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## THE INDOOR RADON AND THORON CONCENTRATIONS IN SCHOOLS OF SKOPJE (REPUBLIC OF NORTH MACEDONIA) AND BANJA LUKA (REPUBLIC OF SRPSKA) CITIES MEASURED BY RADUET DETECTORS

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**Abstract:** Radon ( $^{222}\text{Rn}$ ) and thoron ( $^{220}\text{Rn}$ ) are natural radioactive gases, generated in the terrestrial materials. They are the main sources of public exposure to ionising radiation in any of indoor environment worldwide. Differences in half-lives of  $^{222}\text{Rn}$  ( $T_{1/2} = 3.8$  d) and  $^{220}\text{Rn}$  ( $T_{1/2} = 55.6$  s) lead to its different indoor behavior. Several studies of indoor  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  in Northern Macedonia have been performed, starting with measurements in dwellings in 2008 and continuing with measurements in schools during 2012. The surveys in the Republic of Srpska began later (in 2011) with the simultaneous  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  measurements in the dwellings and schools of Banja Luka cities. This paper, as a result of our cooperation, summarizes the results and general conclusions obtained from  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  measurements in schools of capitals. In both cities, the measurements were made using Raduet - nuclear track detectors; deployed at distances:  $>0.5\text{m}$  (Skopje) and  $0.2\text{m}$  (Banja Luka); and exposed in a period: March 2012 - May 2012 (Skopje) and April 2011 - May 2012 (Banja Luka). Results for  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  concentrations in both cities have a log-normal distribution. The  $^{222}\text{Rn}$  geometric mean value of  $71\text{ Bq/m}^3$  in Skopje is higher than in Banja Luka city ( $\text{GM} = 50\text{ Bq/m}^3$ ). Among different radon potential in the cities, this difference could be related to the different exposure time of detectors. Furthermore, the dispersion of the  $^{222}\text{Rn}$  results in each city expressed through geometric standard deviation is relatively low:  $\text{GSD} = 2.13$  (Skopje) and  $\text{GSD} = 2.11$  (Banja Luka) indicating relatively homogeneous data sets. The  $^{220}\text{Rn}$  concentrations in Banja Luka ( $\text{GM} = 51\text{ Bq/m}^3$ ) were higher than in Skopje ( $\text{GM} = 11\text{ Bq/m}^3$ ). It is obvious that in the case of  $^{220}\text{Rn}$ , the exposure period did not play a significant role. One of the reasons for this difference could be the position of the detectors as well as the different building materials in the schools. On the contrary, the dispersion of the  $^{220}\text{Rn}$  results in Skopje ( $\text{GSD} = 3.38$ ) was greater than in Banja Luka ( $\text{GSD} = 2.07$ ).

**Keywords:** radon, thoron, gas, school.

### 1. INTRODUCTION

Radon ( $^{222}\text{Rn}$ ) and thoron ( $^{220}\text{Rn}$ ) are radioactive gases from the respective natural series of  $^{238}\text{U}$  and  $^{232}\text{Th}$ , which are present in the terrestrial materials from the earth formation to the present day. The existing trace concentrations of  $^{238}\text{U}$  and  $^{232}\text{Th}$ ,

and their corresponding decay products  $^{226}\text{Ra}$  and  $^{224}\text{Ra}$  in building materials and in the underlying rocks and soil are sources of radon and a thoron in a building. The generated gases move through enclosed spaces of the material, emanate from its surface and enter into other environments where they can be accumulated. The dynamics are complex and driven

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mainly by the processes of advection and diffusion. Amount of the accumulated radon or thoron indoors concentration, depends on many factors. In general, they are related to the concentration of the radionuclides in the terrestrial material together with its porosity (radon potential), building characteristics and mode of its use. Additionally, the advection process is in a direct function of the outdoor-indoor temperature gradient, after all, radon and thoron concentration variations strongly depend on the meteorological parameters (temperature, pressure, wind, etc.).

Radon has a relatively long half-life ( $T_{1/2} = 3.8$  d), therefore the gas created in underlying soil in high depths can enter and accumulate in a building before it decayed. Contrary, due to short half-life ( $T_{1/2} = 55.6$  s), thoron can travel only short distances before it decayed. The main consequences of this are the differences in the effect of the factors on the accumulation of these two gases in indoor environments. In general, according to a large number of studies [1-3], it can be said that the main source of radon is the underlying soil (rock) and to a lesser extent the building materials, while in the case of thoron: the building materials are the dominant source in a building. Also, the essential difference between these two gases is that the indoor radon concentrations are homogeneously distributed, unlike the indoor thoron, whose concentrations are at the maximum on the wall and decrease at distance from it. Moreover consequence of the differences in radon and thoron half-lives, are discrepancy in their temporal variations caused by the meteorological parameters. For example, they are more pronounced for radon than for thoron [4-9].

Based on a large number of studies, it has been shown that indoor radon and thoron, are dominant (over all) radioactive sources to public exposure [9-10]. The harmful health effects of chronic exposure to them, have been confirmed [11], so the indoor radon and indoor thoron are very important radiation protection issue in every country. Following world trends, numerous campaigns to measure indoor radon and thoron in the countries of the Balkan, have been performed in the last decade. Thus, many papers have been published, some of which are cited in this paper's references [12-22]. In most of them radon concentrations are measured while studies of indoor thoron concentrations are limited. Depending on the type of indoor environment, the studies were conducted mainly in dwellings, schools (kindergartens) or combined. In Republic of North Macedonia, the first indoor radon and thoron measurements were made in dwellings in 2008 [23] and only later (2012) in schools and kindergartens [24-26]. In Republika Srpska, an entity in Bosnia and Herzegovina, the first systematic survey indoor radon and thoron was launched in 2011, simultaneously measuring both dwellings and schools [27-28]. Most of the results of these studies are already published.

The main purpose of this paper is to show the extracted results of radon and thoron concentration measurements, previously performed as a part of the more complex survey. In this study, we considered, only measured concentrations with the same type of detector, in the schools of the capital cities Skopje and Banja Luka. The geographical positions of the two republics in Europe, as well as the position of the cities, are shown in the Figure 1.

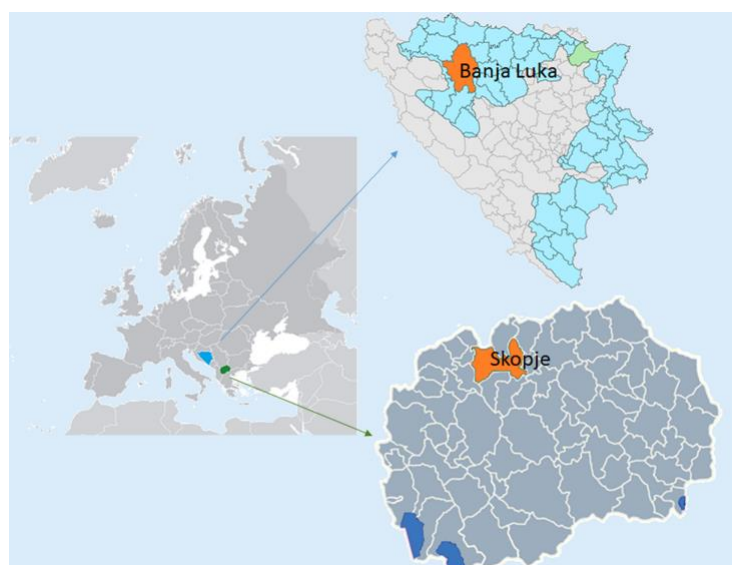


Figure 1. Geographical position of Bosnia and Herzegovina and Macedonia in the European map (left). Sites of the Banja Luka municipality over municipalities of Republic of Srpska (coloured blue) (upper right) and of the Skopje municipalities in the Republic of North Macedonia (down right)

## 2. MATERIAL AND METHODS

The indoor radon and thoron concentrations were measured in the schools of Skopje and Banja Luka using a nuclear track detectors, with Raduet commercial name, manufactured in Radosys, Hungary (Figure 2). The operating principle of Raduet was explained precisely in our previous studies [6, 28].

In Skopje, the detectors were installed in a

classroom on the ground floor at a distance of 0.5 m from any wall surface and exposed in a period of three months, from March to May 2012. In Banja Luka, they were deployed in a shorter distance of 0.2 m from the wall surfaces and exposed for one year, from April 2011 to May 2012. Types of the rooms, the distances to the wall surfaces along with the detectors period of exposure in each of the surveys are specified in Table 1.



Figure 2. Raduet nuclear track detector produced in Radosys, Hungary

Table 1. Characteristic of the detector exposure in both surveys

City	Type of room	Distance from wall surface	Period of detectors exposure
Skopje	Classroom	>0.5m	March-May, 2012
Banja Luka	Assembly hall or hallway	0.2 m	April, 2011-May, 2012

## 3. RESULTS

The histograms of the measured indoor radon ( $^{222}\text{Rn}$ ) and thoron ( $^{220}\text{Rn}$ ) concentrations in both

cities are shown in Figure 3. The best fit for both gases data sets was the log-normal function whose parameters are also present on the graphs in Figure 3.

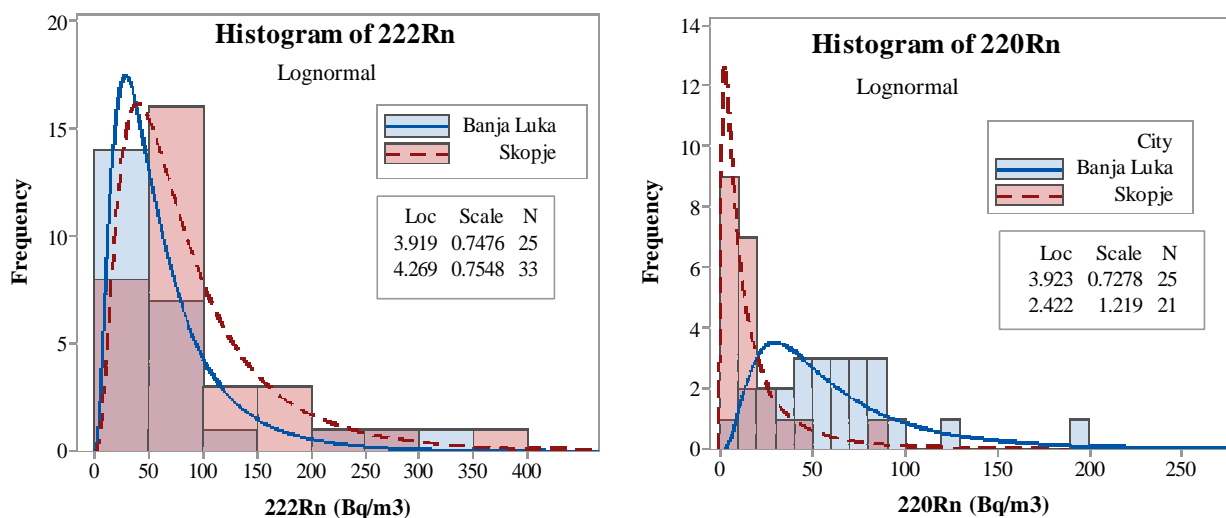


Figure 3. Histograms fitted with a log-normal function of  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  concentrations measured in schools of Skopje and Banja Luka

The number of schools under observation (N), number of schools with measured concentration below detection limit ( $N_{<MDA}$ ), arithmetic mean (AM), standard deviation (SD), geometric mean (GM) and geometric standard deviation (GSD) of indoor radon ( $^{222}\text{Rn}$ ) and thoron ( $^{220}\text{Rn}$ ) concentration measured in the schools of Skopje and Banja Luka cities are given in Table 2. In schools of Skopje, radon values range from 9 to 379 Bq/m<sup>3</sup> and those of thoron range from 1 to 80 Bq Bq/m<sup>3</sup>. The ranges in schools of Banja Luka are 25-341 Bq/m<sup>3</sup> for radon and 7-198

Bq/m<sup>3</sup> for thoron. In 12 schools of Skopje, thoron concentration was below the detection limit of 1 Bq/m<sup>3</sup>. Except in two schools, the radon concentrations in Skopje were higher in comparison to measured thoron concentrations. In Banjaluka, the thoron concentrations were higher than radon concentrations in most cases. The inteervals of  $^{220}\text{Rn}/^{222}\text{Rn}$  ratio in the schools considered in the present study were 0.01 - 4.72 for Skopje and 0.14-3.80 for Banja Luka (Figure 4) with geometric mean values of 0.19 and 1.00, respectively.

Table 2. Basic statistic of indoor radon and thoron concentrations considered in this study

	N	$N_{<MDA}$	AM Bq/m <sup>3</sup>	SD Bq/m <sup>3</sup>	GM Bq/m <sup>3</sup>	GSD
<b><math>^{222}\text{Rn}</math></b>	<b>58</b>	<b>0</b>	<b>85</b>	<b>81</b>	<b>61</b>	<b>2.15</b>
$^{222}\text{Rn}$   Skopje	33	0	94	78	71	2.13
$^{222}\text{Rn}$   Banja Luka	25	0	72	85	50	2.11
<b><math>^{220}\text{Rn}</math></b>	<b>58</b>	<b>12</b>	<b>42</b>	<b>39</b>	<b>25</b>	<b>3.42</b>
$^{220}\text{Rn}$   Skopje	33	12	18	18	11	3.38
$^{220}\text{Rn}$   Banja Luka	25	0	63	40	51	2.07

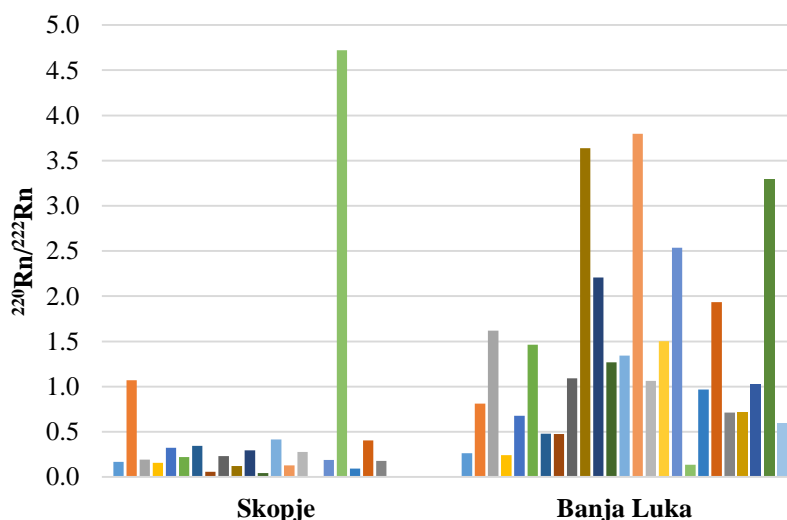


Figure 4. The  $^{220}\text{Rn}/^{222}\text{Rn}$  ratio in schools of Skopje and Banja Luka

#### 4. DISCUSSION AND CONCLUSION

This study presents the results for indoor radon ( $^{222}\text{Rn}$ ) and thoron ( $^{220}\text{Rn}$ ) concentrations measured in schools of Skopje and Banja Luka cities with Raduet detectors exposed in periods of 3 and 12 months, respectively (Table 1). Analysis of the distribution of radon and thoron concentration showed that the best fit of the data was log-normal function. Visually (from Figure 3) and further by testing, the differences between log-normal functions of the Skopje and Banja Luka data sets, was confirmed for radon as well for thoron. The reason for this may be the different contributions of the factors which are affecting radon and thoron concentrations variation in the cities.

The arithmetic and geometric mean values of radon concentrations measured in Skopje are higher than the mean concentrations obtained for Banja Luka (Table 2). We assumed that, among the different radon potentials, the different types of rooms where measurements were performed as well the different periods of detectors exposure, could be a reason for this. But, lower radon concentrations in the hall in comparison to the classroom in Skopje and assembly halls in Banja Luka schools, were not confirmed, so the assumptions about differences in exposure period and radon potential remain. In Banja Luka, the radon concentrations measured by Raduet (this study) in one room are lower than those reported previously, where the radon for each school was presented as a

mean value of measured results, with two different types of detectors in at least two different types of rooms. Furthermore, the geometric standard deviation values (GSD) obtained for radon data from Skopje and Banja Luka (Table 2), are relatively low which indicate relatively homogeneous factors effects on radon variation in each city.

Contrary to radon, the thoron concentrations measured in schools of Banja Luka city are higher in comparison to those of Skopje city (Table 2). It is obvious that in the case of thoron, a period of the detector exposure does not play a significant role. Some of the reasons for this difference could be the position of the detectors as well as the different building materials in the schools. The dispersion of the results in Skopje is greater than the result measured in Banja Luka.

For comparison, the geometric mean concentrations of radon in Banja Luka schools ( $GM = 50 \text{ Bq/m}^3$ ) are lower than those reported by studies conducted in schools: in Skopje ( $GM = 71 \text{ Bq/m}^3$ ), Eastern part of North Macedonia ( $GM = 96 \text{ Bq/m}^3$ ) [25], ( $GM = 87 \text{ Bq/m}^3$ ) [26], Southern Serbia ( $GM = 97 \text{ Bq/m}^3$ ) [29], Osijek, Croatia ( $GM = 70.6 \text{ Bq/m}^3$ ) [30], as well as lower than those published for kindergartens in Sofia, Bulgaria ( $GM = 101 \text{ Bq/m}^3$ ) [31] and Kremikovtsi Municipality, Bulgaria ( $GM = 542 \text{ Bq/m}^3$ ) [32]. The  $GM = 51 \text{ Bq/m}^3$  for thoron measured in Banja Luka schools is not only higher than the  $GM = 11 \text{ Bq/m}^3$  value obtained from measurements in Skopje, but also higher than the usual published values in the literature.

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КОНЦЕНТРАЦИЈЕ РАДОНА И ТОРОНА У ШКОЛАМА СКОПЉА  
(РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА) И БАЊЕ ЛУКЕ  
(РЕПУБЛИКА СРПСКА) МЕРЕНЕ RADUET ДЕТЕКТОРИМА

**Сажетак:** Радон ( $^{222}\text{Rn}$ ) и торон ( $^{220}\text{Rn}$ ) су природни радиоактивни гасови који се генеришу у терестријалним материјалима. Они су главни извори излагања становништва јонизујућем зрачењу у затвореном простору широм света. Разлике у периоду полураспада  $^{222}\text{Rn}$  ( $T_{1/2} = 3,8$  д) и  $^{220}\text{Rn}$  ( $T_{1/2} = 55,6$  с) доводе до њиховог различитог понашања у просторијама. До сада је извршено неколико испитивања  $^{222}\text{Rn}$  и  $^{220}\text{Rn}$  у Северној Македонији, почевши од мерења у становима 2008. године и настављајући са мерењима у школама током 2012. Испитивања радона у Републици Српској започела су касније (у 2011. години) истовременим мерењима  $^{222}\text{Rn}$  и  $^{220}\text{Rn}$  у становима и школама града Бање Луке. Овај рад, као резултат заједничке сарадње, указује на резултате и опште закључке добијене мерењима  $^{222}\text{Rn}$  и  $^{220}\text{Rn}$  у главним градовима обе државе. У оба града мерења су извршена помоћу Raduet – нуклеарних траг детектора; распоређених на растојањима од зида:  $> 0,5$  m (Скопље) и  $0,2$  m (Бања Лука); и изложених у периоду: март 2012. – мај 2012. (Скопље) и април 2011. – мај

2012. (Бања Лука). Резултати концентрација  $^{222}\text{Rn}$  и  $^{220}\text{Rn}$  у оба града имају log-нормалну дистрибуцију. Средња геометријска вредност  $^{222}\text{Rn}$  од  $71 \text{ Bq/m}^3$  у Скопљу је већа него у Бањој Луци ( $\text{ГС} = 50 \text{ Bq/m}^3$ ). Између разлике у потенцијалу радона који утичу на варијације  $^{222}\text{Rn}$ , та се разлика може повезати са различитим временима излагања детектора. Даље, дисперзија резултата  $^{222}\text{Rn}$  у сваком граду изражена геометријском стандардном девијацијом је релативно мала: ГСД = 2,13 (Скопље) и ГСД = 2,11 (Бања Лука) што указује на релативно хомогене скупове података. Концентрације  $^{220}\text{Rn}$  у Бањој Луци ( $\text{ГС} = 51 \text{ Bq/m}^3$ ) биле су веће него у Скопљу ( $\text{ГС} = 11 \text{ Bq/m}^3$ ). Очигледно је да у случају  $^{220}\text{Rn}$ , период изложености није играо значајну улогу. Један од разлога ове разлике могао би бити положај детектора као и различити грађевински материјали у школама. Супротно томе, дисперзија резултата  $^{220}\text{Rn}$  у Скопљу (ГСД = 3,38) била је већа него у Бањој Луци (ГСД = 2,07).

**Кључне речи:** радон, торон, гас, школа.



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