

## Reasons for Elevated Radon Levels Inside the Building in Divača

### Vzroki za povišane koncentracije radona v izbranem objektu v Divači

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*Keywords:* radon, geology, indoor air, soil gas, workplace, Divača, Slovenia

*Ključne besede:* radon, geologija, notranji zrak, talni zrak, delovni prostor, Divača

#### Abstract

A radon ( $^{222}\text{Rn}$ ) survey at a workplace in a public building in the town of Divača, Slovenia, showed radon concentrations as high as  $20,000 \text{ Bq m}^{-3}$ , with average values of  $9020 \text{ Bq m}^{-3}$  in winter and  $2890 \text{ Bq m}^{-3}$  in summer. The main radon source is an under-floor channel connecting rooms on the ground floor. Elevated radon levels at the site are possibly related to a fracture zone connected to a nearby fault.

#### Kratka vsebina

Meritve radona ( $^{222}\text{Rn}$ ) v delovnem objektu v Divači (jugozahodna Slovenija) so pokazale koncentracije radona preko  $20,000 \text{ Bq m}^{-3}$ . Povprečne koncentracije radona so bile pozimi  $9020 \text{ Bq m}^{-3}$ , poleti pa  $2890 \text{ Bq m}^{-3}$ . Glavni vzrok povišanih koncentracij radona v zraku v prostorih je jašek, po katerem so speljani komunikacijski kabli med prostori. Povišane vrednosti na tem območju so verjetno povezane z razpoklinsko cono neposredno pod objektom.

#### Introduction

Radon is a radioactive noble gas appearing in radioactive decay of radium in the natural radioactive decay chains in the Earth's crust, i.e.,  $^{222}\text{Rn}$  isotope ( $\alpha$  decay, half-life  $\tau = 3.82$  days) from  $^{226}\text{Ra}$  in the  $^{238}\text{U}$  chain,  $^{220}\text{Rn}$  isotope ( $\alpha$  decay,  $\tau = 55$  s) from  $^{224}\text{Ra}$  in the  $^{232}\text{Th}$  chain and  $^{219}\text{Rn}$  isotope ( $\alpha$  decay,  $\tau = 3.92$  s) from  $^{223}\text{Ra}$  in the  $^{235}\text{U}$  chain (Nero, 1988). Only a small proportion of the radon (emanation coefficient) enters the space between the mineral grains and is thus able to travel towards the surface, carried either by carrier gases (methane, carbon dioxide) or thermal waters (Etiope & Martinelli, 2002). It accumulates in underground spaces (karst caves, mines) and buildings, and

eventually reaches the atmosphere. Radon levels in the environment depend on the geology of the region (the content of U-Ra isotopes), geological structure (the permeability of soil), seismic activity and hydro-meteorological parameters (soil and air temperature and humidity, barometric pressure, rainfall). This provides the basis for using radon in geological, tectonic and seismic research, although the main scientific interest is directed toward its detrimental effects on human health, being aware that more than half the effective doses from all natural radioactive sources are caused by breathing in air contaminated by radon and its radioactive descendants (UNSCEAR, 2000). Of the three radon isotopes, only  $^{222}\text{Rn}$  is usually of concern, as it appears at considerable le-

vels in our living and working environment because of its long half-life, compared with those of  $^{220}\text{Rn}$  and  $^{219}\text{Rn}$  (Nero, 1988). Therefore, following general practice, hereafter 'radon' (Rn) refers to  $^{222}\text{Rn}$ .

Radon surveys under the Slovenian national radon programme revealed that the majority of buildings with elevated indoor air radon levels are found in the karstic region (Vaupotič et al., 1994; Vaupotič et al., 1998; Vaupotič et al., 2000; Popit & Vaupotič, 2002a; Popit & Vaupotič, 2002b), although this was unexpected, because of the low U-Ra content in limestone, compared to that in the magmatic and metamorphic complex of the Pohorje area. Here, due to karstic phenomena (underground cracks, fissures, corridors) radon can easily travel long distances, thus resulting in high radon concentrations in the air of near-surface closed rooms. Therefore, thorough radon measurements have been performed in the last decade in living and working environments in this region, aimed at assessing effective doses and undertaking mitigation measures where necessary. In the town of Divača, indoor air radon concentrations higher than the Slovene national limit of  $1000 \text{ Bq m}^{-3}$  for workplaces (ULRS, 2004) have been found in several public and private buildings. For this study a public building was selected, and radon monitored in various seasons in indoor air at workplaces and in soil gas nearby. The dependence of indoor radon concentration on geology and environmental parameters (temperature and barometric pressure) is discussed.

### Geological characteristics of the site

The investigated area is part of the Karst and is located in the south-eastern part of the Trieste-Komen plateau, in Divača (Fig.1). Structurally, the area belongs to the External Dinarides (Placer, 1999) which are divided into more lower-order structural units. The northern, structurally highest, is Trnovo nappe and is underthrust towards the south by Hrušica nappe, Snežnik thrust sheet, Komen thrust sheet, Koper thrust fault and the Istrian autochthon (Placer, 1981). The Karst belongs to the Komen thrust sheet and, more precisely, to the Trieste-Komen anticlinorium.

Palaeogeographically the Karst area belonged to the Dinaric Carbonate Platform (Bu-

ser, 1989) which formed in the southern part of the Slovenian Carbonate Platform after it disintegrated in the Middle Triassic. The Dinaric Carbonate Platform experienced shallow-water sedimentation in the Karst region until the Lower Eocene when the platform drowned and flysch sedimentation began.

The Trieste-Komen plateau is composed predominantly of Cretaceous beds which are in contact locally with the Palaeogene beds (Fig.1) (Buser, 1973; Pleničar, 1973; Jurkovšek et al., 1996). Sedimentary rocks of this area are predominantly carbonates and, rarely, clastites. In the southern part of the Trieste-Komen plateau, Cretaceous and Paleocene succession was divided into seven formations (Jurkovšek et al., 1996). In the Divača region the Cretaceous Sežana, Repen and Povir Formation were recognized and are separated from the Palaeocene Liburnian Formation by the Divača fault. Formations are characterized predominantly by limestone, and exhibit solution porosity, which is most intense in fissured zones.

The most significant structure of the investigated area is the Divača fault in the NW-SE direction. Its kinematic development is very complex (Jurkovšek et al., 1996). During the Cretaceous-Palaeocene compression in the first phase it was a reverse fault with an overthrusting tendency towards the south-west. During the relaxation of regional pressures, it acquired the characteristics of a normal fault. In the Neogene and Quaternary it evolved into a strike-slip fault because of the compression in the north-south direction.

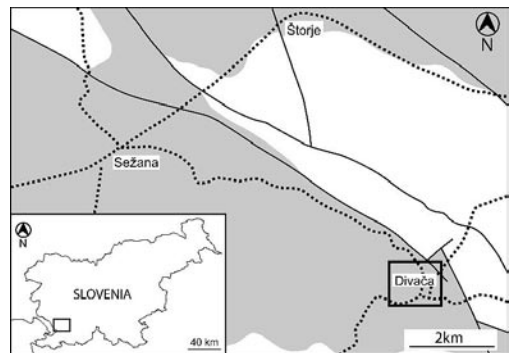


Figure 1. Location and simplified geological map of the south-eastern Karst (modified after Buser, 1968); Cretaceous carbonates are shaded in grey and Palaeogene beds in white, full line presents faults and dashed line main roads, investigated area is marked by rectangle.

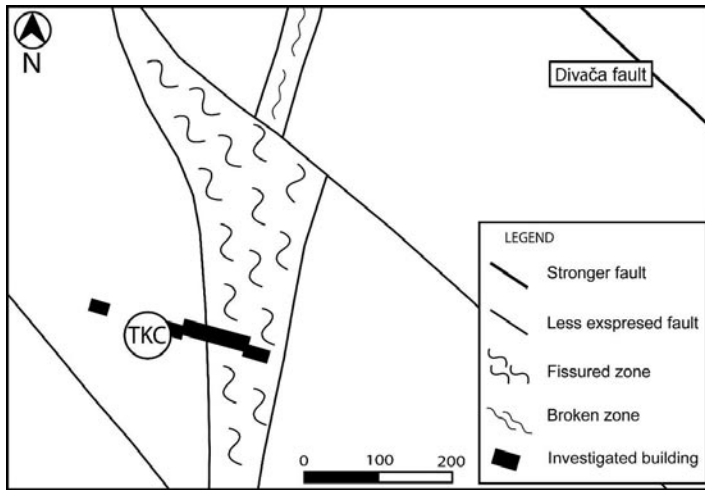


Figure 2. Structural map of the Divača site and position of the TKC room.

The Divača fault, as the main regional structure, is considered to be the predominant influence on the structural characteristics of the investigated area. From the structural mapping around Divača we defined two smaller scale NW-SE (dinaric) faults which are parallel and situated south-west of the Divača fault. Fissured zones exist in the north-south direction, between the dinaric faults, and are very probably the result of a local extensional tectonic regime. Fissured zones are considered to be potential migration routes of radon and the building with the highest radon levels is situated directly above one of them. A structural map of the site is shown in Fig. 2.

## Experimental

### *Description of buildings surveyed*

This study was carried out in a public building in Divača in which our previous radon survey had shown elevated indoor air radon concentrations (Vaupotič et al., 2004). The building is more than 150 years old, built mainly of stone. The entire complex is composed of a main two-storey building to which two smaller one-storey side-buildings are attached at each end, and a small one-storey building about 50 m away from the others. In these buildings, indoor radon concentrations at workplaces greatly exceed  $1000 \text{ Bq m}^{-3}$ , and thus present a real radon problem to be mitigated. Although in our study radon has been thoroughly investigated in all rooms, in this paper we

limit our attention only to the TKC room, as an example of how to find and identify the main radon source in a room with elevated indoor radon concentration. The room is on ground floor with no basement underneath. The rooms on the ground floor are connected to an under-floor channel that conveys electric, telephone and communication cables, and runs, in the front courtyard, at a level below the concrete floor, all along the building complex. The channel is 1 m deep and 30 cm wide with a total length of about 100 m. It is constructed of coarse concrete. The exit of the channel into each room is covered by a simple metal cover, not tightly sealed. The TKC room has no air-conditioning and is ventilated only by opening windows and door. During winter, the room is heated with hot-water radiators connected to a central heating system based on oil. Working hours are from 7 a.m. to 3 p.m. every day, including weekends.

In addition to the indoor air of the TKC room, radon was monitored in soil gas in an 80 cm deep borehole drilled in the garden close to the TKC room.

### *Radon measurement devices*

To observe fluctuations of radon concentration in the indoor air and in air in the channel, portable Sarad EQF3020 and RadonScout devices (manufactured by Sarad, Dresden, Germany) were used. They measure concentrations of activity (hereafter simply called concentrations) of radon and radon short-lived decay products, as well as air temperature and relative air humi-

dity (Streil et al., 1996). The frequency of sampling and analysis was once every two hours.

Radon in soil gas was monitored with a Barasol MS450 probe (manufactured by Al-gade, Bessines, France). Once every hour, it measures and records radon concentration,

barometric pressure and soil temperature. The devices were calibrated on purchase and then recalibrated every two years by the manufacturer, and are checked regularly at the inter-comparison experiments organized annually by the Slovene Nuclear Safety Administration (Križman, 2001).

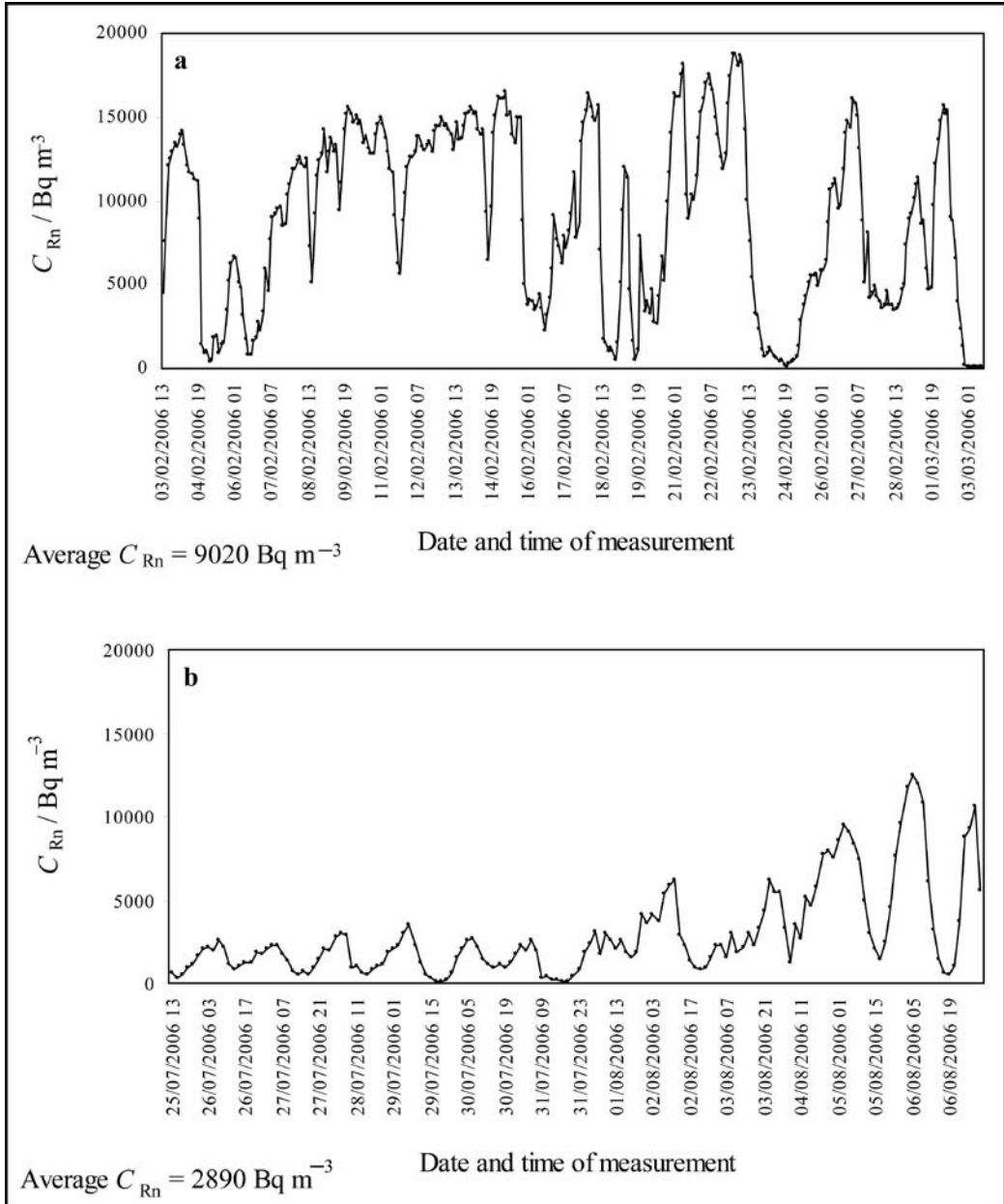


Figure 3. Time variation of indoor air radon concentration in the TKC room: a) in winter, from February 3 to March 3, and b) in summer, from July 25 to August 6.

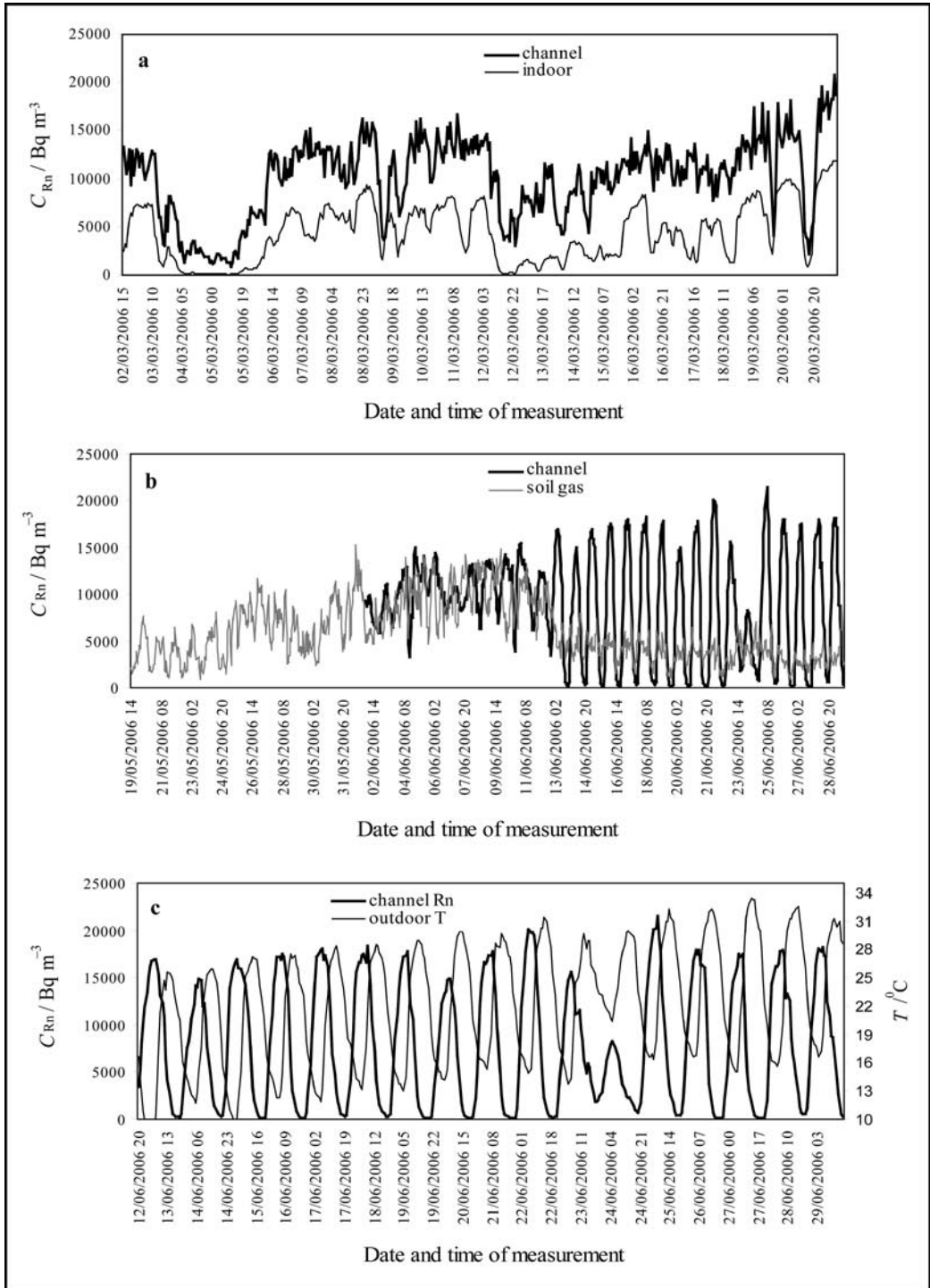


Figure 4. Relationships between a) radon concentration in indoor and channel air, b) radon concentration in the channel air and soil gas, and c) radon concentration in the channel air and outdoor air temperature.

## Results and Discussion

Diurnal variations of indoor radon concentration in the TKC room in winter and summer 2006 are shown in Figs. 3a and 3b, respectively. It can be seen that instantaneous values can reach values as high as 10,000 Bq m<sup>-3</sup> and very rarely fall below the national limit of 1000 Bq m<sup>-3</sup> (but neither of these during working hours), with average values of 9020 Bq m<sup>-3</sup> and 2890 Bq m<sup>-3</sup>, respectively. As expected (Vaupotič et al., 1998), concentrations in summer were lower than in winter. Because of occupation 7 days a week, no increase was observed during weekends (Vaupotič, 2002), i. e., February 4–5, February 11–12, February 18–19, February 25–26, July 29–30 and August 5–6.

Soon after the first inspection, the under-floor channel was suspected to be the main source of the high indoor radon concentration. This was confirmed by simultaneous radon monitoring in the room and channel. Radon levels in the channel were followed by radon levels in the room without measurable time delay (Fig. 4a). Radon concentration in the room was only three times lower than in the channel, demonstrating that the metal cover of the channel is a poor barrier for entry of radon into the room.

Fig. 4b compares radon concentrations in the channel air and in soil gas. In the period of June 2–12 the values are similar. After this, soil gas values decrease while the channel values increase, showing pronounced fluctuations between less than 100 Bq m<sup>-3</sup> up to as high as 20,000 Bq m<sup>-3</sup>. This may be explained by an increase in outdoor air temperature, which produces an increase in radon exhalation from the ground. This resulted in a lower soil gas concentration in the upper 60 cm layer and in enhanced radon accumulation in the channel. Fig. 4c shows that minima in radon concentration in the channel air coincide, with only a short time delay, with maxima in outdoor air temperature. When, on a sunny day, the outdoor air temperature reached 30 °C, the temperature of the concrete slab above the channel in the courtyard reached even higher values. Because the indoor air temperature in the TKC room is kept below 25 °C, this temperature difference causes a 'chimney effect' in the channel, producing a draught of air from the courtyard towards the room, thus sweeping radon-rich air from the channel into the TKC room and, further, into the outdoor

air. When the outdoor air temperature starts to decrease in the afternoon, the temperature difference in the channel steadily decreases, air draught is reduced and eventually stopped (or minimised), and radon starts to accumulate to reach its highest concentration during the night.

Because the under-floor channel is known to be the main radon source, the problem in the TKC room (and also in other rooms of this building complex) could be successfully mitigated by either closing the channel exits into the room (by completely sealing the cover) or by installing a fan into the channel to periodically ventilate the channel and thus prevent radon from accumulating. Undertaking mitigation measures is beyond the scope of this work and will be dealt with in a separate project.

## Conclusions

Our survey in the TKC room of a public building in Divača has shown that radon concentrations in the air at a workplace may easily reach values up to 10,000 Bq m<sup>-3</sup>, in which case they are likely to fall very rarely below the national limit of 1000 Bq m<sup>-3</sup> for workplaces. These elevated values are presumably related to the fracture zone that connects the two smaller-scale dinaric (NW-SE) faults which are parallel to the main structure of the area, the Divača fault. The main radon source in the building is the under-floor channel connecting the rooms. In order to mitigate radon problem, the channel should be either ventilated with a fan to prevent radon from accumulating in the channel or completely isolated to prevent radon from entering the room.

## Acknowledgments

This study was financed by the Slovene Research Agency. The authors thank Ms. Petra Dujmovič for her field measurements and laboratory analyses and Mr. Jože Čar and Mr. Boštjan Rožič for help with structural mapping of the area. The cooperation of the management and personnel of the building are appreciated.

## References

- Etioppe, G. & Martinelli, G. 2002: Migration of carrier and trace gases in the geosphere: an overview. - *Phys Earth Planetary Interiors*, 129, 185-204.
- Buser, S. 1968: Osnovna geološka karta SFRJ, list Gorica, 1:100.000. - Zvezni geološki zavod, Beograd.
- Buser, S. 1973: Tolmač lista Gorica. Osnovna geološka karta SFRJ 1:100.000. - Zvezni geološki zavod, L 33-78, 50 pp., Beograd.
- Buser, S. 1989: Development of the Dinaric and Julian carbonate platforms and the intermediate Slovenian basin (NW-Yugoslavia). In: Carulli, G.B., Cucchi, F. & Radrizzani, C.P. (ed.), *Evolution of the Karstic carbonate platform: relation with other periadriatic carbonate platforms*. - *Mem. Soc. Geol. Ital.*, 40 (1987), 313-320, Roma.
- Jurkovšek, B., Toman, M., Ogorelec, B., Šribar, L., Drobne, K., Poljak, M. & Šribar, Lj. 1996: Formacijska geološka karta južnega dela Tržaško-komenske planote. Kredne in paleogenske kamnine, 1:50.000. - Inštitut za geologijo, geotehniko in geofiziko, 143 str., Ljubljana.
- Križman, M. 2001: Report on the Intercomparison Experiment for Radon and Progeny in Air. - URSJV Report RP 47/2001. Nuclear Safety Administration, Ljubljana.
- Nero, Jr, A.V., 1988: Radon and its decay products in indoor air: an overview. In: Nazaroff, W.W., Nero, Jr, A.V. (ed.), *Radon and its Decay Products in Indoor Air*. - John Wiley & Sons, 1-53, New York.
- Placer, L. 1981: Geološka zgradba jugozahodne Slovenije. - *Geologija* 24/1, 27-60, Ljubljana.
- Placer, L. 1999: Contribution to the macro-tectonic subdivision of the border region between Southern Alps and External Dinarides. - *Geologija*, 41, 223-225, Ljubljana.
- Pleničar, M., Polšak, A. & Šikić, D. 1973: Tolmač lista Trst. Osnovna geološka karta SFRJ 1:100.000. - Zvezni geološki zavod, 68 pp., Beograd.
- Popit, A. & Vaupotič, J., 2002a: Indoor radon concentrations in relation to geology in Slovenia. - *Environ. Geol.*, 42, 330-337.
- Popit, A. & Vaupotič, J. 2002b: The influence of geology on elevated radon concentrations in Slovenian schools and kindergartens. - *Geologija*, 45, 499-504, Ljubljana.
- Streil, T., Holfeld, G., Oeser, V., Feddersen, C. & Schönfeld, K. 1996: Sarad EQF 3020 a new microsystem based monitoring system for the continuous measurement of radon and the attached and unattached fraction of the radon progeny. In: Glavič-Cindro, D. (ed.), *IRPA (International Radiological Protection Association) Regional Congress on Radiation Protection in Neighbouring Countries in Central Europe - 1995*, Portorož, 334-341.
- UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), 2000: Sources and Effects of Ionizing radiation. - *UNSCEAR 2000 Report to the General assembly, with Scientific Annexes*, 1.
- ULRS, 2004: Uradni list RS. Uredba o mejnih dozah, radioaktivni kontaminaciji in intervencijskih nivojih, Uradni list RS, 49/2004.
- Vaupotič, J., Križman, M., Planinič, J., Pezdič, J., Adamič, K., Stegnar, P. & Kobal, I. 1994: Systematic indoor radon and gamma measurements in kindergartens and play schools in Slovenia. - *Health Phys.*, 66, 550-556.
- Vaupotič, J., Planinič, J. & Kobal, I. 1998: Long-term radon investigation in four selected kindergartens in different geological and climate regions of Slovenia. - *J. Radioanal. Nucl. Chem.*, 238, 61-66.
- Vaupotič, J., Šikovec, M. & Kobal, I. 2000: Systematic indoor radon and gamma-ray measurements in Slovenian schools. - *Health Phys.*, 78, 559-562.
- Vaupotič, J. 2002: Do long-term average radon concentrations in schools and kindergartens differ from the average during working hours? - *Health Phys.*, 83, 237-242.
- Vaupotič, J., Kalin, N., Dujmovič, P. & Kobal, I. 2004: Radon and gamma radiation in working environment: buildings on risk areas - I part. - *IJS Report-9068* (in Slovene, abstract in English).

