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The results of integration measurements of indoor radon activity concentration in houses in Ružomberok town (Northern Slovakia)

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Abstract: Integration measurements of indoor radon in houses were performed within the framework of the project "Harmonization of determining the radiation dose of the population originating from radon in V4 countries". In Slovakia, the survey was performed in three localities: Záhorská Bystrica, Mochovce and Ružomberok. Monitoring started in March 2012 and lasted for one year. In Ružomberok ten houses were selected for monitoring purposes. The houses built before 1990 were predominantly chosen for the investigation. In selected houses in Ružomberok, radon activity concentration rarely exceeded 400 Bq/m^3 in a three month period, in this case the inhabitants were advised how to lower radon exposure. No house was found with an annual radon activity concentration of more than 400 Bq/m^3.

Key words: radon, activity concentration, integration monitoring, risk, house

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1. Introduction

Exposure to radon gas in the home accounts for about half of all non-medical exposure to ionizing radiation. The radioactive gas radon and its decay products, contribute significantly to doses through inhalation (*UNSCEAR, 2000*). Radon in the home accounts for about 9% of deaths from lung cancer and about 2% of all deaths from cancer in Europe (*Darby et al., 2005*).

Indoor radon concentration depends on many factors. One of the main sources of indoor radon is the local geology (*Sundal et al., 2004; Borgoni et al., 2014*). Radon enters a house by diffusion or pressure driven flow if suitable pathways between the underlying rocks and soils and living spaces are present. Soil characteristics such as porosity and permeability also can impact on indoor radon levels. Indoor radon activity concentration is usually higher in rooms in direct contact with the subsoil. In older houses insulation from the subsoil may be broken and radon can enter the living space through the cracks in the basement. In rooms with a cellar underneath, radon accumulates in the air of the cellar. However, in some studies no significant difference between houses with and without a cellar was found (*Baross-Dios et al., 2007*).

The second greatest contributor to indoor radon is the building material of a house. The design of a house and its ventilation system also strongly influence indoor radon levels. Elevated indoor radon in older family houses may result from using stone or other local building materials (*Baross-Dios et al., 2007; Cosma et al., 2013*).

The first indoor radon monitoring in Slovakia was realized at the beginning of nineties. In total 3657 randomly selected dwellings were investigated using the integral method (*Vičanová, 2003*). On the basis of the results a map of annual average effective dose for inhabitants to indoor exposure from radon and its daughter products for the districts of Slovakia was constructed.

According to the Regulation from the Ministry of Health SR No. 528/2007, so-called action level 400 Bq/m^3 is recommended for an annual average radon activity concentration for existing residential buildings and 200 Bq/m^3 for new and reconstructed residential buildings.

Integration measurements of indoor radon and thoron in houses were performed in the framework of the project "Harmonization of determining the radiation dose of the population originating from radon in V4 countries"

(*Műllerová et al., 2014*). The objective of the project was to elaborate a common measurement protocol of the Visegrad countries for the measurement of indoor radon and thoron concentration (the placement of detectors, type of detectors, questionnaires). In Slovakia, the radon and thoron survey was performed in three localities: Záhorská Bystrica (high radon risk area), Mochovce and Ružomberok (medium and low radon risk areas).

In this paper the results of the [integrated/integration] radon monitoring in Ružomberok are presented.

2. Site description and methods

Radon monitoring in houses in Ružomberok, Northern Slovakia, started in March 2012 and lasted for one year. According to the radon risk, Ružomberok belongs to the medium and low radon risk area (Fig. 1). From a geological point of view, the study area consists predominantly of sedimentary rocks of the Central Carpathian Paleogene and Quaternary fluvial sediments.

Ten houses were selected for monitoring purposes (Fig. 1). No radon research was previously performed before in these houses. The monitored houses were irregularly positioned throughout the town; this was due to the distribution of the residential districts with houses in the town. Houses built before 1990 were chosen for investigation; however, two of them were reconstructed in 2000. Measurements were performed in two ground floor rooms, detectors were placed 15-20 cm from the wall, as far as possible from the windows, doors and heating bodies. Information about the building material, window tightness, intensity of ventilation, year of construction and reconstruction, number of inhabitants and time spent in monitored rooms were obtained through the questionnaire.

Passive alpha track detectors Raduet (Radosys, Hungary) were used, for discriminatively determining radon and thoron concentrations (*Tokonami et al., 2005; Chen et al., 2008*). Fours sets of detectors were used, sets were changed after three months of exposure to compare the changes in radon activities during the year. The first period (spring) lasted from March to May 2012, the second (summer) from June to August 2012, the third (autumn) from September to November 2012 and the last (winter) from December 2012 to February 2013. Due to technical problems, only ten

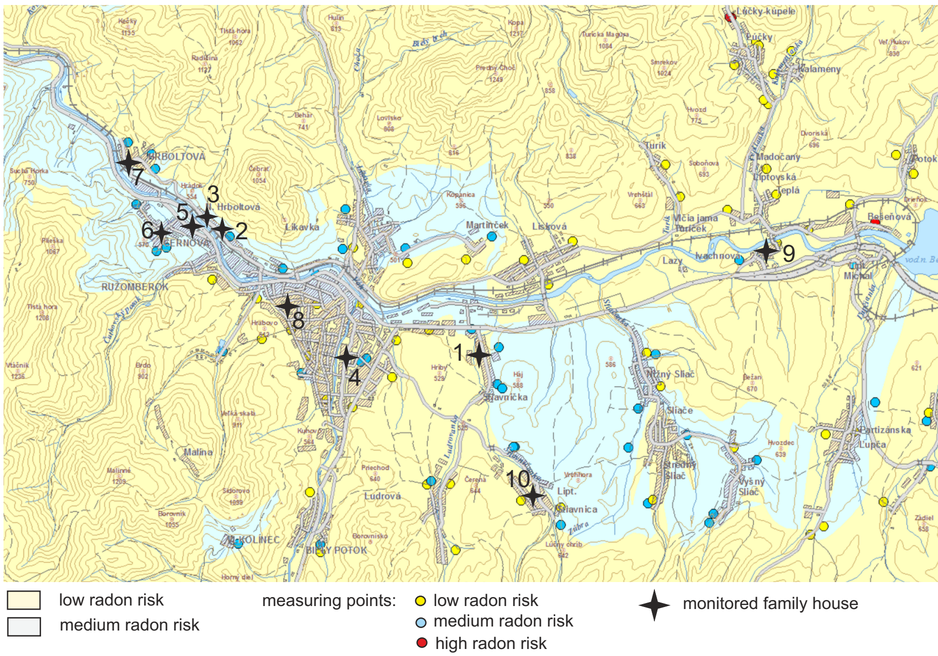

Fig. 1. Radon risk map with the position of monitored houses in Ružomberok (prepared after *Maps of natural radioactivity, radon risk map, map server of SGIDŠ*; *Čížek et al., 1992*).

detectors were available during the summer period, therefore they were predominantly placed in the rooms that were in direct contact with the subsoil (in both rooms in houses No. 1, 4, 5, 8 and in one room in houses No. 2 and 3). After exposure, the detectors were sealed and sent to the laboratory of Institute of Radiochemistry and Radioecology, University of Pannonia in Hungary for evaluation.

3. Results and discussion

Radon activity concentration in the air of twenty rooms in ten selected houses was analyzed. A half of the monitored rooms were situated above the cellar (Table 1).

Most of the houses were built from two types of building material, ei-

Table 1. Annual average of radon activity concentration in monitored rooms of ten houses in Ružomberok and descriptive characteristics of the room.

house	room	^{222}Rn [Bq/m^3]	building material	cellar	construction/ reconstruction
1	kitchen bedroom	200 170	brick brick	no no	1953/1986
2	living room bedroom	92 122	slag block slag block	no no	1964
3	living room bedroom	74 80	brick brick	no no	1962
4	kitchen living room	132 211	stone, brick brick	yes yes	1905 1940
5	study room guest room	215 288	slag block slag block	yes yes	1981
6	corridor guest room	84 168	brick brick	yes yes	1978
7	living room bedroom	95 107	brick brick	no yes	1929/2000
8	kitchen living room	173 139	slag block slag block	yes yes	1974
9	kitchen bedroom	236 280	brick brick	no no	1923/2000
10	living room kitchen	208 222	slag block slag block	yes no	1962

ther bricks or slag blocks, constructed between 1950 and 1990 (Fig. 2). The rooms, where the inhabitants spend most of their time, such as the bedroom, kitchen and living room, were predominantly selected for radon monitoring (Fig. 2).

A histogram of the frequency distribution for the annual average indoor radon concentration in twenty monitored rooms is depicted in Fig. 3. The arithmetic mean of the annual average radon concentrations was equal to 165 Bq/m^3. In most of the dwellings a seasonal variation of indoor radon concentration was confirmed, however in several monitored rooms the differences among radon activities registered in the four periods were less distinctive.

Fig. 4 shows the distribution of radon activity concentration during the four monitoring periods. The average indoor radon activity in the winter and spring periods was roughly the same, up to 183 Bq/m^3. The higher

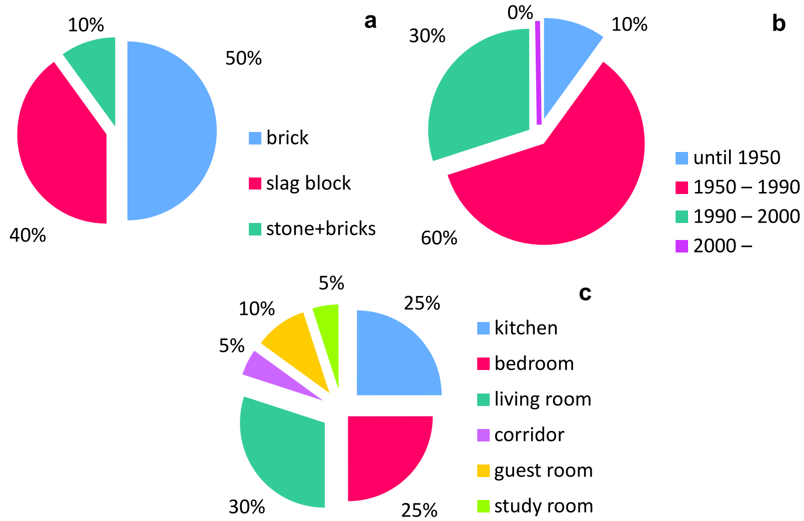

Fig. 2. The distribution of monitored houses according to a) building material, b) year of the construction/reconstruction of the house, c) monitored room.

values in comparison with the other two periods may be explained by less intensive ventilation of the rooms in the colder seasons of the year. The indoor radon minimum was found in the summer and autumn periods, when the average ^{222}Rn activity concentration reached 140 Bq/m^3 and 144 Bq/m^3.

In the summer the highest radon activity concentration during the whole period of monitoring was determined, in house No. 5, equal to 446 Bg/m^3. The room monitored was situated above the cellar, the house was built from

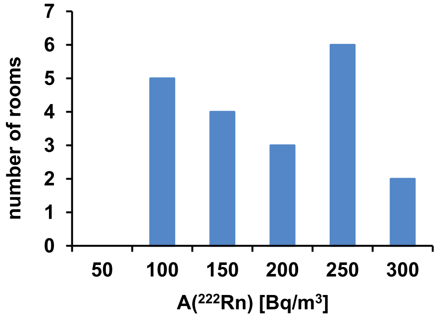

Fig. 3. The frequency distribution of the annual average of radon activity concentration in monitored rooms of ten houses in Ružomberok.

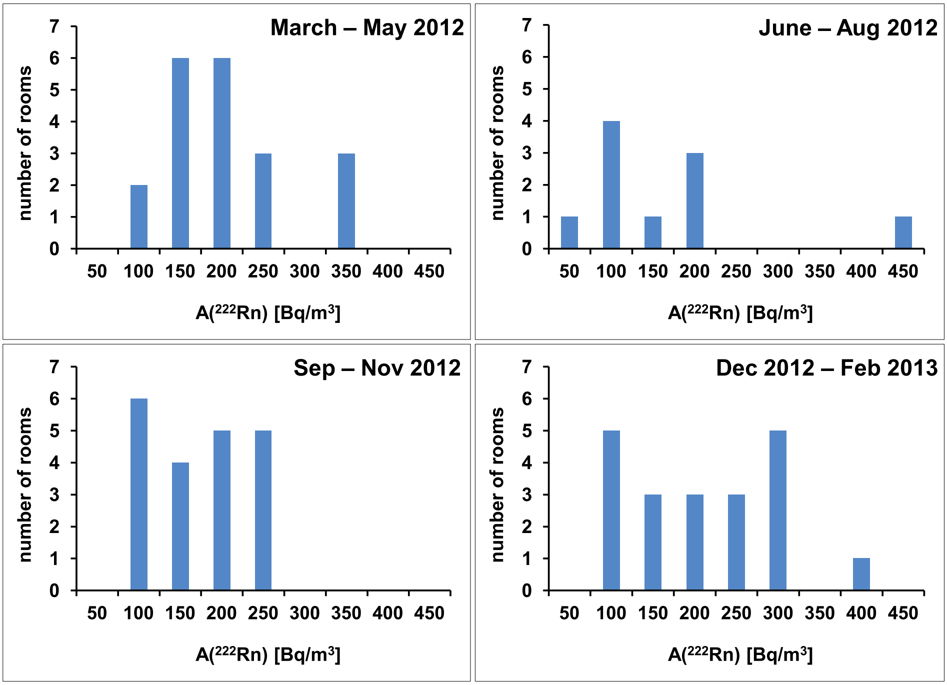

Fig. 4. The comparison of the radon frequency distribution in ten monitored houses in Ružomberok in four monitoring periods.

slag blocks and the window tightness was very good. Monitored room was a guest room and, furthermore, the highest annual average indoor radon activity among all twenty monitored rooms, up to 290 Bq/m^3, was measured there. According to the questionnaire, the ventilation was weak during the summer period. Also in the first period an indoor radon level was relatively high, reaching 300 Bg/m^3. However, during the third and fourth monitoring periods radon levels were lower, equal to 150 Bq/m^3, resp. 250 Bq/m^3, maybe as a result of more effective ventilation, because house owners were instructed how to lower increased indoor radon concentration. However, because that house was built in 1981, according to the Regulation of the Ministry of Health of the Slovak republic No. 528/2007, the action level for the realization of the remedy actions to reduce an irradiation equal to 400 Bq/m^3 in average per year was not exceeded.

Annual average indoor radon activity exceeding 280 Bq/m^3 was found in a room of house No. 9. In the second monitored room radon level was up to 240 Bq/m^3. Both rooms were in direct contact with the subsoil. The house was originally built from the bricks in 1923, but was reconstructed in 2000, hence according to the Regulation of the Ministry of Health of the SR No. 528/2007 the action level for new/reconstructed buildings equal to 200 Bq/m^3 was exceeded.

Indoor radon concentration exceeding 200 Bq/m^3 in average per year was found in eight monitored rooms, in three houses (No. 5, 9, 10) in both of the examined rooms.

The lowest indoor radon was found in house No. 3, made from bricks. Although monitored rooms were in direct contact with the subsoil, indoor radon activities were less than 100 Bq/m^3 during all four monitoring periods.

Results have been examined with respect to the building material and presence or absence of a cellar. The distribution of radon activities between rooms with and without a cellar underneath is depicted in Fig. 5. Indoor radon concentration is usually expected to be higher in rooms in direct contact with the subsoil, because radon can penetrate through the cracks in the mat-slab foundations. However, it is not observed in all cases, due

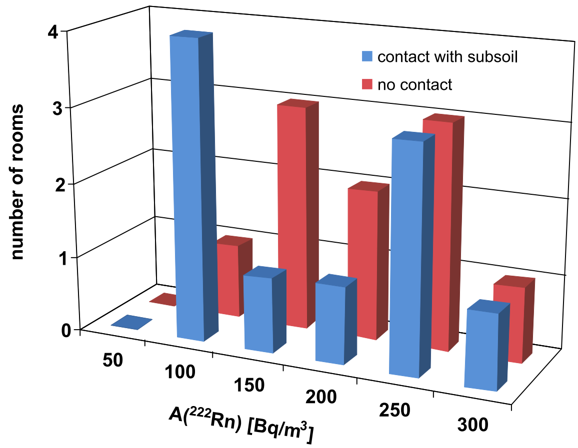

Fig. 5. The frequency distribution of average annual ^{222}Rn activity concentration in rooms with/without direct contact with the subsoil.

to several factors. Low indoor radon activity can be explained by a low amount of radon gas in the subsoil in a low radon risk area. An appropriate and unbroken insulation of the foundations can prevent radon entry into the house. Intensive ventilation can also significantly reduce radon level. When the room is situated above a cellar, radon accumulates in the air of the cellar, unless its walls and floor was thoroughly insulated from the subsoil. Radon from the cellar may enter a room when cracks or other suitable pathways occur in the floor slab of the room above.

No significant difference in indoor radon level was observed between rooms with/without a cellar in monitored houses in Ružomberok. Low activities in rooms with direct contact with the subsoil can be explained by factors mentioned above. In cases of high radon concentration in rooms above the cellar (house No. 5), the radon concentration in the cellar can be examined and possible pathways to the inhabited rooms can be found and eliminated or the building material may be a radon source. Many houses in Slovakia built in the second half of the 20-th century were made from home-made slag blocks, in which radioactive elements content is unknown.

The distribution of radon activities between rooms with walls made of bricks and slag blocks is depicted in Fig. 6. The room in an older part of house No. 4 made from combination of rocks and brick was not included

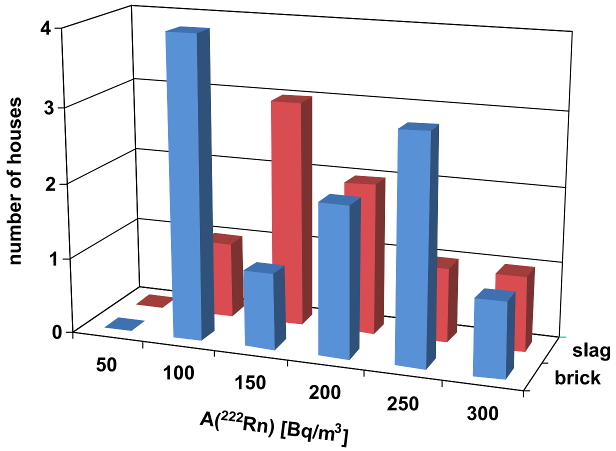

Fig. 6. The frequency distribution of average annual ^{222}Rn activity concentration in rooms with walls made of bricks/slag blocks.

in that comparison. The annual average of indoor radon in mentioned room was 130 Bq/m^3. The house was built in 1905 and we can only assume that a local rock was used for a building material. Prevalent rocks in Ružomberok surroundings are carbonates, which usually have low uranium content. Contrary, in the second monitored room in a newer part of the house, constructed using bricks in 1940, the annual average of indoor radon activity reached 211 Bq/m^3. Both rooms were situated above the cellar.

No unambiguous difference in indoor radon was found between the houses made from bricks and slag blocks. Measured activities were with the highest probability influenced by the presence or absence of a cellar room, quality of the cellar insulation from the subsoil, possible pathways in the floor slab for radon entry from the cellar into the monitored rooms and by the building materials. Moreover, the number of monitored houses was too low for performing detailed statistical analyses of the possible impact of the selected factors on indoor radon level.

4. Conclusion

No house with an annual radon activity concentration of more than 400 Bq/m^3 was found. In eight monitored rooms an annual radon activity concentration exceeded 200 Bq/m^3. No distinct effect of either the presence/ absence of the cellar underneath the monitored room, or type of building material was found. The indoor radon activity in a monitored room can be affected by a combination of several influencing factors, as well as by the radon risk of the area and quality of foundation, insulation and ventilation. The owners of the houses with increased indoor radon concentration were instructed how to lower indoor radon level.

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