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Distribution of indoor radon concentrations between selected Hungarian thermal baths

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Abstract. Owing to the high potential of radon to increase the risk of lung cancer, health organizations are enforced to update their regulations and recommendations regarding indoor radon levels each year. In this study, the indoor radon concentrations of three randomly selected thermal baths in Hungary using CR-39 and an AlphaGUARD radon monitor were measured with regard to the new updated standards of the European Basic Safety Standard (EU BSS, Council Directive 2013/59/Euratom, 2014). The annual average of indoor radon concentrations in Parad Medical Bath, Igal Health Spa and Eger Turkish Bath were measured as 159 ± 19, 176 ± 27 and 301 ± 30 Bq/m^3, respectively. Indoor radon concentration in all measurement locations were determined to be below the reference level, with the exception of the main pool, small pool and sparkling bath areas in the Eger Turkish Bath that were measured as 403 ± 42, 315 ± 32 and 354 ± 36 Bq/m^3, respectively. In light of the results, the estimated annual average radon concentration in the thermal baths was below the EU BSS reference level of 300 Bq/m^3. Personal dosimetry is required to estimate the annual effective dose from inhaled radon by the workers at the Eger Turkish Bath. This procedure is required in order to justify the application of the mitigation process of decreasing working hours, improving the ventilation rate or increasing the number of classified employees in response to the official radiation surveillance programme.

Key words: AlphaGUARD • CR-39 • EU BSS • Hungary • radon • thermal bath

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Introduction

Recently, it has been proved that more than half of the exposure to natural background radiation is from radon isotopes and their progenies [1]. The inhalation of radon and its decay products can result in biological changes within the lungs, thus increasing the risk of lung cancer. According to a report of the World Health Organization (WHO), after smoking, radon is the second most frequently reported reason for developing lung cancer [2].

In December 2013, the Council of the European Union prepared the new European Basic Safety Standards (EU BSS). These standards recommended that the annual average radon concentration should not be higher than 300 Bq/m^3 in dwellings or workplaces [3]. Meanwhile, the International Atomic Energy Agency, in accordance with the IAEA Safety Standard Series No. GSR Part 3, recommends that radon concentrations should not exceed 300 and 1000 Bq/m^3 for the public and workers, respectively [4]. By taking into consideration the EU BSS, the European member countries (e.g. Hungary) are going to introduce a national reference level of 300 Bq/m^3 (average annual activity concentration) for indoor radon concentration [3].

Before the discovery of radon gas, it was observed that a high ratio of miners contracted lung cancer [1]. In Hungary, there were a few surveys conducted about the average radon concentration in mines (e.g. radon in the manganese mine in Úrkút) [5].

Caves are one of the most popular tourist attractions of Hungary and are important for their role in developing the tourism industry. Radon concentration levels in caves have shown seasonal fluctuations. In most cases, high levels of radon concentration were observed more often during summer than in winter. As a result of this phenomenon, decreasing the number of working hours for employees may be suggested as a solution for reducing their dose of exposure [6, 7].

Thermal baths are another type of workplace that can have elevated radon levels. In Hungary, bathing has been very popular for a long time because of its geological location. According to national statistics, there are more than a hundred thermal springs in Hungary. Some of these springs are used for medical purposes (e.g. radon therapy through drinking or bathing treatments [8–11]), but some studies show that radon can be absorbed during radon therapy through the skin or by inhalation through the lungs into the bloodstream [12, 13].

In the present study, the indoor radon concentration of randomly selected thermal baths was investigated according to the new standards established by EU BSS and its applicant. This was done in order to establish if the indoor radon concentration was below or above the new EU BSS recommended level.

Study area and sampling

Hungary is a landlocked country, European Union member located in central Europe. The land is extremely rich in thermal waters containing dissolved natural minerals that make it desirable for curative purposes. Three thermal baths, the Eger Turkish Bath, the Igal Health Spa and the Parad Medical Bath, were randomly selected to monitor indoor radon concentrations in different parts of each bath (i.e. pool areas, storage areas, massage rooms, and information desks). The locations of these three selected baths are presented on the map of Hungary in Fig. 1.

The Eger Turkish Bath, as one part of Eger thermal bath, is located in the second largest city of Northern Hungary. Owing to the radon content of the water, the bath is classified as a radon therapy bath [9]. Igal Health Spa, as one of the newest thermal baths in Hungary, was found during an oil exploration in 1948. The hot spot is located at a depth of 650 m below the ground (according to the Igal Health Spa's webpage [14]). The medical thermal bath in Parad has been listed as one of the oldest natural medical centres in Hungary and it has been in operation since 1813. Water in this thermal bath is rich in dissolved minerals. Melted snow infiltrates the inside of a mountain and dissolves minerals within the stones and continues downwards until it ends up in a small lake [15]. This mineral-infused water is heated up to 40°C and used for arthritis therapy.

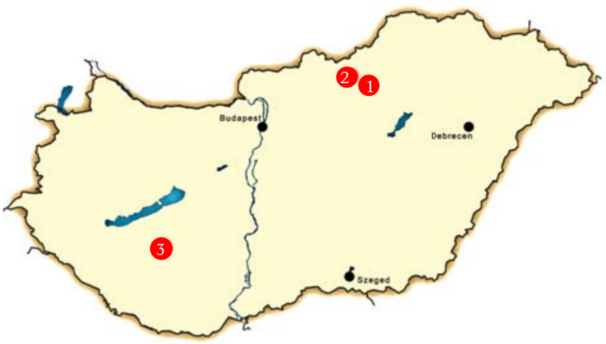

Fig. 1. Location of selected thermal baths: 1 – Eger Turkish Bath, 2 – Parad Medical Bath and 3 – Igal Health Spa.

Materials and methods

Two different methods were used to determine the radon concentrations in the different areas of the spas. For the long-term measurement, solid-state nuclear track (SSNTD) CR-39 detectors were used in two different holding plastic chambers, that is, Raduet and NRPB [6, 16]. The electrically charged alpha particles produced from the decay of radon and its progeny colliding with the surface of the CR-39 detector caused the chemical bonds of polymer chains to break causing tracks. The detectors were placed at least 40 cm away from external doors and windows, 100–180 cm above the floor and about 8–15 cm away from any other objects for a period of 40–60 days, 5 times during 1 year. After each exposure period, the detectors were sent back to the laboratory and the tracks were evaluated after being etched in the 6 M NaOH solution for 3 h at 90°C. Etched tracks were observed and counted using a high-resolution image scanner and image analysis software [17].

The average concentration of indoor radon can be calculated from the counted tracks with the following formula:

$$C_{\mathrm{Rn}} = \frac{(N_T - N_B) \times E}{T \times A} \tag{1}$$

where C_{Rn} is the average indoor radon concentration [Bq/m^3], N_T is the number of total tracks, N_B is the number of background tracks, E is the calibration factor [Bq·h·mm^2/m^3], T is the exposure period (hours) and A is the area in which tracks were detected [mm^2]. In this calculation, the calibration factor E is given by Eq. (2):

$$E = \frac{C_{\mathrm{Rn}} \times T \times 1.025}{N_n} \tag{2}$$

where N_n is number of net tracks and 1.025 is the detection area [mm^2].

The short-term measurements were carried out by AlphaGUARD radon monitor (SAPHYMO GmbH, Germany) in order to investigate the radon concentration during the working hours. Using this method, the AlphaGUARD monitor was set at 10-min diffusion and placed in the middle of each measuring location during working hours. The average measurements at each location were calculated to determine the ^{222}Rn concentration.

Determination of calibration factor

In order to determine the calibration factor of track detectors, several CR-39 detectors were covered with a radon-proof material and placed in a Certified Radon Chamber (CRC) with an AlphaGUARD PQ2000PRO radon monitor as a reference device. The cover of the detectors was removed immediately before exposure and was then exposed to a constant ^{222}Rn concentration of 2000 Bq/m^3 for 6 days. The radon concentration inside the chamber was maintained by a RN2000A type ^{226}Ra standard source (104.9 kBq ± 0.4%) manufactured by Pylon Electronics Inc.

Results and discussion

The average radon concentrations were obtained by calculating the average of the NRPB and Raduet results from each measuring location. Figures 2–4 are showing the results of these measurements. The Eger Turkish Bath exhibited higher average radon concentrations than the other two baths with an av-

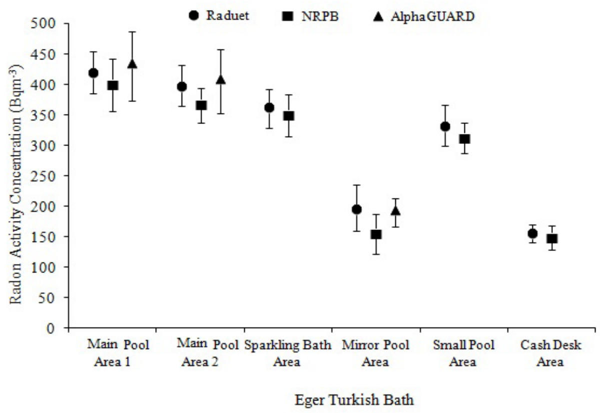

Fig. 2. Comparison of the radon concentrations in different parts of the Eger Turkish Bath.

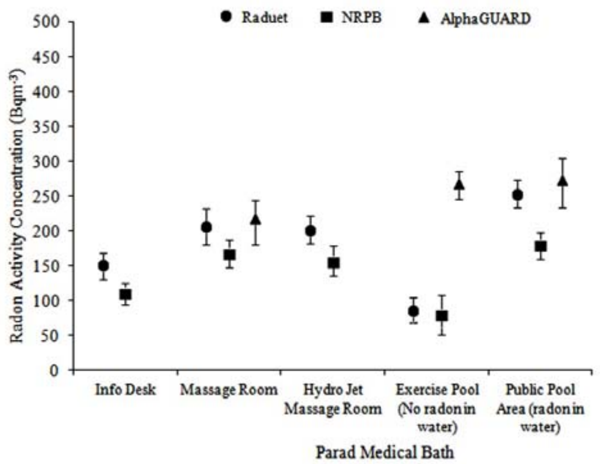

Fig. 3. Comparison of the radon concentrations in different parts of the Parad Medical Bath.

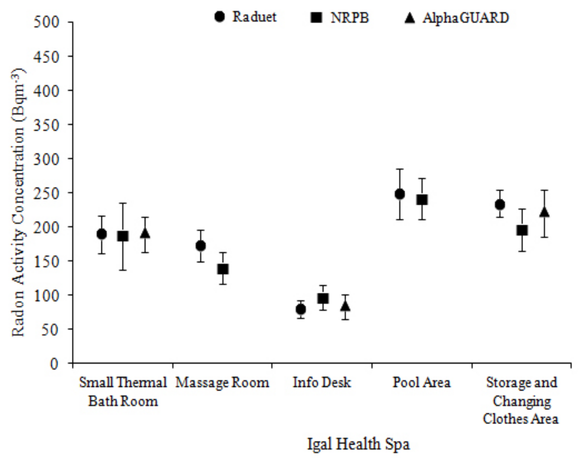

Fig. 4. Comparison of the radon concentrations in different parts of the Igal Health Spa.

erage of 301 Bq/m^3, while the average indoor radon concentrations in the Parad Medical Bath and Igal Health Spa were measured as 159 ± 54 and 176 ± 62 Bq/m^3, respectively.

In light of these results, radon concentrations at all the measured locations are below the recommended level of 300 Bq/m^3 (EU BSS) except for the main, small and sparkling pool areas in the Eger Turkish Bath with an average (Raduet, NRPB and AlphaGUARD) of 403 ± 42, 315 ± 32 and 354 ± 36 Bq/m^3, respectively.

The AlphaGUARD was used in a few randomly selected locations for very specific purposes. First, it was used as a controller to ensure the results deriving from the passive method owing to parameters such as temperature, humidity and pressure, which could affect CR-39 detectors. Second, because CR-39 integrally measures the radon concentration over a long period (e.g. 40 days, night- and daytime), a short-term measurement was necessary to check the daily (working hours) fluctuation (i.e. AlphaGUARD). For example, it was observed that the radon concentration is higher during working hours than during the all day (24 h) in the exercise pool (using radon free water) area in the Parad Medical Bath.

The results of three different detectors (NRPB, Raduet and AlphaGUARD) were generally similar with small variations. However, significant differences in radon concentrations were detected between the passive detectors and the AlphaGUARD at the exercise pool room of the Parad Medical Bath where the water of the pool was free of radon. The average of integral radon concentrations (passive measurements) in this bath was determined to be lower than the radon concentration during the working hours. As the exhaled radon from water is the main source of indoor radon in the thermal baths, the air exchanged from the other parts of the bath to the exercise pool area by visitors and workers could be the reason for the different radon concentrations between integral and short measurements.

The radon concentrations in the main, small and sparkling pool areas of the Eger Turkish Bath did not greatly exceed the reference level (300 Bq/m^3, EU BSS, 2014). However, following the EU BSS recommendation, a personal radon dosimetry is required for monitoring workers who work in these areas – main, small, and sparkling pool – in order to check if the inhaled radon exceeds the maximum dose recommended level.

Conclusions

In recent decades, indoor radon concentrations have been under intense scrutiny because of the potential for increasing the risk of lung cancer. The newly updated EU BSS recommends a strict indoor radon concentration level of 300 Bq/m^3, regardless of workplace or dwelling classifications. In light of the present results, the average indoor radon concentrations (Raduet and NRPB) in the Parad Medical Bath and the Igal Health Spa were measured as 159 and 176 Bq/m^3, respectively, consequently, below the recommendation level. The exception was met in the Eger Turkish Bath, where the highest radon concentrations averaged up to 301 Bq/m^3. Therefore, personal dosimetry is recommended for workers of this bath in order to determine the total annual dose received from inhaled radon. If the total annual dose exceeds the limit, it will be necessary to conduct a mitigation process by increasing ventilation or classifying workers under regulations where employees are exposed to radiation. In addition, increasing the number of employees and reducing the number of working hours can be considered as a potential solution.

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