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Long-term measurements of radon, thoron and their airborne progeny in 25 schools in Republic of Srpska

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ABSTRACT

This article reports results of the first investigations on indoor radon, thoron and their decay products concentration in 25 primary schools of Banja Luka, capital city of Republic Srpska. The measurements have been carried out in the period from May 2011 to April 2012 using 3 types of commercially available nuclear track detectors, named: long-term radon monitor (GAMMA 1)- for radon concentration measurements (C_{Rn}); radon-thoron discriminative monitor (RADUET) for thoron concentration measurements (C_{Tn}); while equilibrium equivalent radon concentration (*EERC*) and equilibrium equivalent thoron concentrations (*EETC*) measured by Direct Radon Progeny Sensors/Direct Thoron Progeny Sensors (DRPS/DTPS) were exposed in the period November 2011 to April 2012. In each school the detectors were deployed at 10 cm distance from the wall. The obtained geometric mean concentrations were $C_{Rn} = 99$ Bq m^{-3} and $C_{Tn} = 51$ Bq m^{-3} for radon and thoron gases respectively. Those for equilibrium equivalent radon concentration (*EERC*) and equilibrium equivalent thoron concentrations (*EETC*) were 11.2 Bq m^{-3} and 0.4 Bq m^{-3}, respectively. The correlation analyses showed weak relation only between C_{Rn} and C_{Tn} as well as between C_{Tn} and *EETC*. The influence of the school geographical locations and factors linked to buildings characteristic in relation to measured concentrations were tested. The geographical location and floor level significantly influence C_{Rn} while C_{Tn} depend only from building materials (ANOVA, $p \leq 0.05$). The obtained geometric mean values of the equilibrium factors were 0.123 for radon and 0.008 for thoron.

1. Introduction

Radon (^{222}Rn), a decay product of ^{226}Ra, and thoron (^{220}Rn), a decay product of ^{224}Ra, are naturally occurring radioactive gases. They can be found in rocks, soil, and water of the earth's crust, and they can accumulate to high concentrations in the indoor environment. The difference in half lives of radon (3.825 d) and thoron (55.6 s) implies that they behave very differently in indoor air (Doi et al., 1994; Urosevic et al., 2008).

The main source of indoor radon is ^{226}Ra in soil. The radon gas can diffuse out of the underlying soil into indoor air. In some cases, building materials can make a significant contribution. The pathway for radon generation in rock and soil to its accumulation indoors is controlled by a number of geogenic and anthropogenic factors (Cosma et al., 2013 and Cosma et al., 2015). The source of indoor thoron is thought to be building material in most cases. Due to its short half-life it cannot be expected to migrate over long distances. Therefore a possible geogenic contribution, which is usually most relevant for radon, is normally thought to be of minor importance, for thoron. Another consequence of the short half-life

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of thoron is that there is a distinctly decreasing concentration profile of thoron away from exhaling surface (Doi et al., 1994; Urosevic et al., 2008).

Since radon is the main natural source of ionizing radiation, measures to control the public health risk from this gas within each country, must be determined using knowledge of indoor radon concentration distribution all over the country. This implies the need for radon surveys and radon mapping. Many national radon programmes have been started since 1970, mostly in developed countries, to obtain a representative distribution of radon concentration and set appropriate standards and actions (WHO, 2009). Worldwide data are published by the UNSCEAR, most recently in 2006 (UNSCEAR, 2006). On the other hand, no comparable number of survey data exists for thoron in the literature. Mainly, exposure to thoron and its decay products in indoor environment is usually much lower than that from radon and its decay products. But in recent years, exposure to thoron and its decay products and its possible health effects has gained increasing attention as indicated in the UNSCEAR 2006 Report. During the past few years, several studies of indoor thoron gas (Stojanovska et al., 2013) and its decay product concentrations have been published for the Balkan region (Gulan et al., 2012; Stojanovska et al., 2014; Mishra et al., 2014).

The health risk associated to radon and thoron rises from the inhalation of the short-lived decay products, mainly reported as equilibrium equivalent concentration (*EEC*). The equilibrium equivalent concentration for radon *EERC* and equilibrium equivalent concentration for thoron *EETC* are the quantities directly related to the Potential Alpha Energy Concentration in air and hence to the inhalation dose. *EERC* is related to individual ^{218}Po, ^{214}Pb and ^{214}Bi activity concentrations, denoted C_1, C_2 and C_3 respectively, through the relation (UNSCEAR annex B p. 103, 2000):

$$EERC = 0.105(C_1) + 0.516(C_2) + 0.380(C_3), \quad (1)$$

and, *EETC* is related to the individual ^{212}Pb and ^{212}Bi activity concentrations, denoted C_1 and C_2 respectively through the relation:

$$EETC = 0.913(C_1) + 0.087(C_2). \quad (2)$$

For more precise dose estimation, accurate techniques to measure concentration of radon and thoron decay products are important. As in the cases of radon and thoron gases there are active and passive techniques. To measure radon and thoron progeny concentration in indoor environment, time integrating passive technique is more appropriate in assessment of human exposure than active techniques. For this purpose, few years ago, low cost time integrating passive detectors for *EERC* and *EETC* measurements have been developed (Zhou and Iida, 2000; Mishra and Mayya, 2008).

A survey of radon, thoron and their decay product concentrations has been implemented in primary schools of Banja Luka city, largest and the most populated city in the Republic of Srpska (Fig. 1). The long term measurements were started as a research activity in 2011 and were conducted during one year. Primary schools in Banja Luka city were chosen for representative measurements due to their correlation with the number of residents (Žunić et al., 2010; Vaupotič and Kávási, 2010). A radon survey of primary schools may serve as a proxy to identify radon prone areas (Bossew et al., 2014). The main motivation for conducting research of radon concentrations in schools is children's health care, since they belong to the most sensitive categories of the human population, taking into account the time spent in that environment. Following the previous work (Ćurguz et al., 2013) in which active and passive measurements of radon concentrations in schools of Banja Luka city were investigated, the main objective of this study is to present analysis of long term radon, thoron and their decay products concentrations in schools.

Fig. 1. Map of Republic of Srpska and location of Banja Luka city.

2. Materials and methods

2.1. Detectors

The measurements were carried out with three different types of nuclear track detectors (SSNTD), explained in the following:

a.) The C_{Rn} was measured by "Long term radon gas monitor" commercially named "Gamma 1", consisted of a CR-39 detecting material placed on the bottom of a cylindrical diffusion chamber (dimensions ⌀58 mm × 20 mm), provided and analysed by Landauer company, Sweden (LANDAUER AB). The relative expanded combined uncertainty, given at 95% confidence level was in interval from 12% (for low C_{Rn}) to 28% (for high C_{Rn}).

b.) The C_{Tn} was measured using the commercially named "Raduet"-radon-thoron discriminative monitor, originally developed by the National Institute of Radiological Science (NIRS), Chiba, Japan (Tokonami et al., 2005). It consists of two CR-39 detector chips fixed in the lower sections of two diffusion chambers (⌀60 mm × 30 mm). The detector's primary chamber is sensitive to radon, whereas the secondary chamber is sensitive to both radon and thoron. These detectors were provided and analysed by collaborators from Japan (NIRS) and used for measurements of thoron activity concentrations. The reported expanded combined uncertainty, at 95% confidence level for C_{Tn} in this survey was ranged from 5% (for high C_{Tn} and low C_{Rn}) up to 100% for low C_{Tn} and high C_{Rn}.

c.) The *EERC* and *EETC* measurements were done by detector named Direct Radon Progeny Sensors/Direct Thoron Progeny Sensors (DRPS/DTPS) (Mishra and Mayya, 2008; Mishra et al., 2009). These monitors consist of two absorber mounted LR 115 type detecting material for measuring time-integrating decay products concentrations. DTPSs are absorber (aluminized mylar of 50 μm thickness) mounted LR-115 type