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LONG-TERM MEASUREMENTS OF EQUILIBRIUM EQUIVALENT RADON AND THORON PROGENY CONCENTRATIONS IN REPUBLIC OF SRPSKA DWELLINGS

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Abstract: The long–term measurements of radon and thoron equilibrium equivalent concentrations (*EERC* and *EETC*) were carried out the first time in Republic of Srpska in 25 schools of its capital Banja Luka and in its wider surroundings. After this successful survey, the measurements continued using the same type of the LR 115 nuclear track detectors, i.e., Direct Radon Progeny Sensors/Direct Thoron Progeny Sensors (DRPS/DTPS), and they were deployed in the 36 dwellings nearby the investigated schools. The detectors were exposed for one year period at 15–20 cm distance from the walls. The *EERC* and *EETC* were found to vary in the range from 6.3 to 14.4 Bq/m^{3}and from 0.10 to 1.1 Bq/m^3, with geometric mean 9.3 and 0.36, respectively. The same variance of *EER* and *EET* concentrations, measured in living and bedrooms of buildings built with different construction materials as well at different floors have been obtained. The insignificant correlations between *EERC* and *EETC*, show that these concentrations appeared to be independent in investigated dwellings. The calculated ratio of *EETC* to *EERC* ranged from 0.01 to 0.16 with the geometric mean of 0.04. The aim of this study is to give possible scientific contribution considering the explanation of *EERC* and *EETC* behavior in an indoor environment.

Keywords: EERC, EETC, indoor, dwellings.

1. INTRODUCTION

Radon (^{222}Rn) and thoron (^{220}Rn) are naturally occurring radioactive gases with half-lives of 3.82d and 55.3 s, respectively. There are direct decay products of the respective isotopes of radium (^{226}Ra and ^{224}Ra) in ^{238}U and ^{232}Th chains. Radon and Thoron gases are generated in terrestrial materials, emanated from their surfaces, and then accumulated in the indoors. These processes are complex and depend on a large number of geogenic and anthropogenic factors. Based on a large number of researches and results compounded in UNSCEAR reports, radon and thoron have been proven to be the major sources of public exposure [1].

Chronic exposure to high concentrations of radon and thoron can cause negative health effects [2]. Practically, the health risk due to radon and thoron is associated with inhalation of their short-lived decay products, which activities are reported as

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equilibrium equivalent concentration (*EEC*). The equilibrium equivalent concentration for radon *EERC* and for thoron *EETC* are the quantities relevant to the Potential Alpha Energy, concentration in air and therefore to the inhalation dose. *EERC* is a combination of radon short-lived decay products: ^{218}Po, ^{214}Pb and ^{214}Bi activity concentrations, denoted C_1, C_2 and C_3 respectively, through the relation [1]:

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

and, *EETC* is compounded by the thoron short-lived decay products ^{212}Pb and ^{212}Bi activity concentrations, denoted C_1 and C_2 respectively, which is expressed by the relation:

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

For more precise dose estimation, accurate techniques to measure the 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 an indoor environment, time integrating passive technique is more appropriate in the assessment of human exposure than active techniques. For this purpose, a few years ago, low-cost time integrating passive detector for *EERC* and *EETC* measurements have been [3,4], named DTPS/DRPS detector.

As a result of international collaboration between scientists from the former Yugoslav Republics, during the past few years, several studies of the long–term equilibrium equivalent concentration for radon *EERC* and for thoron *EETC*s have been performed. The *EERC* and *EETC* were measured on 388 different locations [5], using the DTPS/DRPS detectors. The surveys were performed in 122 dwellings in the region of Sokobanja, Serbia [6,7], 48 dwellings in Kosovo and Metohija [8], 44 schools in Republic of North Macedonia [9], 112 dwellings in Slovenia [10], as well as in the Republic of Srpska.

In the period 2011-2012, the first long–term measurements of EERC and EETC were carried out in 25 schools in Banja Luka city (the capital of Republic of Srpska) and in its wider surroundings [11]. Later these measurements of *EERC* and *EETC* were carried out in 37 individual dwellings in its the most frequently occupied room, nearby the investigated schools in Banja Luka, using the same type of direct progeny sensing detectors. This paper presents these results.

Figure 1. The geographical position of Banja Luka

2. MATERIALS AND METHODS

The direct progeny sensing detector system is based on the registration of alpha tracks originating from the deposited progeny activity on LR-115 detectors [4]. The energies of an alpha particle are selected by mounting absorbers of suitable thicknesses on the LR-115 detectors. The direct thoron progeny sensor (DTPS) is made up of an LR-115 track detector mounted with an aluminized mylar absorber of 50 mm thickness to selectively detect only the 8.78 MeV alpha particles emitted from ^{212}Po atoms (Mishra R.et al 2009). Similarly, the direct radon progeny sensor (DRPS) has an absorber thickness of 37 mm to detect mainly the alpha particles emitted from ^{214}Po (7.69 MeV). In a mixed radon and thoron progeny environment, this can have some interference from the alpha particles from ^{212}Po, which needs to be subtracted using the thoron sensor data. The LR-115 films were then removed and processed in the laboratory for measurements of radon and thoron progeny concentrations. The measurements were made by DRPS/DTPS (Direct Radon Progeny Sensors/Direct Thoron Progeny Sensors) which were left exposed inside the house in the period of 12 months, from December 2011 to December 2012, in 37 houses inside rooms at 15-20 cm distance from walls or any available room surfaces. The houses were randomly chosen with an idea of surrounding a greater geographical part of Banja Luka city (Republic of Srpska-Balkan Region).

Figure 2a. Direct Radon Progeny Sensor

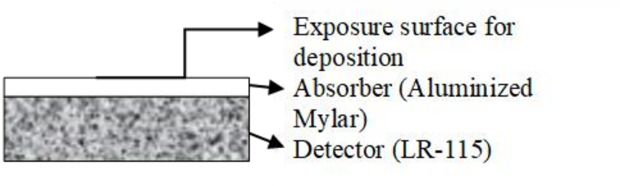

Figure 2b. Detector LR-115 structure

3. RESULTS AND DISCUSION

Descriptive statistic and frequency distribution of indoor *EERC* and *EETC* are given in Table 2 and Figure 3. Both data sets were approximated with a log-normal function, the null hypothesis was confirmed at 5% error probability.

The *EERC* and *EETC* were found to vary in the range from 6.3 to 14.4Bq/m^{3}and from 0.10 to 1.1 Bq/m^3, with geometric mean 9.3 and 0.36 respectively. The same variance of *EER* and *EET* concentrations measured: in living rooms and bedrooms, buildings built with different construction materials as well at different floors were obtained.

In Figure 4 Geometric mean values of *EERC* and *EETC*, obtained in this study are compared with values reported from some former Yugoslav Republics.

The geometric mean value GM and related (GSD) of 9.3Bq/m^3 (1.23) for *EERC* in this study is lower than the 11.2 Bq/m^3 (1.26) previously reported for the schools in the Republic of Srpska [11]. It is also lower than those found in Serbian dwellings, 11 Bq/m^3 (1.5) [6], and also in comparison with those in dwellings of Kosovo and Metohija 30 Bq/m^3 (2.1) [8], in schools of North Macedonia 27 Bq/m^3 (1.4) [9]. The value of 0.36 Bq/m^3 (2.00) for *EETC* obtained for dwellings in this study is similar to 0.40 Bq/m^3 (2.20) obtained for schools in Banja Luka but lower than those reported for dwellings in Serbia, 0.86 Bq/m^3 (2.1) [6]; and Kosovo and Metohija, 1.9 Bq/m^3 (1.9) [8]; as well as those reported in schools of North Macedonia, 0.75 Bq/m^3 (2.5) [9].

Table 1. Descriptive statistic of measured EERC and EETC

Statistic	*EERC*(Bq/m^3)	*EETC*(Bq/m^3)
No. of observations	37	37
Minimum	6.3	0.10
Maximum	14.4	1.10
Median	9.5	0.38
Arithmetic mean	9.5	0.44
Standard deviation	2.0	0.28
Skewness	0.3	0.84
Kurtosis	-0.4	-0.03
Coefficient of variation	21%	64%
Geometric mean	9.3	0.36
Geometric standard deviation	1.23	2.00

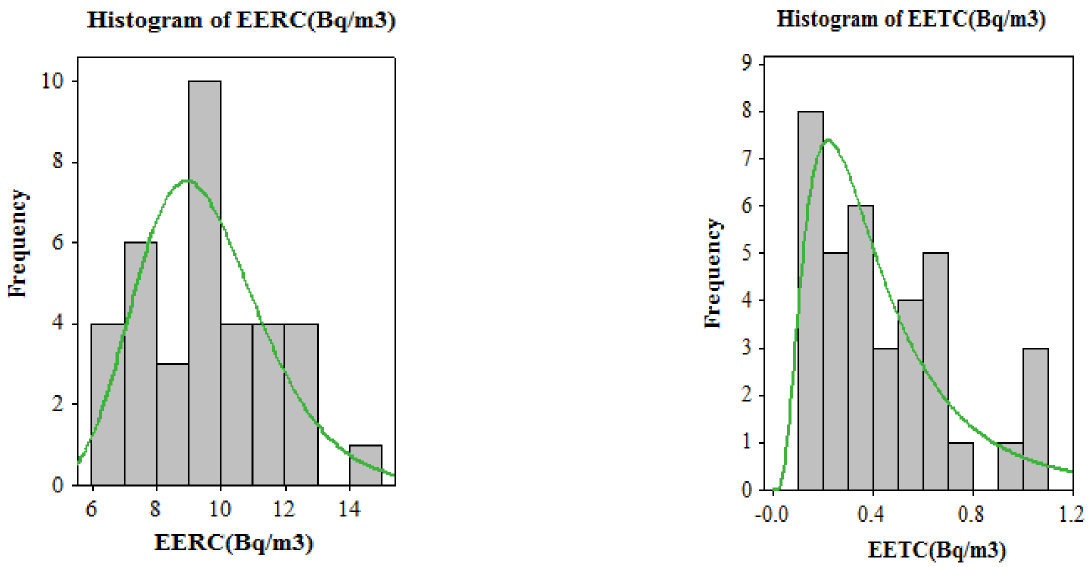

Figure 3. Histograms of EERC and EETC fitted by log- normal function

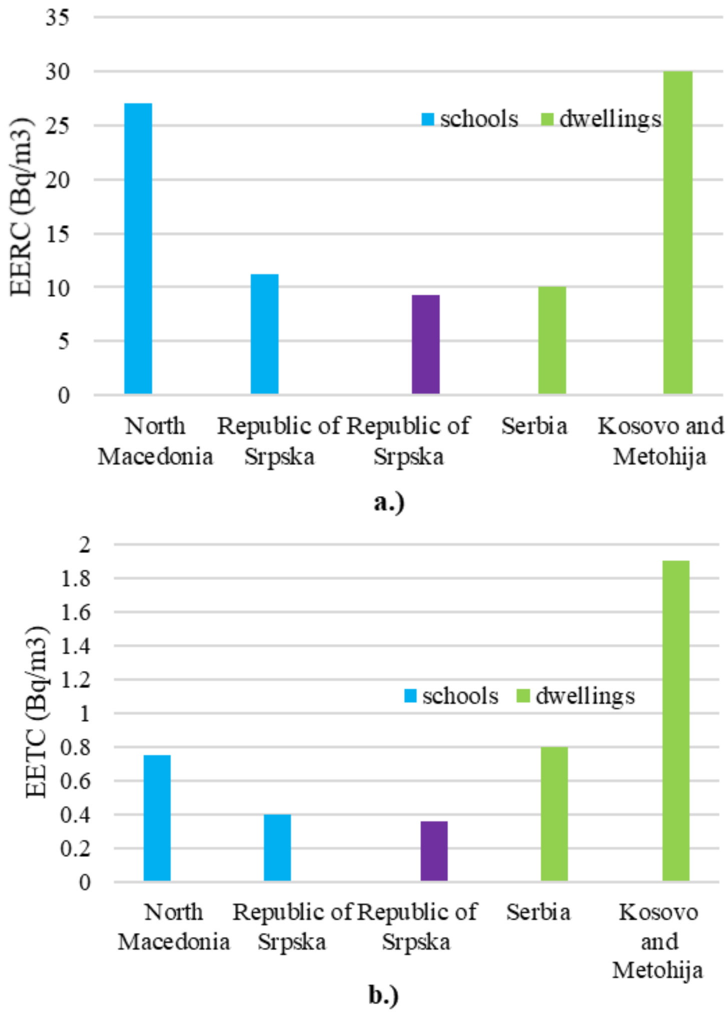

Figure 4. The geometric mean values of a.) EERC and b.) EETC obtained in this study and studies performed in some former Yugoslav Republics

The range of *EETC*/*EERC* ratio in dwellings considered in the present study was between 0.01 and 0.16, and GM of 0.039 (2.02). The results agree with Banja Luka schools [11-14] which were in a range from 0.01 to 0.12 and the same geometric mean as in the dwellings.

The correlation between *EERC* and *EETC* was tested. For this purpose, a model of parametric linear regression (LR) was applied on ln-transformed data in order to reduce the influence of extremes on the tests. The test results showed that the correlation between *EERC* and *EETC* was insignificant (Figure 5). It means that these concentrations appeared to be independent in investigated dwellings.

In the literature, different results from the correlations analysis between *EERC* and *EETC* have appeared. For example, the correlation in Banja Luka schools was not significant [11] as in the homes, neither it was significant in the schools of Northern Macedonia [9], while in the homes of Kosovo and Metohija the correlation was significant with a relatively high coefficient of determination (R^2 = 0.56) [8].

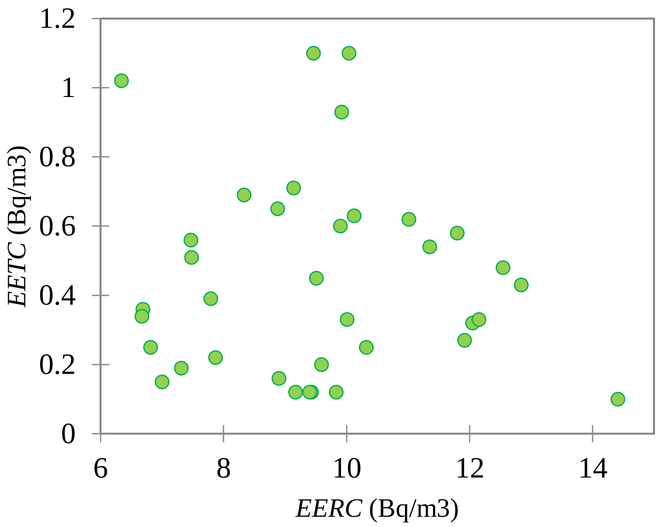

Figure 5. Scatter plot of EETC and EERC.

4. CONCLUSION

This work presents simultaneous long-term measurements of *EERC* and *EETC* in dwellings of Banja Luka with nuclear track detectors. *EERC* values were in the range from 6.3 to 0.1 Bq/m^3, and *EETC* were in the range from 0.10 to 1.10 Bq/m^3 while as the interval of the ratio *EETC/EERC* was between 0.01 and 0.16. The geometric mean and (geometric standard deviation) values of 9.3 Bq/m^3 (1.23) for *EERC* and 0.36 Bq/m^3 (2.00) for *EETC* obtained in this study are lower in comparison with GM values reported from the countries in that region.

Further investigation of the equilibrium factors in the dwellings of Banja Luka is planned.

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ДУГОРОЧНА МЈЕРЕЊА ЕКВИВАЛЕНТНИХ РАВНОТЕЖНИХ КОНЦЕНТРАЦИЈА РАДОНА И ТОРОНА У КУЋАМА РЕПУБЛИКЕ СРПСКЕ

Сажетак: Дугорочна мјерења еквивалентних равнотежних концентрација радона и торона (EERC and EETC) први су пут извршена у Републици Српској у 25 школа града Бањалуке и шире околине. Након овог успјешног истраживања, мјерења су настављена коришћењем истог типа нуклеарних траг детектора LR 115, тј. сензора директних потомака радона и торона (DRPS / DTPS) и распоређених у 36 домова у близини школа. Детектори су били изложени током једне године на удаљености 15–20 cm од зидова. Откривено је да се EERC и EETC разликују у опсегу од 6,3 до 14,4 Bq/m^3 и од 0,10 до 1,1 Bq/m^3, са геометријском средином 9,3 и 0,36, респективно. Добијена је иста разлика у концентрацији EEP и EET, измјерена у дневним и спаваћим собама зграда изграђених од различитих грађевинских материјала и на различитим подлогама. Незнатна повезаност између EERC-а и EETC-а показује да су ове концентрације биле независне у испитиваним становима. Прорачунати однос EETC-а и EERC-а кретао се у распону од 0,01 до 0,16 са геометријском средином 0,04. Циљ ове студије је анализа могућих објашњења понашања EERC и EETC у затвореном простору.

Кључне ријечи: EERC, EETC, затворен простор, куће.

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