

Geological structure and radon concentration in the territory of Serbia

SNEŽANA KOMATINA¹, MIOMIR KOMATINA¹, NENAD Č. BOJAT², UNA PETROVIĆ¹

¹ ASSOCIATION OF GEOPHYSICISTS AND ENVIRONMENTALISTS OF SERBIA (AGES), BELGRADE, SERBIA

² FACULTY OF ECONOMICS AND ENGINEERING MANAGEMENT (FIMEK), NOVI SAD, SERBIA

Lately, a hot topic in Serbia is the concentration of radon in the territory of the country and its impact on the health of the population. According to the statements of the National Agency for Protection against Ionizing Radiation and Nuclear Safety, above all, it is impossible to discover when the measurements of the concentration of this gas have been performed and which part of the country is covered by investigations, but the conclusion is that the results are in the highest percentage within the expected range. However, according to the available data performed by the competent geological institutions and the Vinča Institute, risk areas have been defined, where appropriate measures should be implemented. The data are analyzed in the paper and their correlation with the geological structure of the terrain is presented. Keywords: Radon, public health, Serbia.

Introduction

Environmental contamination by radioactive elements is certainly at the top of all the problems that have ever existed, and there is concern for the need to protect the nature and the man. Among all, radon in gaseous state is characterized by the ability to migrate through groundwater to large distances and to concentrate indoors, showing unwanted effects. The critical organ is the lungs, where it is fixed, causing malignant disease. Epidemiological studies have shown that this gas is the second leading cause of lung cancer (after smoking) (Komatina-Petrović S., 2011). Just like in most European countries, the problem of deaths caused by radon needs a more serious approach,

and the first step is to use the existing geological and other appropriate data and to carry out radon risk mapping. It is logical that the research work should start from the most risky areas, marked by uraniferous formations and phenomena of uranium (Komatina M., et al., 2012).

In Serbia, systematic studies of nuclear mineral resources started at the end of the first half of the last century. Namely, in the period from 1948 to 1990, about 50% of the potential uranous territory of Serbia was covered by Geoinstitute - Belgrade and hundreds of anomalous zones of high radioactivity were discovered (Komatina M., 2016). The data collected are particularly valuable when it comes to preventive medical operation and organization of health care, because they indicate the risky areas, where human population is suffering the most, and which require urgent protection measures (areas of Stara Planina, Bukulja and Cer Mts. with uranium deposits, ore bodies in the Kukavica Mt. near Vranje and Muhova at Golija Mt., areas with uranous phenomena at Lepenski vir, Brnjica, Plavna, Kosmaj - Babe, Stuble near Gnjilane, etc., Vranje-Bujanovac, Poljanica, Pčinjski, Sokobanjski, Zaplanjski, Koritničko-babušnički sedimentary basins, etc.) (Komatina S., 2004).

Particular attention should be also directed to the results of the measurements of the radioactive gas radon concentration, performed during the last two decades by Vinča Institute at several localities over the country (Žunić S.Z. et al., 2014). It has been shown, for example, that the measurements of the radon content in the

In the Southern Serbia, the measurements of radon content covered 300 primary schools, and high (anomalous) concentrations were registered in every tenth school. Furthermore, exactly the half of the registered anomalies refer to the areas of Surdulica, Vranje and Bujanovac (Uševce, Dobrejanec, Kruševo, Surdulica, Misurica, Krševica, Košarno, etc.). In the mentioned areas, the primary carriers of ore occurrences are granitoids of Surdulica, Bujanovac and Kukavica, but also volcanites of the Lece massif, while secondary uranium deposits are related to the Paleogene sandstones of Poljanica basin, Vrla, etc. (Bossey P., et al., 2013).

The territory of Serbia is characterized by different petrographic content and complex structural relations (Fig.1). Within the territory, the following geotectonic units are defined (Fig.2):

- Carpatho-Balkanides, with the part of Dakian basin;
- Serbo-Macedonian mass;
- Vardar zone;
- Dinarides and
- Pannonian basin.

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Figure 1. Geological map of Serbia

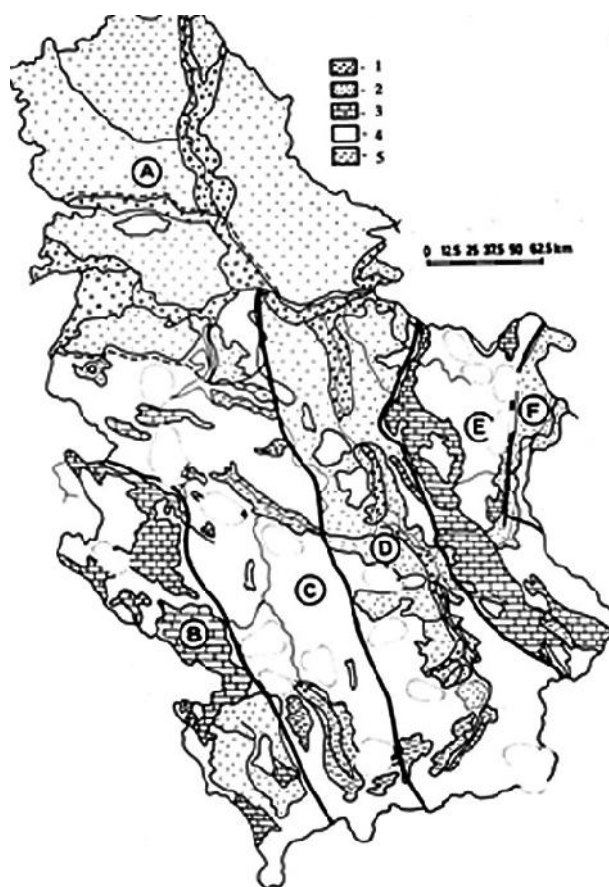


Figure 2. Geotectonic units of the territory of Serbia.
A. Pannonian basin; B. Dinarides of Western Serbia; C.
22 Vardar zone; D. The Serbo-Macedonian mass; E.
Carpatho-Balkanides; F. Dakian basin;
1. Alluvial formations;
2. Neogene lacustrine sediments;
3. Limestones;
4. Fractured formations;
5. Neogene clay sediments

Arandelovac, Kragujevac, Trstenik, Podujevo and Gnjilane, towards the National boundary with FYRM (Fig.2).

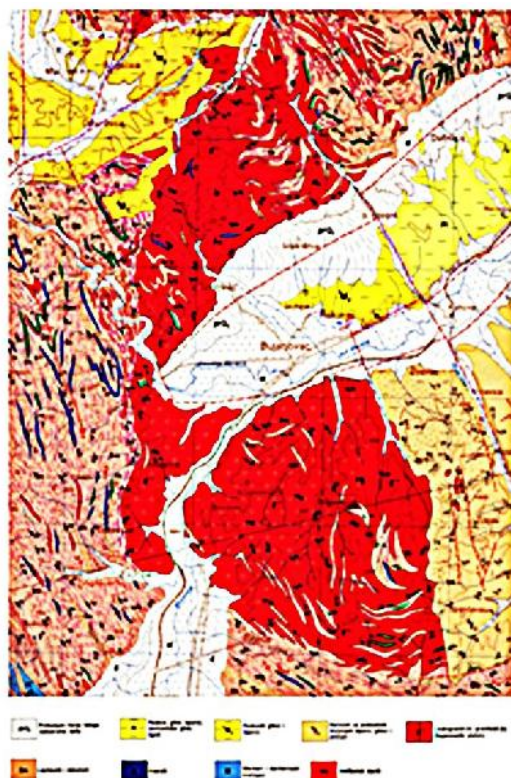


Figure 3. Geological map of Bujanovac pluton (Žunić S.Z. et al., 2014)

The study area from the Serbo-Macedonian mass is characterized by complex geological structure - numerous geological formations of different origin and age. In other words, Precambria to Quaternary magmatic, metamorphic and sedimentary formations are present (Komatina M., 2001).

Precambrian and Paleozoic schist rocks are predominant, defined as upper and lower crystalline complex. Bottom crystalline complex is made of gneiss, mica schist and leptynolite, with lenses of marble and quartzite (Fig.1). Marble formations are predominant along the edge zone to Vardar geotectonic unit, extending from Propaslica, to Kmetovac, Preševo and Staro Nagoričane (Fig.3). The top complex (known as Vlasina) is made of low-level crystallinity shale (green shale facies) - mica-chlorite schists, amphibolites, mica schist and quartzite. This complex extends from Golubac (Danube

river), to the Pek river, Babička gora and Seličevica to Osogovo and along the National boundary with Bulgaria. Granite layers of Mt. Kukavica and the Slatinska river, but also granitoid layers of Božica are intruded into the top complex shale. Furthermore, within schist formation, intruded magmatic rocks (granite, diorite, granitoid formations of Vlačina), as well as granitoid of Bujanovac pluton and SE from Gnjilane (intruded 234 million years ago) (Fig.3) are significant.

Uranium-bearing formations of the Southern Serbia

During the last six decades, systematic investigations related to uranium content were performed in Serbia. That is why in 1949, several uranium-bearing minerals were discovered by geologists from The Geoinstitute, Belgrade, and in 1955-1959, a conclusion that the terrains made of old schist and granite layers are the most perspective geological environment for uranium minerals was announced. In the period 1960-1971, beside Žirovski vrh in Slovenia, deposits in Permian red sandstones of Stara planina Mt. (Gabrovica, Srneći do, Dojkince), granites of Bukulja Mt. (Paun Stena, Cigankulja) and numerous other mineralizations (Zaplanje, Barbes, Slatinska river, Stublovača near Gnjilane, Muhov on Golija Mt., etc.) and radioactive anomalies, were discovered.

Systematic regional and detailed investigations were performed over one half of the potential uranium-bearing territory of Serbia, when several hundreds of high- radioactivity zones were defined. Besides uranium, radium and potassium, radon was subject of investigations not only in the prospecting stage, but also during discovering nuclear raw materials deposits. Because of the high migration ability and appearance in various geological formations, which is characteristic in comparison to almost all other metals, uranium is of very unique metalogenesis. Besides, once deposited, uranium can be easily moved into another formation and concentrated depending on geological and hydrogeological conditions existing after forming the deposit. However, in different

areas all over the world, uranium production is carried out from deposits in appropriate petrographic formations, as: quartz sandstone (USA, Nigeria, etc.), conglomerates (Canada is at the second place in the world in reserves from conglomerates; S. Africa and Brazil), uranium-bearing phosphates in Morocco, uranium-bearing schist rocks (N.Australia, Sweden, Spain, etc.) and granites (Spain, France, Czech Republic, Germany, etc.).

In Serbia, the following uranium-bearing units are recognized:

- crystalline massifs with alkaline type granitoid outcrops. It has been already mentioned that these rocks are particularly present in SE part of Serbia, within the Serbo-Macedonian mass. Significant appearances are: Nekudovo, Resavica, Trepetljak, Klokočevac, etc. Shales of Mt. Kitka in FYRM, from the same geotectonic unit, with radon-gas concentration of 15,000 Bq/l, as well as gneiss in Selecka Mt., characterized by the series of radioactive anomalies, should be mentioned. The granitoid formations are defined as an environment consisting of the greatest number of uranium appearances and deposits (Janja granite with deposits, Mezdreja, Gabrovnica, Srneći Do; granites of Bukulja Mt. with Paun Stena and Cigankulja deposits; granites of Kukavica and Cer, etc.). It is worth mentioning that granitoides were uranium sources, contributing to forming deposits in adjacent younger sediments;
- Old terrigenous sediments (sandstones and similar) are the most important formations for uranium mineralization in former Yugoslavia. The best known are: Permian Greden sandstones (Žirovski Vrh deposit in Slovenia) and Permian red sandstones in Stara planina Mt. (Dojkinci deposit), etc.
- Terrigenous sedimentary basins, particularly basins with Lower Tertiary sediments, formed within or along the edge of crystalline/granitoid massifs. The Uranium mineralization of this type has been discovered in Vranje basin (Fig.3), but the environment suitable for depositing is also present in Toplica, Leskovac, Sokobanja and Babušnica basin.
- Uranium deposits can be formed in crushed zones of volcanic rocks. Uranium mineralization in the Zletovo river (FYRM) is

related to the crushed zones of andesite and pyroclastite in Zletovo-Krapovo volcanogenic area. Southern from Gnjilane, lava flows and pyroclastites of alkaline volcanism (Fig.4). Stublovača hill, southward from the town, is made of trachyte, containing uranium veins, visible near Stuble village. Trachytes are characterized by very high content of thorium and uranium.

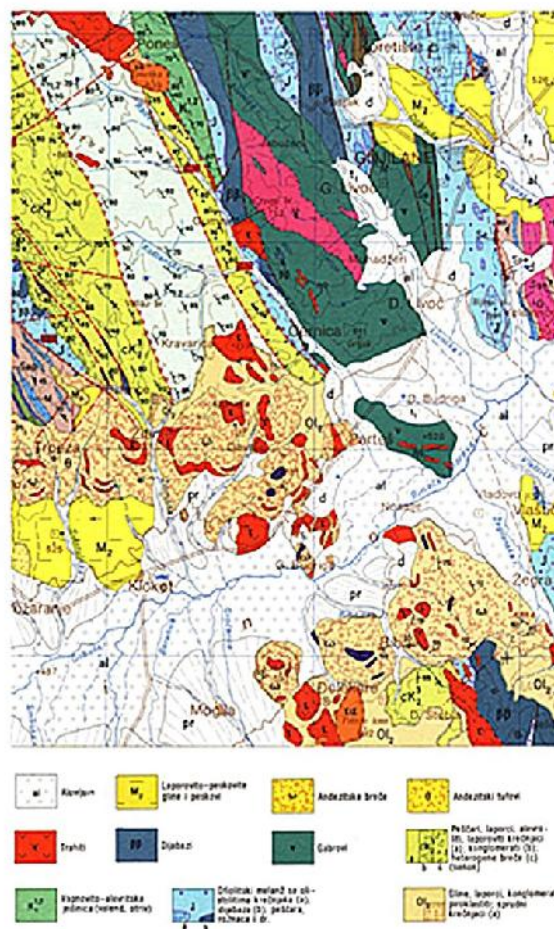


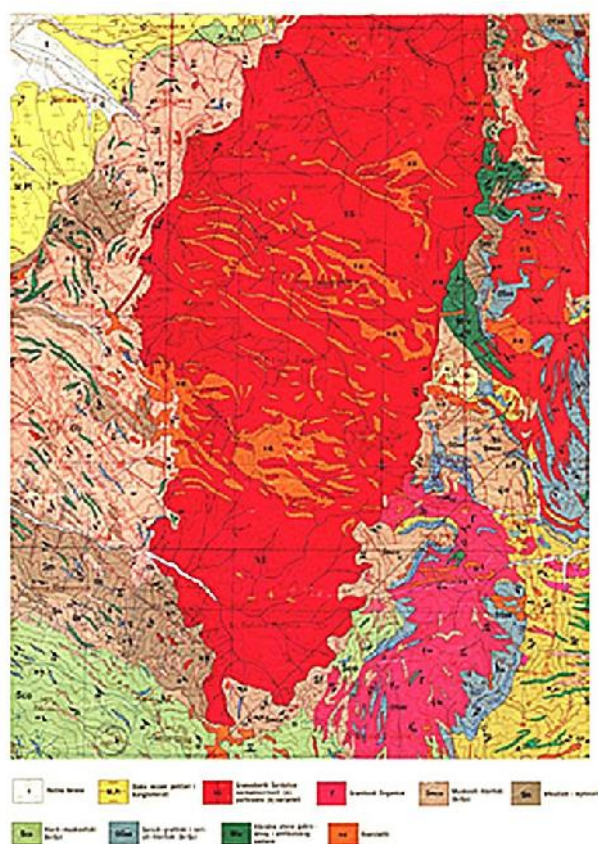
Figure 4. Geological map of Gnjilane and its vicinity
(Žunić S.Z. et al., 2014)

Besides partly investigated ore zones of Stara planina, Bukulja and Cer Mts., the following areas of S. Serbia have not been studied enough:

1. Surdulica granodiorite massif (Fig.5), particularly the Slatina river, containing granites with high uranium content (it is expected to be a uranium deposit). Because of the present mineralization, the locality of the Slatina river has been the subject of exploratory drilling and lab investigations. Furthermore, within volcanic rocks (dacites,

2. The complex of Lece massif volcanic rocks (predominantly andesite), SE from Kuršumlja (Fig.6), is characterized by high uranium content. The average uranium content is 3.35 ppm and of thorium: 14.50 ppm.
3. Within the investigations of the Tertiary basins in Serbia, radiometric measurements have been carried out in the area of the upper part of the Pcinja river, as a perspective regarding the discovery of the uranium deposits. Here, large amounts of uranium have been brought by volcanic activity. It was determined that the majority of the discovered uranium occurrences are distributed along the appropriate stratigraphic horizons in Paleogene sediments, particularly in facies where sandstones are predominant. Uranium outcrops are visible in Saince- Mezdraja zone. Neogene sediments are, also, carriers of uranium mineralization, but only in Žbevac-Klinovac zone. In the southern part of Surlica tufaceous series, narrow-localized uranium occurrences are present in breccias close to the main fault, along which dacite-rhyolites are outcropping.
4. Pegmatite containing beryl and radioactive minerals are located in Pasjača and Vidovača Mts., southern from Prokuplje, at the area of approx. 200 km² (Fig.7).

Neogene basin (uranium content in water: 2.14 mg/l), granitoides of Bukulja near Garasi village (1.30 mg/l), volcanic rocks (trachyte) of Klokot Tertiary basin near Balance village (eastern from Uroševac) (up to 0.65 mg/l) (Fig.4), granitoides of Janja (Eastern Serbia) (up to 0.40 mg/l). High radon content in groundwater directs to the relationship with some uranium mineralization – uranium degradation in contact with water. Migration of this radioactive gas is carried out along fault zones and fracture systems, and it is more expressed than for uranium and radium (Komatina M., 2004).



The highest distinguished values of hydrochemical radon anomalies in Serbia are: Grban – in Proterozoic metamorphites of Stalac gorge (radon content: 5,020 Bq/l) and Majur-Slatina spring in granitoides of Bukulja Mt. (1,000 Bq/l), etc. The anomaly in the area of Kitka Mt. is also interesting – approx. 20 km southern from Skopje (FYRM), where peak value of radon content in groundwater of Crvena voda spring of 19,640 Bq/l was determined. It is possible that the main aquifer is made of Paleozoic marble,

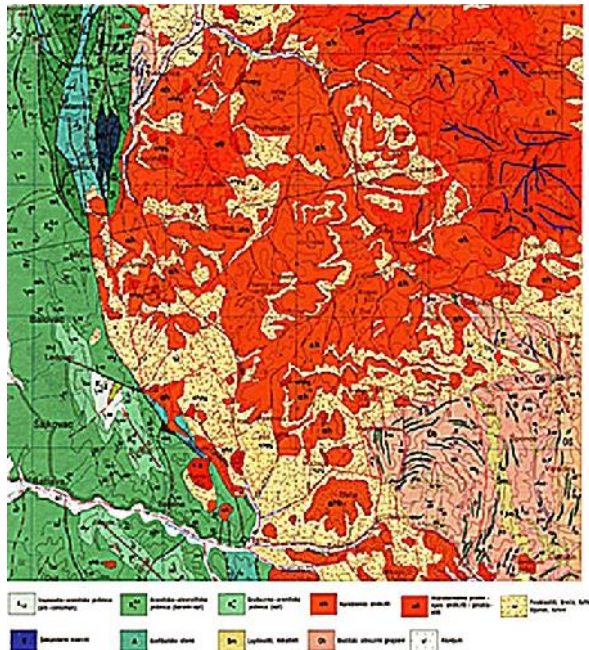


Figure 6. Geological map of Lece andesite massif (Bossew P., et al., 2013)

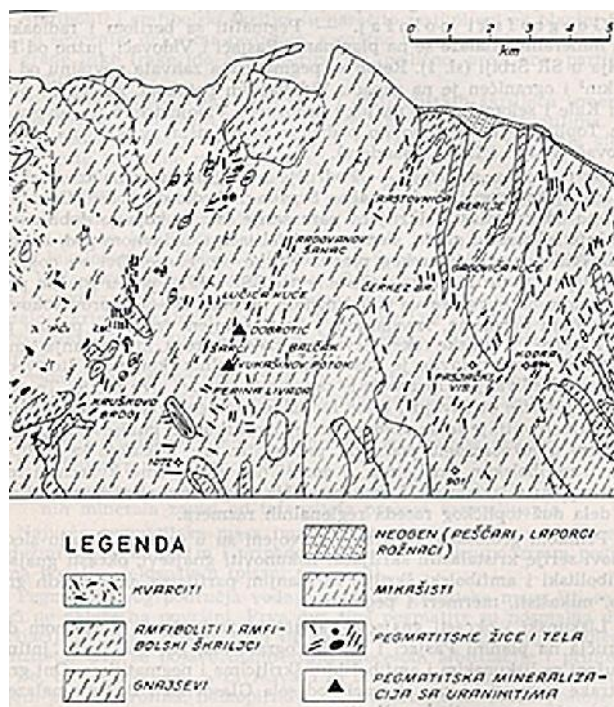


Figure 7. Geological map of the area southern from Prokuplje (Komatina M., 2016).

confined by impermeable metamorphites and intrusions (Fig.8). From marble, groundwater flows along the fault zone, being in contact with uranium deposits and becoming rich in radon and radium. The deposit has been probably

formed by accumulating uranium and other mineralization at the contact of magmatic intrusion and marble.

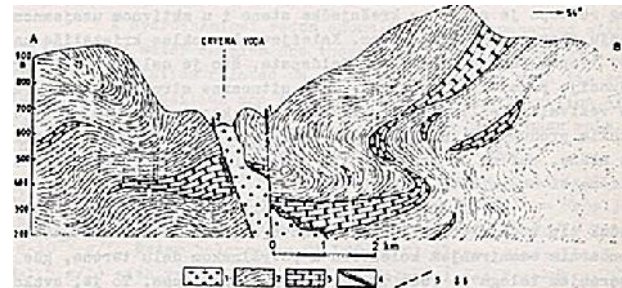


Figure 8. Prognosed geological cross-section (Komatina M., 2016)

1. granite;
2. gneiss and mica schist;
3. marble;
4. mineralization;
5. fault;
6. radioactive spring

Conclusions

Environmental contamination by radioactive elements is certainly at the top of all the problems that have ever existed, and there is concern for the need to protect the nature and the man. Among all, radon in gaseous state is characterized by the ability to migrate through groundwater to large distances and to concentrate indoors, showing unwanted effects. The critical organ is the lungs, where it is fixed, causing malignant disease. Epidemiological studies have shown that this gas is the second leading cause of lung cancer (after smoking). According to the statements of the National Agency for Protection against Ionizing Radiation and Nuclear Safety, above all, it is impossible to discover when the measurements of the concentration of this gas have been performed in Serbia and which part of the country is covered by investigations, but the conclusion is that the results are in the highest percentage within the expected range. However, according to the available data collected by the competent geological institutions and the Vinča Institute, risk areas have been defined, where appropriate measures should be implemented. In the paper, the relationship between high radon concentration and geological structure of the area is discussed.

On the basis of this analysis, further investigations should be performed and measures for public health protection carried out. The data collected are particularly valuable when it comes to preventive medical operation and organization of health care, because they indicate the risky areas, where human population is suffering the most, and which require urgent protection measures (areas of Stara Planina, Bukulja and Cer Mts., with uranium deposits; ore bodies in the Kukavica Mt. near Vranje and

Muhova at Golija Mt.; areas with uranium phenomena at Lepenski vir, Brnjica, Plavna, Kosmaj - Babe, Stuble near Gnjilane, etc.; Vranje-Bujanovac, Poljanica, Pčinjski, Sokobanjski, Zaplanjski, Koritničko-babušnički sedimentary basins, etc.). Investigations related to radon concentration in primary schools have been performed in the area of the Serbo-Macedonian mass, southern from Jastrebac Mt., as well as Sokobanja (spa), within Carpatho-balkanides.

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Correspondence to:

Snežana Komatina

**Association of Geophysicists and
Environmentalists of Serbia (AGES) Belgrade**

komsne@yahoo.com

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Geološka građa i koncentracija radona na teritoriji Srbije

SAŽETAK

U poslednje vreme se u Srbiji sve više govori o koncentraciji radona na teritoriji države i njenom uticaju na zdravlje stanovništva. Prema saopštenjima Agencije za zaštitu od jonizujućeg zračenja i nuklearnu sigurnost Srbije se, pre svega, ne vidi kada su vršena merenja koncentracije ovog gasa i koji deo zemlje je obuhvaćen, ali se zaključuje da su rezultati u najvećem procentu u očekivanom opsegu. Na osnovu raspoloživih podataka vršenih od strane nadležnih geoloških institucija i Instituta Vinča, mogu se definisati rizična područja, gde bi trebalo sprovesti odgovarajuće mere zaštite. U radu se analiziraju ovi podaci i daje njihova korelacija sa geološkom građom terena.

Ključne riječi: Radon, zdravlje stanovništva, Srbija.