave, warmer than the air outside, flows out into the atmosphere carrying the radon emanated from the rocks. As a result, the concentration of radon inside the cave drops. A sharp rise and drop in the concentration at the turn of winter/spring and autumn/winter, respectively, is related to the beginning of the process described above, after the average air temperature in the cave (6.1–6.6 °C) has been exceeded. That is why the process is very fast and leads to a sharp increase or decrease in the radon concentration inside. The process causes fluctuations of radon concentration at an amplitude of 2.7 kBq/m^3 (fig. 3). The highest concentrations are observed during the high tourist season.

The average radon concentration in the Niedźwiedzia Cave from July 1995 to December 1996 (from 222 measurements of average monthly radon concentrations) amounted to 1.22 kBq/m^3. The average monthly radon concentrations are not very high when compared with other caves in the world (table I), thus they do not pose a threat to visitors or workers who stay in the cave up to 30 hours a month.

The spatial distribution of changes of the average monthly radon concentration is as expected. The highest values were noted at measurement points most distant from the entrances (no. 2, 3 and 6), while the lowest ones at measurement point no. 5. The values

TABLE I. – *Values of average monthly radon concentrations* (kBq/m^3) *in the air of selected world's caves* (*after* [1-5, 8-9]) *in comparison with the results from the Niedźwiedzia Cave.*

Cave	Mean radon concentration (kBq/m^3)
Niedźwiedzia Cave (Poland)	1.22
Radochowska Cave (Poland)	0.45
Mamoth Cave National Park (USA)	2.6
Altamira Cave (Spain)	5.9
Moestroff Cave (Luxemburg)	5.0
Slovenian Karst Caves (Slovenia)	5.0
Tourist caves of Slovenia (Slovenia)	3.7
Szemlő Hill Cave (Hungary)	5.3
Pál Valley Cave (Hungary)	3.3
Gyokusen-do Cave (Okinawa, Japan)	1.5

measured at measurement point no. 1 were often among the highest because in this place a crack runs connecting the touristically accessible level with the lower level situated approximately 20 m below. The crack (called the Giant Crack) must be the route by which the radon-rich air from the lower level enters the tourist level. The process is assisted by air circulation near the entrance, as the biggest temperature differences occur in this part, causing formation of periodical currents.

5. – Conclusions

In the Niedźwiedzia Cave enhanced radon concentrations and their seasonal changes occur. Significantly higher concentrations are noted during the warm half-year (April-September (October)). A sharp rise and a fall in concentrations are observed in spring and autumn, respectively. This phenomenon is caused by a commencement of intensive air exchange between the cave and the atmosphere when the atmospheric air temperature drops below the average yearly temperature inside the cave. Then, the warmer (lighter) air masses from inside the cave, carrying radon accumulated in them, flow out of the cave. Such process may be observed in autumn, whereas in spring an opposite situation takes place. When the temperature of the atmospheric air exceeds the average yearly temperature inside the cave, the air from the cave stops flowing out. In the air stagnating inside, radon starts to accumulate, and its concentration rises quickly. Thus, the ventilation process is the major factor controlling radon concentration changes in the air of the Niedźwiedzia Cave. The level of radon concentration depends on the content of radon parent isotopes in the rocks surrounding the object and on the emanation coefficient of the rocks.

The spatial variability of radon concentrations is controlled mainly by the distance of a measurement point from the entrances. Higher radon concentrations are observed at more distant points. Only near the Giant Crack (measurement point no. 1) high radon concentrations are noted, which are caused by the inflow of the air rich in radon from the lower parts of the cave.

In the light of these facts it is possible to use radon as a radioactive tracer of air movements inside the Niedźwiedzia Cave. Such research has already been undertaken and it should help with better understanding of its microclimate.

REFERENCES

[1] EHEMAN C., CARSON B., RIFENBURG J. and HOFFMAN D., *Occupational exposure to radon daughters in Mammoth Cave National Park, Health Phys.*, **60** (1991) 831-835.

[2] FERNÁNDEZ P. L., QUINDÓS L. S., SOTO J. and VILLAR E., *Radiation exposure levels in Altamira Cave, Health Phys.*, **46** (1984) 445-447.

[3] KIES A. and MASSEN F., *Radon and underground climate in the Moestroff Cave,* in C. DUBOIS *et al.* (Editors), *Gas geochemistry*, *University of Franche-Comté, Besançon, France* (Science Reviews, Northwood) 1995, pp. 63-70.

[4] KOBAL I., SMODIŠ B., BURGER J. and ŠKOFLJANEC M., *Atmospheric* ^{222}Rn *in tourist caves of Slovenia, Yugoslavia, Health Phys.*, **52** (1987) 473-479.

[5] KOBAL I., SMODIŠ B. and ŠKOFLJANEC M., *Radon-222 air concentrations in the Slovenian Karst Caves of Yugoslavia, Health Phys.*, **50** (1986) 830-834.

[6] PRZYLIBSKI T. A., *Radon concentration changes in the air of the Niedźwiedzia Cave in Kletno* (*Sudety*), *Przegląd Geologiczny*, **44** (1996) 942-944 (in Polish).

[7] PRZYLIBSKI T. A. and PIASECKI J., *Radon as a natural radioactive tracer of permanent air movements in the Niedźwiedzia Cave* (*Śnieżnik Kłodzki, Sudety Mts.*), *Kras i Speleologia*, **9** (1998) 179.

[8] SZERBIN P., *Radon concentrations and exposure levels in Hungarian caves, Health Physics*, **71** (1996) 362-369.

[9] TANAHARA A., TAIRA H. and TAKEMURA M., *Radon distribution and the variation of a limestone cave on Okinawa, Geochem. J.*, **31** (1997) 49-56.

[10] DON J., *Geological evolution of the Śnieżnik Massif and the cave*, in JAHN A., KOZŁOWSKI S. and WISZNIOWSKA T. (Editors): *The Cave Jaskinia Niedźwiedzia in Kletno* (Ossolineum, Wrocław) 1989 (in Polish).

[11] FRĄCKIEWICZ W., TEISSEYRE H., *Detailed geological map of the Sudety*, Scale 1 : 25 000, Sheet Międzygórze with Explanations (1977) (Wydawnictwa Geologiczne, Warszawa) 1976 (in Polish).

[12] OBERC J., *Geological structure of Poland,* Vol. IV, *Tektonics*, Part 2 (Wydawnictwa Geologiczne, Warszawa) 1972 (in Polish).

[13] BANAŚ M., *Mineralization symptoms in metamorphic massif of Śnieżnik Kłodzki, Prace Geologiczne Komisji Nauk PAN*, Kraków, 1965, No. 27 (in Polish).

[14] BORUCKI J., GŁOWACKI Z., MASŁOWSKI W., SAŁDAN M., UBERNA J. and ZAJĄCZKOWSKI W., *Estimation of perspectives of uranium deposits searching in Poland, Prace Instytutu Geologicznego* (Wydawnictwa Geologiczne, Warszawa) 1967 (in Polish).

[15] CACOŃ S., MĄKOLSKI K., *Geodetic survey in the cave*, in JAHN A., KOZŁOWSKI S. and WISZNIOWSKA T. (Editors), *The cave Jaskinia Niedźwiedzia in Kletno* (Ossolineum, Wrocław) 1989, pp. 168-179 (in Polish).

[16] PRZENIOSŁO S., *Uranium geochemistry in alluviums of eastern part of metamorphic massif of Lądek and Śnieżnik Kłodzki, Biul. Inst. Geol.* (1970), No. **224**, *Z badań petrograficzno-mineralogicznych i geochemicznych w Polsce. (From the petrographic-mineralogical and geochemistry research in Poland*), edited by M. O. JĘDRYSEK, Vol. 4, published by International Isotopo Society and University of Wrocław, (Wrocław) 1994, pp. 205-298 (in Polish).

[17] CIĘŻKOWSKI M., *Preliminary measurements of some gases concentrations and radioactivity in Niedźwiedzia cave in Kletno, Acta Universitatis Wratislaviensis*, No. **311**, *Geographical Studies*, Vol. **24** (1978) 91-95.

[18] CIĘŻKOWSKI W., PRZYLIBSKI T., SOBINA M. and ZŁOCH K., *222-radon in Niedźwiedzia Cave* (*SW Poland*), in *Extended abstracts, Isotope Workshop II, 25-27 May 1994, Książ Castle, Poland*, published by International Isotopo Society and University of Wrocław, edited by M. O. JĘDRYSEK (Wrocław) 1994, pp. 10-12.