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# Thoron, radon and air ions spatial distribution in indoor air

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Spatial distribution of radioactive gasses thoron (Tn) and radon (Rn) in indoor air of 9 houses mostly during winter period of 2013 has been studied. According to properties of alpha decay of both elements, air ionization was also measured. Simultaneous continual measurements using three Rn/Tn and three air-ion active instruments deployed on to three different distances from the wall surface have shown various outcomes. It has turned out that Tn and air ions concentrations decrease with the distance increase, while Rn remained uniformly distributed. Exponential fittings function for Tn variation with distance was used for the diffusion length and constant as well as the exhalation rate determination. The obtained values were similar with experimental data reported in the literature. Concentrations of air ions were found to be in relation with Rn and obvious, but to a lesser extent, with Tn.



## 1. Introduction

In recent years in several countries of Balkan region i.e., Serbia with Kosovo, Slovenia, Republic of Srpska and Macedonia extensive and systematic indoor Rn and Tn surveys have been performed (Žunić et al., 2001, 2010a; Milić et al., 2010; Gulan et al., 2012; Vaupotič et al., 2008, 2013; Ćurguz et al., 2015; Stojanovska et al., 2013, 2014). Since 2008, in Serbia in the Sokobanja municipality, a systematic survey on Rn in 26 schools has been started and carried out until 2010 (Žunić et al., 2010b, 2013; Carpentieri et al., 2011; Žunić et al., 2013; Bochicchio et al., 2014; Bossew et al., 2014). From 2011 to 2012 this survey has continued and extended to houses which surrounded schools in the villages of the Sokobanja municipality, as well as in the Sokobanja town itself (Mishra et al., 2014). In most of the houses, Tn levels were higher than those of Rn, as already observed in traditional Japanese houses (Doi et al., 1994), in Italian buildings made of volcanic material (Bochicchio et al., 1996) and in cave dwellings in China (Tokonami et al., 2004; Zhang et al., 2005). Because in such cases the contribution of Tn to Rn doses may not be simply ignored (Akiba et al., 2010; Tokonami, 2010; Vaupotič et al., 2013), we decided to pay additional attention to Tn and its spatial distribution, particularly due to the high indoor Tn concentrations and low Rn concentration in the dwellings in villages of southern Serbia and Slovenia.

The sources of Rn and Tn are radium and thorium, respectively in the soil and building materials. Their transport by diffusion and advection through the porous environment is driven by the concentration and pressure gradient, respectively. The relatively short Tn half-life of 55.6 s compared to the Rn long life of 3.8 days resulting in different distribution within the indoor environment. In absence of pressure driven flow, the diffusion process is expressed with equation (UNSCEAR, 1982):

$$C(x) = C_0 e^{-\frac{x}{L}} \quad (1)$$

where $C(x)$ is the Rn or Tn concentration at distance $x$ from the exhalation surface expressed in m; $C_0$ represents the Rn or Tn concentration at the surface, $L$ is Rn or Tn diffusion length in m. Furthermore, the $C_0$ can be expressed due to Tn or Rn exhalation rate $E$ from the source, $D$ diffusion coefficient ($m^2s^{-1}$); and decay constant $\lambda(s^{-1})$ using the relation:

$$C_0 = \frac{E}{\sqrt{\lambda D}} \quad (2)$$

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Air ions in indoor air are generated mostly by MeV-energy α-particles produced in radioactive transformations of Rn and Tn and its short-lived descendants. Since the intensity of all other air ionizing sources is significantly lower and mostly constant in time, air ions may serve as confident indicator for spatial and temporal distribution of $^{222}Rn$ and $^{220}Rn$ concentrations indoors. The near-ground ionization rate caused by background ionization of 10 ion pairs $cm^{-3}s^{-1}$ is considered as a standard in continental areas (Chalmers, 1967). Ratio of positive and negative small air ion concentrations is called coefficient of unipolarity and in clean air is equal to $n^+/n^- = 1.12$ (Hõrrak, 2001).

In this study we present the experimental results of Rn, Tn and air ions spatial distribution measurements in indoor environment. Mentioned values were measured simultaneously at three different distances from walls in 9 houses during the winter period.

## 2. Material and methods

For our study nine houses have been selected, 7 in Serbia and 2 in Slovenia (Table 1). The measurements were performed in December 2014 in closed indoor conditions. In the villages of Serbia (SRB-#1-5 and SRB-V), Tn concentrations nearby walls and floors were higher than Rn while in one village in Serbia (SRB-#6) and two villages in Slovenia (SLO-#1-2), Rn concentrations measured nearby walls and floor were much higher than Tn. Following equipment was used for the measurements: two Rad7 (Durridge, USA) and one RTM 1688-2 (Sarad, Germany) Rn/Tn monitors, and three Gerdien-type air-ion CDI-06 detectors (Kolarž et al., 2009). Typical set-up is shown in Fig. 1.

During the measurements, inlets of measuring devices were fixed at different distances from the walls (from 0.5 to 40 cm) and about 1 m above the floor. All measurements were in total 24 h long except in house (marked as: SRB-#3) where measurements lasted 2 h. The measurements were divided in time series of several minutes.

For quality assurance purpose, the inter-comparison of air ion and Rn/Tn measuring instruments were performed day before measurements. The measuring procedure and results are presented in Kolarž et al. (2016). Standard deviations of the means of measured Rn concentrations were below to 5%. Also, inter-comparison of 4 ion counters showed relatively small standard deviation within 5% which is very satisfactory concerning non ideal measuring conditions, micro-climatic influence on position of each counter and overall uncertainty of air ion measurements, which assures a reliability of the measurements.

**Fig. 1.** Typical experimental setup.

## 3. Results and discussion

### 3.1. Tn and Rn measurements

The scatter plots of Tn and Rn concentrations measured in all houses on three distances is presented in Fig. 2. Houses in Serbia are marked as SRB (SRB-#1 to SRB-#6), while houses in Slovenia are marked as SLO (SLO-#1 and SLO-#2). Vertical gradient measurements are marked with SRB-V. Because of wide range of measured concentrations as well in some cases small differences in concentrations between the houses for better perception, the results for Rn and Tn are presented in separate graphs for separated houses.

From this graph, it is obvious that there is no relation between Rn concentration and distance. This assumption was also confirmed by statistical test. The calculated correlation coefficient was not statistically significant at 95% confidence interval. Practically the Rn mean values at different distance were in the range of measured Rn fluctuations.

Although measurements were performed in indoor conditions, the results indicate that the Rn diffusion flow is affected by outdoor

**Table 1**
Name, date of measurements and description of measuring places.

| House ID | Village and date of measurements | Building material | Year of costruction | Type of heating, average temperature |
|---|---|---|---|---|
| SRB-#1 | Bogdinac 25.11.2013. | Fired bricks of clay from Moravica river, concrete floor; | 1970 | Quartz heater switched on upon our arrival, T = 15 °C; |
| SRB-#2 | Čitluk 26.11.2013. | Fired bricks of clay from Moravica river, concrete floor covered with a parquetry; | 1962 | Wood – burning stove, fired on upon our arrival; T = 14.5 °C; |
| SRB-#3 | Trubarevac (long) 29.11.2013. | Fired bricks of clay from Moravica river, concrete floor covered with a parquetry; | 1974 | Wood – burning stove, T = 20 °C - 14.6 °C (during the night); |
| SRB-#4 | Trubarevac (short) 27.11.2013. | Wood, straw, mud of red clay “crvenica”, concrete floor with a parquetry and a carpet; | 1951 | Wood – burning stove, T = 14.5 °C; |
| SRB-#5 | Resnik 30.11.2013. | Fired bricks of clay from Moravica river, concrete floor covered with a parquetry; | 1980 | Central heating with radiators, T = 22.8 °C; |
| SRB-#6 | Niška Banja 13.05.2014. | Blocks and concrete, concrete floor covered with a parquetry; | 2006 | No heating, T = 22.5 °C; |
| SRB-V | Sokobanja 24.11.2013. | Concrete basement walls, rammed earth floor; | 2002 | No heating, T = 17.2 °C; |
| SLO-#1 | Rakitna 18.12.2013. | Brick and concrete, concrete floor covered with a parquet and carpet; | 1980 | Alpine-type oven,T = 18.5 °C; |
| SLO-#2 | Gorišnica 16.12.2013. | Brick and concrete, concrete floor covered with a parquet and carpet; | 1977 | Central heating, T = 17.2 °C. |

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