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DETERMINATION OF EQUILIBRIUM EQUIVALENT OF THORON AND RADON CONCENTRATION IN SCHOOLS OF THE CITY OF BANJA LUKA

Zoran Ćurguz[1], Dragoljub Mirjanić[2]*
[1] Faculty of Traffic Engineering, University of Eastern Sarajevo, Vojvode Mišića 52, Doboj, Republic of Srpska, BiH
[2] University of Banja Luka, Faculty of Medicine, Save Mrkalja 14, Banja Luka and Academy of Sciences and Arts of the Republic of Srpska, Bana Lazarevića 1, Banja Luka, Republic of Srpska, BiH

Summary: The paper analyzes the relationship of short-lived progenies of radon and thoron decay. Concentration of progenies is expressed as equilibrium equivalent concentration of *EETC* (equilibrium equivalent concentration of thoron) and *EERC* (equilibrium equivalent concentration of radon) abbreviated (*EETC*/ *EERC*). Measuring of radon and thoron progenies was carried out in 25 schools in the territory of the City of Banja Luka using CR -39 (RADUET) detectors. Detectors were exposed for six months and were set in the staff room at the height of 30 cm from the ceiling in internal wall. The relationship is determined (*EETC*/ *EERC*) and comparison carried out of obtained results with the world standards, and then the correlation coefficient between radon and thoron was determined.

Keywords: radon, thoron, equilibrium equivalent concentration of thoron, equilibrium equivalent concentration of radon, CR -39 (RADUET).

1. INTRODUCTION

In real conditions, radon, thoron and their progenies give the largest individual contribution (over 50%) to the annual effective dosage received by the population by ionizing radiation from the nature [1].

Radon originates by radioactive transformation of ^{238}U, ^{235}U, ^{232}Th and it exists in various concentrations in all materials from the soil. There are three isotopes of radon in the nature:

− radon ^{219}Rn, known as actinon and stems from the range ^{235}U;

− radon ^{220}Rn, known as thoron and stems from the range ^{232}Th (Figure 1);

− radon ^{222}Rn and stems from the range ^{238}U (Figure 2).

Due to low concentration of radon ^{235}U in the soil and short period of half-life ^{219}Rn ($T_{1/2}$= 3,96 s) this isotope does not contribute to significant total radiation dosage. Radon ^{220}Rn (thoron) has short period of half-decay ($T_{1/2}$= 55,6 s), however its presence cannot be neglected. Further on, due to its short period of half-life, thoron cannot be expected to migrate to the higher distance from the wall. As a consequence, there is a strong dependance of thoron concentration from distance from the wall, and there is no dependance from the speed of air exchange. On the other hand, their progenies have sufficiently long half-decay period (^{212}Pb, $T_{1/2}$= 10,6 h и ^{212}Bi, $T_{1/2}$= 1 h) so they can distribute homogenously in the room. Since ^{222}Rn has relatively long period of semi-decay (3,82 days), this isotope is the most significant natural source of radiation in the environment.

There are many different studies on connection between radon and lung cancer at miners in mines [2], and also a range of experimental studies was conducted on affiliation and preservation of radon progenies in lungs, which enabled quantitative evaluation of radiation dosage in bronchial epithelium, stemmed from certain concentration of radon progenies in the air.

Studies on harm of radon are later spread to the population having in mind that the people in developed countries spend about 80% of time in closed premises. In the end of the 80-ies, more comprehensive measurement of radon in residential structures has began, which was published in publications of UNSCEAR [3]. Behaviour of radon progenies indoors is described by Jacobi parameter

[*] Corresponding author: curguzzoran@yahoo.com

differential equations [4], which take into account radioactive decay and disappearance of radon progenies by ventilation, deposition and transition from one element into another. According to UNSCEAR from 1993, average concentration of radon is 37 Bq/m3 in indoor space, " indoor radon" and 10 Bq/m3 in outdoor space "outdoor radon". By using appropriate factors from 0,4 for "indoor" and 0,8 for "outdoor" radon, we obtain average effective concentration (EEF) 16 Bq/m3 in rooms and 8 Bq/m3 in an outdoor environment. On the basis of the conversion factors, according to UNSCEAR, effective equivalent dosage is (E) is 9x10-6 mSv/h of 1 Bq/m3 of effective equivalent concentration (EEC) of radon in outdoor and indoor space, and 1,5x10-3 mSv/god for inhaled radon of 1 Bq/m3 dissolved in tissue.

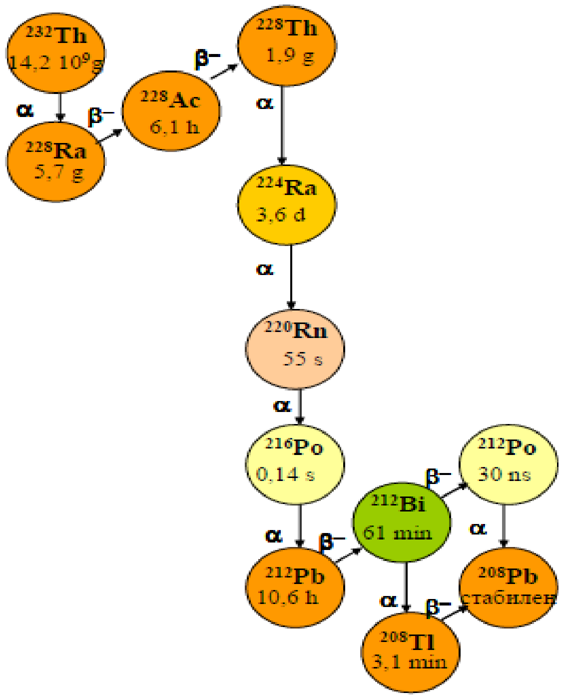

Figure 1. Range of decay ^{232}Th

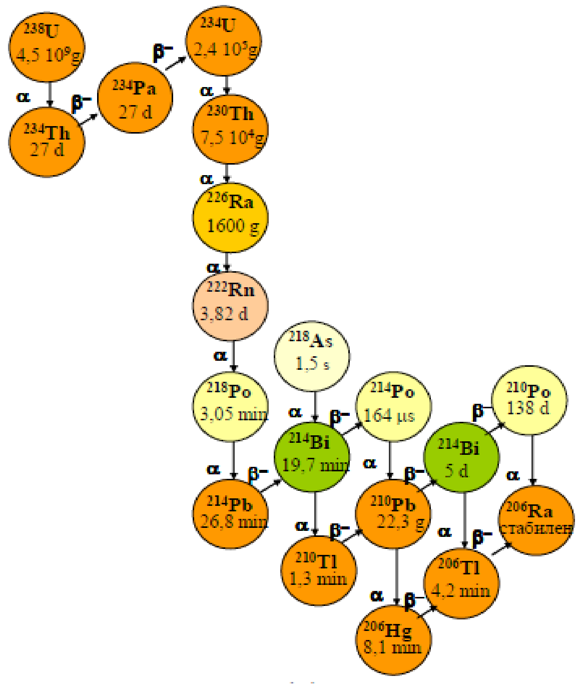

Figure 2. Range of decay^{238}U

2. MEASUREMENT TECHNIQUE

Methods of radon measurement with the aim to determine its concentration, comprise identification and counting of nuclear events [5]. They are based on detection and registration of effects of interaction of electrified particles (α and β) or radiation (γ) with material of detector. All methods are divided into active and passive ones, depending on whether the results processing is carried out in the course of the process of measurement itself (active) or after long-term exposure in the radon atmosphere (passive). In both cases, registration threshold from physical point of view presents loss of energy of ionizing particles necessary for breaking of certain number of chemical bonds in the polymer of material of detector. Methods of measurement are based on determination of density of traces of α particles from the decay of radon (number of traces per unit of detector area). One of the manners of measuring of radon concentration is by application of passive measurement technique with the use of nuclear trace detectors. Comparison of the results of passive and active method as well as determination of Pearson correlation coefficient between these two methods has been carried out in the paper [6].

Passing through a solid dielectric medium, heavy electrified particles produce visible defects (traces) in the crystal structure. These defects are distinguishable from impurities and irregularities in the crystal itself and they can be seen by optical microscopy after a certain chemical treatment [7].

After exposure of the detector and their return to the lab, they are opened, and then the microfilms are separated from the diffusion chamber to prepare for the chemical treatment

Damage traces (latent traces) can be made visible under the microscope by the action of various agents that corrode faster the place of damage than the surrounding undamaged material, and as a result of this difference in the speed of corrosion, an extended trace is obtained. Depending on the energy, the electrification and the size of the ions, the latent trace can be 1-10 nm in diameter [8].

By the process of corrosion, the traces become larger, with a diameter in the interval of 10-20 μ m[5]. Microfilm corrosion is done in a corrosion vessel. The detectors were chemically developed over 1 hour in 6.25 normal solution of NaOH at 98 °C. Once removed from the bathroom, the detectors were rinsed, for the first time by distilled water, then tap water and left for 30 minutes in 2% aqueous solution (distilled water) of acetic acid in order to stop the further development of traces. The solution for detector development was verified by a thermometer and a device measuring the density of NaOH solution. After that, the detectors were rinsed again and left to dry. After drying the detector, it is possible to count the traces [9].

Two fully automated systems (imageanalysisread-out) were used to search and analyze traces. The first one is the TASL system [10] with the TASL operating program, version 10.9, and the second system used is the Politrack system with the program Politrack, version 4.1. The precision of the measurements was evaluated in the conditions of field work with both reading systems by the comparison of paired detectors. The median coefficient of variation (CV) of measured concentrations was 8% for TASL system and 4% for Politrack [11].

3. EXPERIMENTAL WORK

Measuring of radon and thoron progenies in this paper was carried out using the Detector CR -39 (RADUET) . Detector is consisted of two CR-39 films placed on the bottom of diffusion chamber of the dimension of ϕ 60 mm x 30 mm (Figure 3). Diffusion chambers are caharacterized by various rates of air exchange. The low air rate exchange chamber (LER) registers Rn, and the high air exchange chamber (HER) registers both Tn and Rn. Rn gas in the air arrives to the LER chamber through very narrow invisible channels, while Tn diffuses through evenly spaced assembled holes on the wall of HER chamber. Lower detection limit LLD is calculated on the basis of ISO Guide [12].

Figure 3. Detector Cr -39 (RADUET)

Detectors CR -39 (RADUET) were placed in 25 schools. All detectors are placed to be 0,3m from the ceiling and from the neighbouring wall in order to avoid errors appeared by addition of concentrations of thoron from the measured and neighbouring walls. In every school (in the staff room), there was one detector of this type.

4. MEASUREMENT RESULTS

As a result of the radioactive decay of the radon and thoron indoors, their short-lived progenies of decay appear. Concentration of progenies is expressed as the equilibrium equivalent concentration of EES ie. EERC (Equilibrium Equivalent Radon Concentration) and EETC (Equlibrium Equivalent Thoron Concentration) and their values are determined by equations:

$$EERC = 0,105 \cdot C_{^{218}\mathrm{Po}} + 0,515 \cdot C_{^{214}\mathrm{Pb}} + 0,380 \cdot C_{^{214}\mathrm{Bi}}$$

$$EETC = 0,913 \cdot C_{^{212}\mathrm{Pb}} + 0,087 \cdot C_{^{212}\mathrm{Bi}}$$

Intervals of measured values are: 6,79-16,84Bq/m^3 for *EERC* and 0,09-1,16 Bq/m^3 for *EETC*. Log-normal distribution was confirmed in both groups of results (KS, p=0,315 for *EERC* and p=0,542 for *EETC*). The Figure 4 shows histograms of EERC and EETC fitted by log-normal function and graph ln of transformed EERC and EETC fitted by normal distribution.

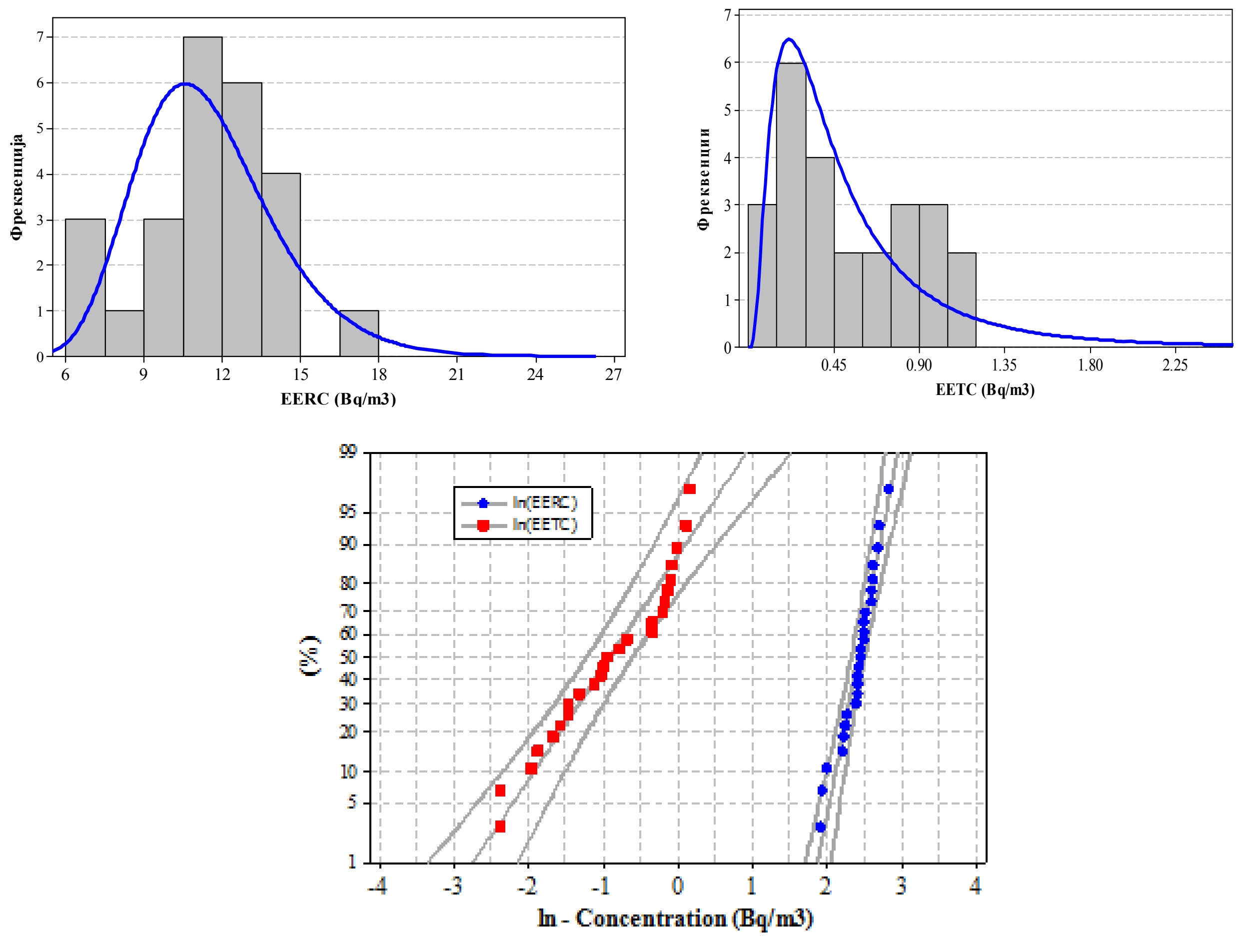

Figure 4. Histograms of EERC and EETC fitted by log-normal function and graph ln of transformed EERC and EETC fitted by normal distribution.

Relationship between *EETC and EERC*: (*EETC*/ *EERC*) was calculated and obtained values are within the interval from 0,008 to 0,118 with geometric mean value of 0,036 (GSD-2,22).

The number of researches and published papers specifically for EETC is still limited in order to make a generalization of EETC / EERC values at a global level. For example, in the report [13] the model proposed by the ICRP is accepted that on the basis of the physical characteristics of the entry of radon and thoron into building structures, the speed of exchange of air (ventilation) is 0.7 h^{-1}. Based on this model, the expected concentrations of products of decay of products in indoor facilities are: for radon: EERC = 15 Bq / m^3 (2-50 Bq / m^3) for thoron: EETC = 0.5 Bq / m^3 (0.04 - 2 Bq / m^3), where it stems that EETC / EERC = 0.03.

Correlations of concentrations

Figure 5 shows graphically how measured and ln transformed concentrations are interdependent. Visually and through linear regression, confirmed is the correlation between concentrations of the thoron and radon (Figure 5 above to the left) and between the concentrations of the thoron and the EETC (Figure 5 below right).

Parameters of linear regression and correlation among concentration of radon, thoron and their decay products are shown in Table 1. For quantification of correlation, used were Pearson and Spearman coefficient and their squared value as a coefficient determination.

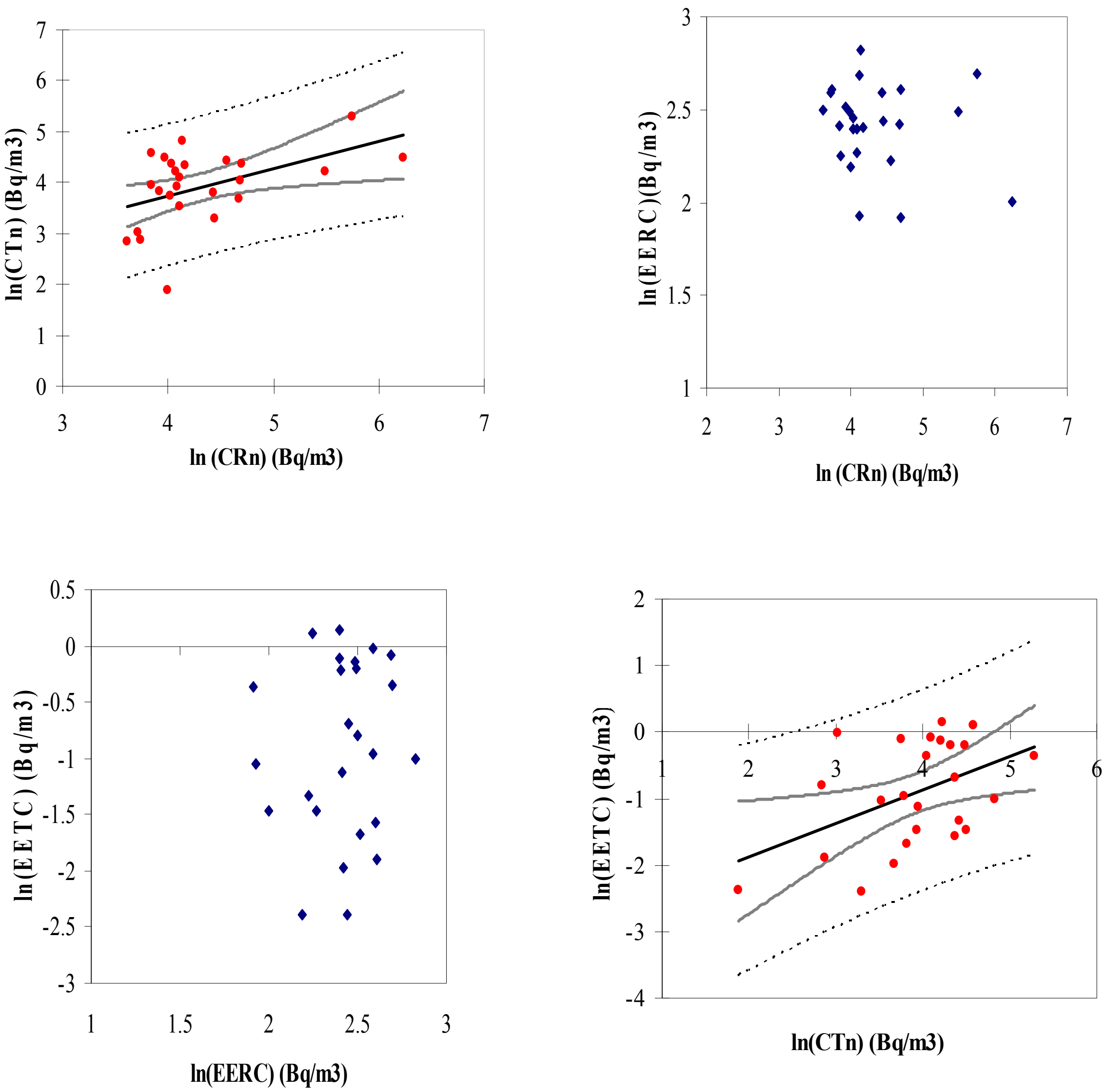

Figure 5. In case of significant statistical correlation, the link between sizes is modelled by linear function (black full line). On the same graph, grey full line presents 95% of confidence interval of mean value, and dashed black line presents 95% of confidence interval of the model.

Table 1. Parameters of linear regression and correlation between concentration of radon, thoron and their decay products

	p	*y = ax + b*		*R* R^2
		a	*b*	
ln(CRn1)- ln(CTn)	0.008	0,457±0.158	2,715±0.630	0,51 026
ln(CRn2)- ln(CTn)	0.005	2.640±0.517	0,401±0.130	0,550 0,303
ln(CRn3)- ln(CTn)	0.091			
ln(EERC)- ln(EETC)	0.605			
ln(EERC)- ln(CRn1)	0.352			
ln(EERC)- ln(CRn2)	0.300			
ln(EERC)- ln(CRn3)	0.296			
ln(EETC)- ln(CTn)	***p*=0.020**	2.883±0.799	0.501±0.201	0,462 0.213

**in case of significance of correlation, error probability p<0.05*

From Table 1, we can see that even in the case of the concentration of the thoron and *EETC*, the correlation is weaker compared to the correlation of the radon and the thoron. This is not unexpected because various factors affect the concentration of the gas of radon and thoron, and various for their products of decay. For example, the generation of radon and thoron depends on the concentration of radium and thorium in the source (soil, building materials). Radon concentration, due to its sufficiently long half-life period is homogeneously distributed in the indoor space, while in thoron it decreases with the increase of the distance from the source (wall, ceiling). Concentration of decayed progenies depends on the concentration of radon and thoron, and also additional factors influence their concentration such as concentration of aerosol indoors and speed of air exchange to which they are more sensitive compared to the gas itself. Speed of air exchange influences the concentration of decayed thoron products less than the concentration of radon decay products [14].

5. CONCLUSION

Equilibrium equivalent concentrations of radon and thoron have been determined. Their relation (*EETC*/ *EERC)* is within the interval from 0,008 to 0,118 with geometric mean value of 0,036 (GSD-2,22). Obtained result has wide dispersion compared to the results of world standards where *EETC*/ *EERC*=0,03. It can be concluded that correlation of thoron concentration and *EETC* is weaker comparing to correlations of radon and thoron. Correlation coefficient between radon and thoron is 0,605 which can be considered as a result that is within the limits of previous researched results.

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ОДРЕЂИВАЊЕ РАВНОТЕЖНОГ ЕКВИВАЛЕНТА КОНЦЕНТРАЦИЈА ТОРОНА И РАДОНА У ШКОЛАМА ГРАДА БАЊЕ ЛУКЕ

Апстракт: У раду се анализира однос краткоживећих потомака распада радона и торона. Концентрација потомака се изражава као равнотежна еквивалентна концентрација *EETC* (равнотежна еквивалентна концентрација торона) и *EERC* (равнотежна еквивалентна концентрација радона) − скраћено (*EETC*/*EERC*). Мјерење потомака радона и торона извршено је у 25 школа на подручју града Бање Луке помоћу CR -39 (RADUET) детектора. Детектори су изложени шест мјесеци и постављани су у зборници на висини 30 cm од плафона на унутрашњем зиду. Одређен је однос (*EETC*/*EERC*) и извршено поређење добијених резултата са свјетским стандардима,а затим је одређен и коефицијент корелације узмеђу радона и торона.

Кључне ријечи: радон, торон, равнотежна еквивалентна концентрација торона,равнотежна еквивалентна концентрација радона, CR -39 (RADUET).

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