JURNAL DE MEDICINĂ PREVENTIVĂ
2001; 9(1); 5-12

POPULATION EXPOSURE TO INDOOR RADON AND THORON PROGENY

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Abstract. The goal of our work was to determine the distributions of radon and thoron progeny concentrations in dwellings, the magnitude of individual and collective exposures and to assess the potential lung cancer risk. The radon and thoron short-lived decay products concentrations have been measured in 586 typical urban and rural houses, randomly selected from 6 cities and 84 villages in eastern part of Romania. The method used to determine the volumetric activity of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb is an active one by pumping a known volume of air through an open-faced high-efficiency filter paper at known flow rate for a certain collection time and counting the deposited activity with a ZnS alpha scintillation counter. Internal exposure due to inhalation of radon and thoron progeny indoors and outdoors has been expressed in terms of effective dose. In dose estimates the conversion coefficients adopted by the UNSCEAR 2000 Report have been used. The values of indoor Equilibrium Equivalent Concentrations of radon and thoron presented a log-normal distribution. The average values of EEC of radon have been of 22.2 Bq m^{-3} in detached houses and 9.0 Bq m^{-3} in block o
f flats and for EEC of thoron, 1.2 Bq m^{-3} in detached houses and 0.6 Bq m^{-3} in block of flats, respectively. The overall annual effective dose of 1.16 mSv and the resultant annual collective effective dose of 6032 manSv might be responsible for 440 life-time radio-induced lung cancers.

Key words: indoor population exposure, radon and thoron progeny, effective dose, lung cancer risk.

Rezumat. Lucrarea noastră a avut ca obiective determinarea distribuției concentrației descendenților radonului şi toronului în locuințe, a mărimii expunerii individuale şi colective precum şi aprecierea riscului potențial de cancer pulmonar asociat acestei expuneri. Concentrațiile individuale ale descendenților de viață scurtă ai radonului şi toronului au fost măsurate în 556 locuințe reprezentative pentru mediul rural şi urban, alese întâmplător în 6 orașe şi 84 de sate din Moldova. Metoda folosită pentru determinarea activității specifice a ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb este activă, măsurând cu un radiometru cu detector de scintilație ZnS radioactivitatea alfa reținută pe un filtru cu eficiență ridicată, după aspirarea unui volum de aer cunoscut la un anumit debit şi într-un anumit timp de prelevare. Expunerea internă datorată inhalării descendenților radonului şi toronului în aerul interior şi exterior a fost exprimată în termeni de doză efective, folosind pentru estimări coeficienții de conversie adoptati de raportul UNSCEAR 2000. Valorile concentrației echivalente de echilibru a radonului şi toronului în aerul interior au o distribuție log-normală, valoarea medie fiind pentru radon de 22,2 Bq m^{-3} în case şi 9,0 Bq m^{-3} în blocuri, iar pentru toron, de 1,2 Bq m^{-3} în

case şi respectiv de 0,6 Bq m^{-3} in blocuri. Doza efectivă anuală a fost de 1.16 mSv iar doza efectivă colectivă anuală de 6032 omSv. Această doză ar putea fi responsabilă de 440 cancere pulmonare radioinduse în timpul vieții.

Cuvinte cheie: expunere populație, descendenți radon, toron, doză efectivă, risc cancer pulmonar

INTRODUCTION

The radiation dose from indoor radon and thoron progeny inhaled is the dominant component of population exposure to natural radiation sources accounting for about 60 per cent in Romania (1).

The objectives of our work were to determine the distributions of radon and thoron progeny concentrations in dwellings, the magnitude of both individual and collective exposures and to assess the potential lung cancer risk.

The indoor radon and thoron progeny measurements in rural areas have been multiplied since our last study due to higher concentrations found there (2). The rural houses differ from those built in urban areas by structures, construction technology, design, building materials, heating. They are usually single-family dwellings where raised levels of radon and thoron progeny are expected to occur because of their activity concentrations in subjacent ground and surrounding soil.

MATERIAL AND METHODS

The radon and thoron short-lived decay products concentrations have been measured in 586 typical urban and rural houses, randomly selected from 6 cities and 84 villages in eastern part of Romania.

The method used to determine the volumetric activity of ^{218}Po, ^{214}Pb, ^{214}Bi and ^{212}Pb is an active one by pumping a known volume of sample air (about 0.6 m^3) through an open-faced high- efficiency filter paper (98%) at known flow rate (0.01-0.08 m^3/ min) for a certain collection time (usually 10 minutes) and counting the deposited activity with a ZnS alpha scintillation counter (40% efficiency) during four counting intervals. A computer program, very versatile in handling multiple input parameters, has been developed to solve the decay equations for obtaining the activity concentrations of daughters in air, to calculate the EECs, the potential alpha energy concentrations and the equilibrium factor F for radon daughters. The detection limits of our method are, in optimum sampling and counting conditions, 1 Bq m^{-3} for each ^{218}Po, ^{214}Pb, ^{214}Bi and 0.1 Bq m^{-3} for ^{212}Pb (3).

Internal exposure due to inhalation of indoor and outdoor radon and thoron progeny has been expressed in terms of effective dose. In dose estimates, the dose conversion coefficients adopted by the UNSCEAR 2000 Report of 9 nSv / Bq h m^{-3} has been used for radon daughters, indoors and outdoors, and, for thoron progeny, of 40 nSv / Bq h m^{-3} indoors as well as outdoors (4). An indoor occupancy factor of 0.75 and a population size of

5.2 million inhabitants have been considered in all calculations.

RESULTS AND DISCUTION

The results included in table 1 represent the arithmetic means and standard deviations of indoor and outdoor radon and thoron progeny activity concentrations and the resulting equilibrium equivalent concentrations, EECs.

Table 1. Indoor and outdoor average concentrations for ^{222}Rn and ^{220}Rn progeny

LOCATION	Average activity concentration (Bqm^{-3})				Equilibrium Equivalent Concentration (Bqm^{-3})	
	^{218}Po	^{214}Pb	^{214}Bi	^{212}Pb	^{222}Rn	^{220}Rn
INDOORS (number)						
Detached house (441)	42 ± 20	22 ±15	17 ±13	1.0 ± 0.8	22.2 ± 16.7	1.2±0.8
Block-of-flats (145)	13 ± 8	9 ± 6	8 ± 4	0.6 ± 0.4	9.0 ± 6.4	0.6 ± 0.4
OUTDOORS	5.3 ±2.8	3.6 ±1.3	3.0±1.4	0.2 ±0.1	3.6±1.5	0.2 ±0.1

In detached houses, the average values of EEC of radon and thoron were 22.2 Bqm^{-3} and 1.0 Bqm^{-3}, respectively.

In block of flats, these average values were approximately two times lower, 9.0 Bqm^{-3} for radon progeny and 0.6 Bqm^{-3} for thoron progeny. The corresponding values for outdoors were 3.6 Bqm^{-3} and 0.2 Bqm^{-3} for radon and thoron progeny, about 5 times lower than indoor ones.

The results of all measurements show a log-normal distribution, as illustrated in Fig. 1- for ^{222}Rn progeny and in Fig. 2 - for ^{212}Pb, the most important short lived decay product of thoron.

The average value for equilibrium factor F for indoor radon short-lived decay products was 0.51 ± 0.19, ranging from 0.1 to 0.9. The value of F varies in dwellings with ventilation rate and the presence of aerosol sources such as smoking or cooking and is affected to same extent by the incoming air. High ventilation rate and low aerosol concentration give values of F significantly lower than 0.5. When ventilation is low and aerosol concentration is high the value of F is higher and so is also the dose (fig. 3).

Table 2 presents the average equilibrium equivalent concentrations of radon and thoron determined with respect to the building materials, usually used in rural areas.

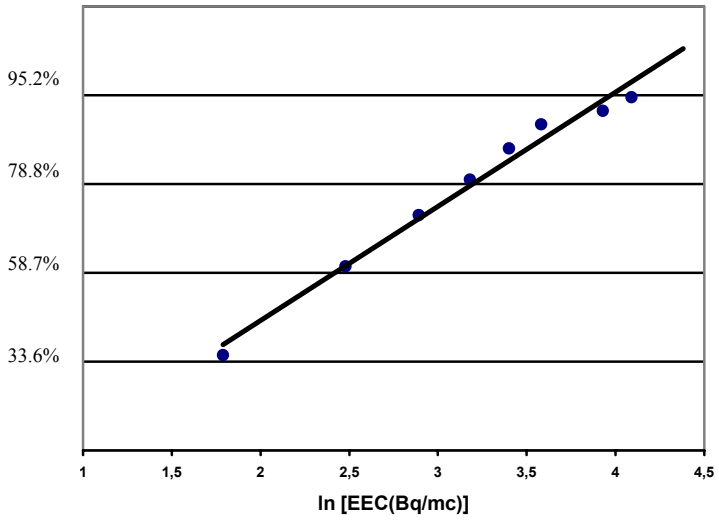

Fig. 1a. Log-normal cumulative frequency plot of radon daughters concentrations

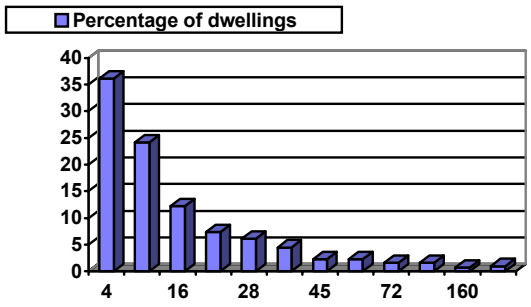

Fig. 1b. Distribution of indoor EEC of radon (total sample)

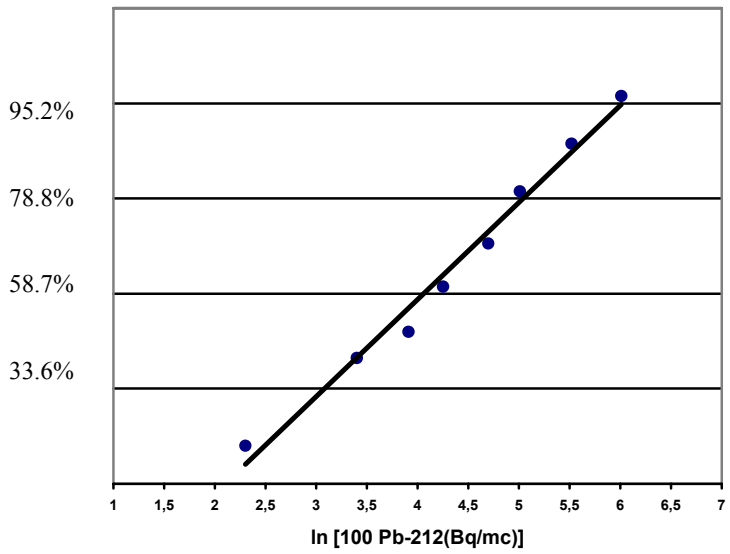

Fig. 2a. Log-normal cumulative frequency plot of ^{212}Pb concentrations

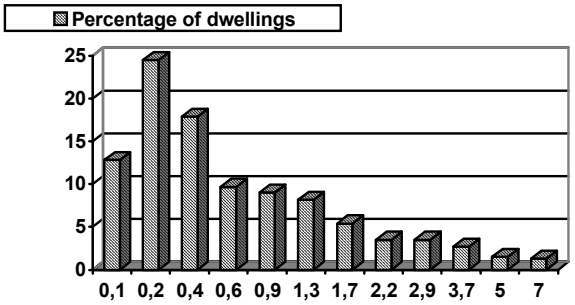

Fig. 2b. Distribution of indoor EEC of thoron (total sample)

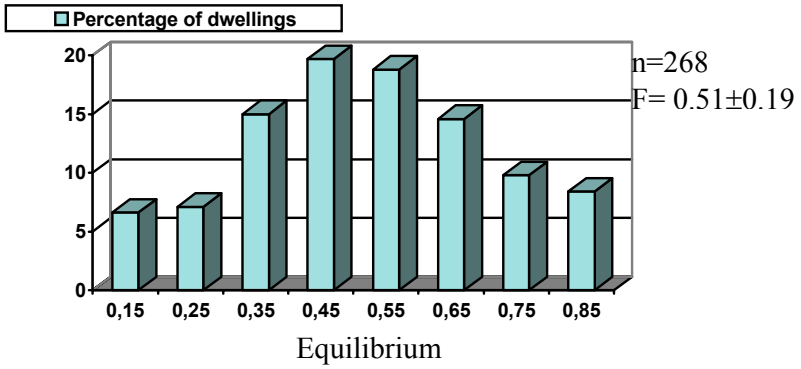

Fig. 3. Distribution of equilibrium factor F for indoor radon daughters

Table 2. Equilibrium Equivalent Concentrations of radon and thoron with respect to the building materials

Building material	Equilibrium Equivalent Concentration, EEC. (Bqm^{-3})			
	Radon daughters		Thoron daughters	
	Average	Limits	Average	Limits
Brick	19.0 ± 14.4	2.3 – 564	0.68 ± 0.52	0.1 – 5.9
Wood	8.3 ± 5.8	1.6 – 37.8	1.11 ± 0.79	0.2 – 6.4
Adobe	18.5 ± 10.2	2.5 – 101	1.46 ± 1.04	0.1 – 12.8
Wattle and daub	26.4 ± 16.2	5.5 – 375	1.66 ± 1.27	0.1 – 6.1
Voussoir	13.7 ± 11.8	2.7 – 39.0	0.77 ± 0.48	0.3 – 1.9
Autoclaved cellular concrete	7.0 ± 3.5	3.4 – 13.3	0.46 ± 0.27	0.2 – 0.9

The average values of EEC of radon in rural dwellings varied from 7.0 to 26.4 Bq m^{-3} as a function of building materials used with individual values ranging from 1.6 Bqm^{-3} to 564 Bqm^{-3}. The weighted average of EEC of radon was 22.2 Bq m^{-3} (table 1). The average values of EEC of thoron were between 0.46 and 1.66 Bq m^{-3} taking into account the building materials, with individual values ranging from 0.1 to 12.8 Bq m^{-3} and weighted average of 1.0 Bq m^{-3}.

Data in table 2 clearly indicate that rural houses built of wattle and daub clay in wooden framework have substantially higher radon and thoron levels than houses constructed of wood, brick or concrete blocks.

The corresponding average individual annual effective doses are listed in table 3.

Table 3. Annual effective doses from ^{222}Rn and ^{220}Rn progeny with respect to the building materials

Building material	Annual effective doses (mSv)				
	Radon daughters		Thoron daughters		Total
	Average	Limits	Average	Limits	Average
Brick	1.0 ± 0.8	0.12 – 30	0.18 ± 0.14	0.03 – 1.55	1.18± 0.81
Wood	0.25 ± 0.19	0.06 – 3.0	0.27 ± 0.24	0.04 – 1.26	0.73± 0.37
Adobe	0.58 ± 0.48	0.09 – 2.39	0.18 ± 0.16	0.02 – 2.04	1.36± 0.60
Wattle and daub	1.30 ± 0.61	0.19 – 13.8	0.42 ± 0.30	0.02 – 1.0	1.85± 0.92
Voussoir	0.48 ± 0.39	0.09 – 1.12	0.14 ± 0.09	0.06 – 0.31	0.93± .65
Autoclaved cellular concrete	0.22 ± 0.08	0.12 – 0.38	0.06 ± 0.04	0.04 – 0.12	0.49± 0.20

The average annual effective doses received by people living in houses of different types of building materials had values between 0.49 mSv for cellular autoclaved concrete houses and 1.85 mSv for houses built of wattle and daub in wooden framework from both, radon and thoron progeny inhalation. Table 3 also indicate that radon and thoron progeny inhaled in detached houses is the most variable source of human exposure, with annual exposures ranging over three orders of magnitude: from 0.06 mSv to 30 mSv for radon daughters and from 0.02 mSv to 2.04 mSv for thoron daughters.

The overall effective dose arising from internal exposure to inhaled radon isotopes during a year was estimated at 1.16 mSv, with 0.90 mSv due to radon daughters and 0.26 mSv to thoron daughters, as table 4 shows.

Table 4. Indoor annual exposure from ^{222}Rn and ^{220}Rn progeny inhalation

	Annual effective dose (mSv)						Annual collective effective dose (man·Sv)
	Radon daughters		Thoron daughters		Total		
	Average	Range	Average	Range	Average	Range	
Detached house	1.18	0.18-30	0.32	0.03-3.36	1.5	0.14-33.4	4680
Block of flats	0.49	0.11-1.15	0.16	0.03-0.75	0.65	0.14-1.9	1352
Population weighted average	0.90	0.11-30	0.26	0.03-3.36	1.16	0.14-33.4	6032

Comparative by annual effective doses received by urban population living in tall blocks of flats, the rural population exposure is about 2.5 times higher.

Taking into account 1.16 mSv as per capita annual effective dose from indoors for people living in eastern Romania (5.2 mil.inh.) of which 60% lives in block of flats and 40% in detached houses, an annual collective effective dose of 6032 manSv has been estimated.

Implication for public health of exposure to indoor radon and thoron

progeny could be estimated from this collective dose by applying the nominal fatality and detriment coefficient of 7.3 10^{-2} Sv^{-1} adopted by ICRP in its Publication 65 for risk assessment (5). Consequently, 440 life-time radio-induced lung cancers each year might be attributed to inhalation of radon and thoron short-lived decay products indoors.

CONCLUSIONS

- The values of indoor Equilibrium Equivalent Concentrations of radon and thoron presented a log-normal distribution.
- The average values of EEC of radon were 22.2 Bq m^{-3} in detached houses and 9.0 Bq m^{-3} in block of flats with individual values ranging from 1.6 Bq m^{-3} to 564 Bq m^{-3}.
- The average values of EEC of thoron were 1.2 Bq m^{-3} in detached houses and 0.6 Bq m^{-3} in block of flats with individual values ranging from 0.1 Bq m^{-3} to 12.8 Bq m^{-3}.
- The per capita annual effective dose was 0.9 mSv from indoor inhaled radon progeny, individual values ranging between 0.11 mSv and 30 mSv.
- The per capita annual effective dose resulted from thoron progeny inhalation indoors was 0.26 mSv, individual values ranging between 0.03 mSv and 3.36 mSv.
- The highest exposure was found in rural houses built of wattle and daub clay in wooden framework.
- The annual collective effective dose of 6032 manSv could be responsible for 440 life- time radio-induced lung cancers.

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