

ASSESSMENT OF RADON POTENTIAL ALONG LOCAL
FAULT SYSTEM IN SOFIA, BULGARIA
(AT SPECIFIC TEST SITE)

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Abstract

Environmental spread of radon gas (^{222}Rn) has been intensively investigated in the last few years due to its harmful effects on human health. A concept of radon index is used to characterize the geogenic radon potential of the terrain, as the latter gives the probability of the presence of radon gas concentration in a building, the genesis of which is directly related to the influence of the earth's surface. One of the approaches for quantifying the radon index is based on a multivariate cross-tabulation, which includes two parameters – radon concentration in soil gas and gas permeability of the earth layer (at 80 cm). The geology of the specific site (approx. 350 m²) is characterized by the Pliocene clayey-sandy Formation, covered with Quaternary sediments. From tectonic point of view, the site as a part of Sofia Graben, has being subject of events related mainly with the Late Alpine deformations heading to very complex structures and fault systems. In situ measurements performed in the summer of 2023 at ten distinct points at the surface and 11 distinct points at two meters in depth from the surface vary as follows: from 44.2 to 189.0 kBq/m³ (radon soil gas), from 2.0E–11 to 1.8E–13 m² (soil gas permeability), and from 0.10 to 0.17 μSv/h (gamma dose rate). Based on that, the radon index of the site is determined from “medium” to “high”, with a predominance of the latter.

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One of the reasons for the high radon potential is the presence of sub-faults connected with the major Sofia fault system and their influence on the radon concentration. Therefore, in future investigations of the radon index, a very detailed survey of the site's geology is needed in the territory with appearing fault systems. In addition, based on the determination of the radon index, the forthcoming construction activities in such areas will be advised to use preventive measures during the construction of the new building to avoid future radon gas influxes on the premises.

Key words: radon, geology, faults, in situ measurements, Bulgaria

Introduction. The naturally occurring radioactive element radon (^{222}Rn) is a noble gas and is a daughter product of radium (^{226}Ra) of the radioactive uranium (^{238}U) family, which is found in every rock and soil in the lithosphere. The half-life of radon is sufficient (3.82 days) for it to pass from the terrestrial environment to the surface. This process can be more intensive because gas migration to the Earth's surface is strictly linked to preferential degassing pathways, such as faults or fracture systems [1, 2]. The physical properties of the terrestrial environment, especially its permeability, can also affect the flux of ^{222}Rn [3, 4]. Therefore, the geological structure is one of the main factors influencing indoor radon variation and thus the radon concentration in buildings and radon exposure [5]. In connection with this, there are field observations and investigations worldwide for the presence of high radon concentrations along fault and fault systems [6–8], some of them on the Balkan Peninsula [9, 10]. The geogenic radon potential (GRP) of the terrain is the probability of the presence of high radon concentration in a building, the genesis of which is directly related to the influence of the earth's surface, and not, for example, from building materials. The concept of radon index is used to characterize GRP. One of the approaches for quantifying the radon index is based on a multivariate cross-tabulation, which includes two parameters – radon concentration in soil gas and gas permeability of the earth layer [11]. In Bulgaria, there are investigations based on the above-mentioned concept regarding the radon concentration in soil gas connected with existing faults [12]. The idea of this investigation is to conduct repeated determinations of the radon index, based on in situ measurement of the concentration of radon in soil and the gas permeability of the surface layer (natural terrain of the site) and after the excavation of approximately two meters of the terrain's sediments at a site with potentially existing fault and sub-fault system in Sofia, Bulgaria.

Materials and methods. Study area – geological settings. The site is located on the territory of the Lozenets district of Sofia (Fig. 1). The approximate area surveyed is 350 m^2 . The geological structure of the specific site is represented by the Neogene (Pliocene) clayey-sandy Formation (officially named the 'Lozenets' Formation), covered by Quaternary sediments. The latter are recent soil with varying depth at the site, ranging from 0.30 to 1.10 m, as the terrain slopes steeply

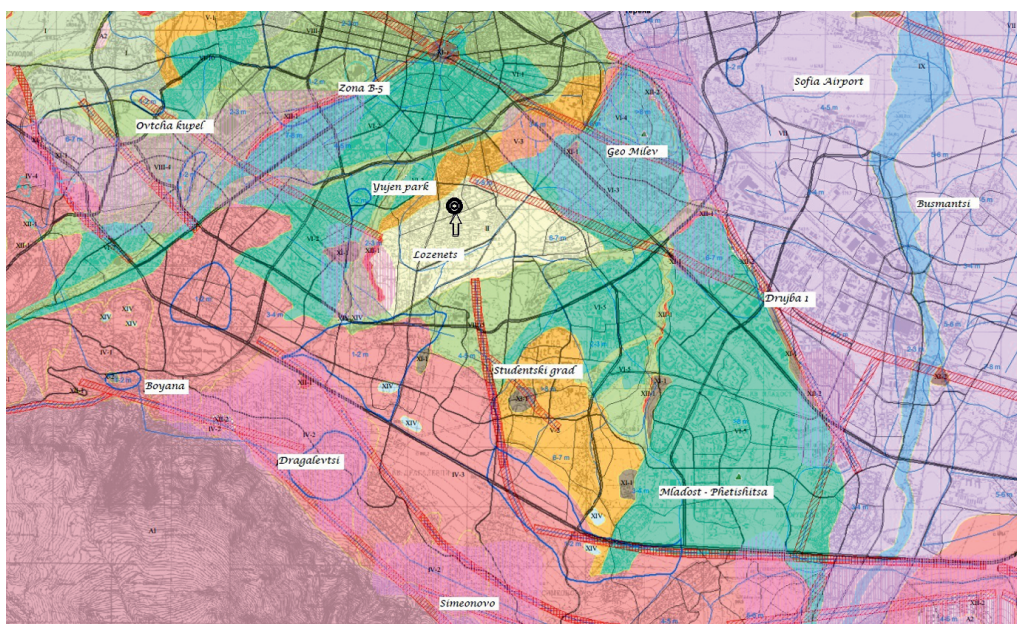


Fig. 1. General scheme of the southern part of Sofia kettle with the investigated site (black point). The known and scientifically suggested faults are given in red thick lines (in accordance with Sofia Municipality engineering geology map)

northward. The Lozenets Formation is composed of an irregular alternation of sand, gravel, silt, and clay with a depth of more than 100 m [13–16]. From a tectonic point of view, the site, as part of the Sofia Graben, has been subjected to events mainly related to Late Alpine deformations, resulting in very complex structures and fault systems.

Equipment. The spatial position of the fault was determined by geophysical measurements performed with PQWT-TC300 instrument developed by Hunan Puqi Geologic Exploration Equipment Institute. The method is based on the measurement of the electric field caused by various mostly natural sources [17]. Gas permeability of the soil was measured by RADON-JOK system manufactured by Radon v.o.s., Czech Republic. The theoretical frame-work for measuring soil gas permeability is based on the Darcy equation [11]. The measurement range is from $2.0\text{E}-11$ to $5.0\text{E}-17$ m^2 . Radon concentration in soil gas was measured by an RM-2 system of the company Radon v.o.s., Czech Republic, based on alpha radiation of radon in soil-gas sample affecting ionization current in an ionization chamber [18]. The range of radon measurements in soil gas is between 3 and 900 kBq/m^3 , at air temperature $+5$ to $+40^\circ\text{C}$ and humidity $\leq 70\%$. Direct gamma dose rate measurements were performed at each test site according to standard operating procedure with a Rados-RDS 110 portable dosimetry device.

Results and discussion. The exact position of the geophysical investigations for local faults are shown in Fig. 2.

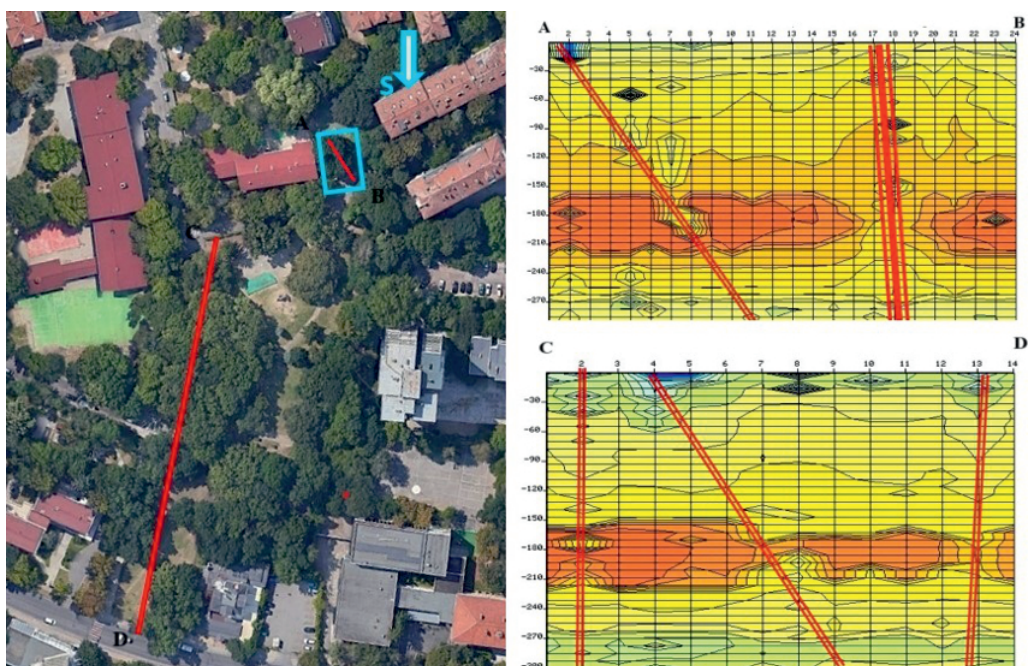


Fig. 2. Location of the geophysical profiles and cross-diagrams with the estimated local faults on the investigated site

The obtained results at the first stage of radon concentration in soil gas, soil permeability, and gamma dose rate measurements in the Lozenets district, as well as the determined geogenic radon potential, are summarized in Table 1. Please

T a b l e 1

Results at the surface of the in situ measurements of radon in soil gas, permeability, and gamma dose rate as well as the determined radon index at the specific site

Measuring points	Radon concentration in soil, kBq/m ³	Soil permeability, m ²	Gamma dose rate, μSv/h	Radon index
SP_1	50.6	1.8E-11	0.14	high
SP_2	52.3	1.9E-11	0.12	high
SP_3	44.9	1.0E-11	0.12	high
SP_4	66.6	1.8E-11	0.13	high
SP_5	44.2	2.0E-11	0.11	high
SP_6	46.3	4.0E-12	0.11	medium
SP_7	116.6	1.8E-13	0.10	high
SP_8	53.8	7.5E-13	0.10	medium
SP_9	46.9	2.0E-11	0.11	high
SP_10	50.7	5.5E-12	0.11	high

note that in the first stage of the investigation several measuring points were established to collect data, denoted as “SP” (surface points). These measuring points were evenly distributed at the site of the forthcoming building in Lozenets district of Sofia.

Although the site is relatively small (350 m²) the results show significant variation as the radon concentration in soil gas ranges from 44.2 to 116.6 kBq/m³; soil permeability values range from very low values of 1.8E–13 to high ones, exceeding 2.0E–11 m²; and gamma dose rate values in the area range from 0.10 to 0.14 µSv/h.

Then, a second investigation was performed positioned two meters below the natural surface, accessible after excavation works. The obtained results at this second stage of radon concentration in soil gas, soil permeability, and gamma dose rate measurements as well as the determined geogenic radon potential, are summarized in Table 2. Measuring points are denoted as “SSP” (sub-surface points) and their position did not coincide with the previous ones although they do not differ significantly due to the small area.

Several trends emerge from the results presented above. Firstly, there is a noticeable decrease in soil permeability with depth. In the case of “SP” measurements, approximately half of the recorded values fall within the range of 1.0E–11 m², whereas in “SSP” measurements, more than half of the results are within the range of 1.0E–12 m², representing a difference of one order of magnitude. This discrepancy is logical, as “SSP” measurements were conducted entirely within the Neogene Formation, which differs in density and bulk density compared to the Quaternary soil.

T a b l e 2

Results at minus two meters of the in situ measurements of radon in soil gas, permeability, and gamma dose rate as well as the determined radon index at the specific site

Measuring points	Radon concentration in soil, kBq/m ³	Soil permeability, m ²	Gamma dose rate, µSv/h	Radon index
SSP_1	50.7	1.0E–11	0.15	high
SSP_2	68.6	3.1E–12	0.13	medium
SSP_3	127.0	6.2E–12	0.15	high
SSP_4	45.4	6.6E–12	0.13	high
SSP_5	32.6	1.1E–11	0.13	high
SSP_6	32.1	2.5E–12	0.12	high
SSP_7	189.0	6.1E–13	0.13	high
SSP_8	181.0	2.6E–13	0.17	high
SSP_9	115.7	1.8E–11	0.16	high
SSP_10	87.4	2.4E–12	0.15	high
SSP_11	134.3	1.1E–12	0.10	high

Secondly, the radon concentration tends to exhibit higher values in the “SSP” dataset, accompanied by a slight increase in gamma dose rates. These trends can be attributed to the fact that Quaternary deposits appear to enhance the migration of radon gas into the atmosphere. Consequently, the radon concentration in the “SP” dataset is lower compared to the “SSP” dataset.

Despite these trends, it is worth noting that the radon index remains consistently “high” in both cases, indicating the reliability of the methodology used, which is based on multivariate cross-tabulation involving two parameters: radon concentration in soil gas and gas permeability. A combined graph of the radon soil gas and permeability measurements at the second stage of the study are shown in Fig. 3. It is seen that the highest values of radon soil gas concentrations coincide with the fault system.

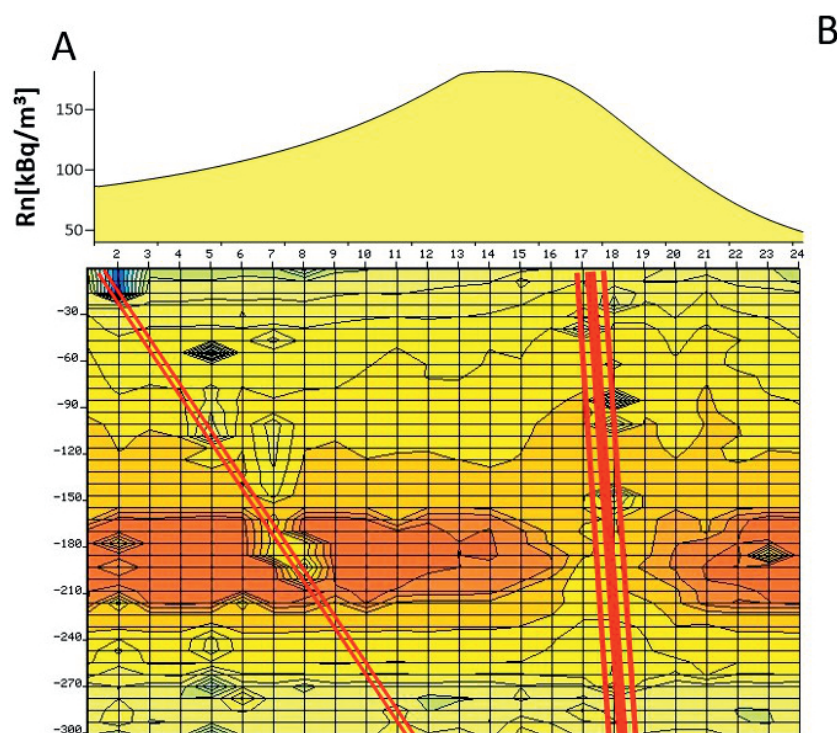


Fig. 3. A combined scheme of the radon soil gas concentration at 2 m below the surface placed together with the estimated local faults

Conclusion. One of the key issues observed is the significant variation in radon concentration within a relatively small area. This variation is attributed to the presence of a fault or sub-fault in the area. Similar relationships have been observed in previous investigations along the Vitosha fault (Sofia Municipality) in the southern direction. In addition, the radon index methodology, based on radon concentration in soil gas and gas permeability, is suitable and applicable

for Neogene/Quaternary terrain. Radon concentration in soil gas can vary significantly even within a small area, especially in regions with complex geological settings. There is a probabilistic influence of fault and sub-fault systems on the radon index and the geogenic radon potential, respectively.

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