EFFECTIVE DOSE FOR REAL POPULATION EXPOSED TO INDOOR RADON IN DWELLINGS OF THE FORMER URANIUM MINE AREA KALNA (EASTERN SERBIA)*

D. A. VUČIĆ[1], D. NIKEZIĆ[2†], J. VAUPOTIČ[3], Z. STOJANOVSKA[4], D. KRSTIĆ[5], Z. S. ŽUNIĆ[6]

[1]Institute of Occupational Health, Vojislava Ilica bb, 18000 Nis, Serbia
[2]Faculty of Science, University of Kragujevac, Radoja Domanovica 12, 34000 Kragujevac, Serbia,
[†]Corresponding author: nikezic@kg.ac.rs
[3]Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia, (janja.vaupotic@ijs.si)
[4]Faculty of Medical Sciences, Goce Delcev University, Stip, FYR of Macedonia
E-mail: stojanovskazdenka@gmail.com
[5]Institute of Nuclear Sciences "Vinca", P.O Box 522, 11000, University of Belgrade, Serbia
E-mail: zzunic@verat.net

Received November 15, 2012

This paper deals with calculated effective doses that members of real population received from radon gas and its short lived progeny during air inhalation in their dwellings at field site Kalna in Eastern Serbia. There are two crucial parameters in effective dose calculation: *Dose Conversion Factor* (DCF) for particular subjects (including real gender, age and physical activity level) and indoor concentration of radon and its short lived progeny in field area. According to the results of indoor radon measurements in the area of former uranium mine, Kalna, the effective dose for this real population was estimated by using the dosimetric lung model, developed by authors according ICRP Publication 66. Authentic software was developed for determination of effective dose per unit inhaled activity of radon progeny, DCF expressed in unit [mSv/WLM]. The results, obtained according to ICRP 66 dosimeter lung model, were compared with results calculated according to ICRP Publication 65. The dosimetric results were, also, compared and discussed with epidemiological approach data, according to UNSCEAR.

Key words: dosimetry, lung model, radon, effective dose, real population.

1. INTRODUCTION

In this work, the effective dose due to radon received by the population of the local community Kalna, in South East Serbia, was determined. The surrounding area is interesting from the geological point of view. The whole area is rich with

* Paper presented at the First East European Radon Symposium – FERAS 2012, September 2–5, 2012, Cluj-Napoca, Romania.

uranium ore, which was actively exploited during the 1960s. Measurement of indoor radon concentration is a starting point for the determination of effective dose received by the local population. To determine the effective dose, it is necessary to know other relevant parameters which influence the *Dose Conversion Coefficient* (DCF). The DCF is defined as the effective dose per unit exposure to radon progeny, and is traditionally given in mSv/WLM. It is possible to find two values for DCF: the epidemiological DCF which is centred between 4 and 6 mSv/WLM, and dosimetric DCF about 15 mSv/WLM. It has been shown previously that DCF strongly depends on various parameters. Based on ICRP 66, the authors of this work developed their own computer software for calculating the DCF. The software consists of 4 independent Fortran90 computer programs, which are performed subsequently, and the final result is DCF for given set of input parameters, which includes gender, age, level of physical activity, as well as aerosol characteristics. Knowing the radon concentration and DCF, it is possible to determine the effective dose for real people. So, we performed such calculations for members of 78 families in the Kalna region. In addition, effective doses were calculated according to ICRP 65 [1].

2. METHOD

2.1. (I) DETERMINATION OF RADON CONCENTRATION

Kalna is a village in South Eastern Serbia at the southern part of Balkan Mountain. The area is reach with uranium ore. Prospection was performed after 2nd World War, and active exploitation was in period 1948 – 1966 when the mine is closed. After the mine was closed, population started to drop, and nowadays, majority of people in this area are above age of 60, with neglecting percent of young and children. There are two main types of houses: old houses are mainly made from soil/clay and wood (so called “cakmara”) and newer ones, usually constructed by brick. Radon measurements were performed with passive, SSI/NRPB CR-39 solid state nuclear track detectors. Detectors were applied four times, during one year, so that results were obtained for each season. Finally, each location was represented with one result which is annual average. Detectors were applied in Kalna and other surrounding villages in totally 78 houses [2-6]. In each house at least two detectors were used, in daily room (or kitchen) and sleeping room. Results obtained from two detectors were not average. It was estimated the fraction of time which is spent in some particular room in respect to the total indoor time. Average value for the whole set houses was 187 Bq/m^3, with the range between 29 Bq/m^3 and 666 Bq/m^3. Seasonal oscillations are obvious: the smallest values were found during the summer season, and the largest in winter season due to poor ventilation and heating style. According to the results presented here there is not any correlation with construction style, neither within age of objects. This refers to the conclusion that construction materials do not contribute significantly to the indoor radon, and that the soil beneath the object is the main source.

2.2. (II) DETERMINATION OF EFFECTIVE DOSE ACCORDING TO ICRP 66

PROGRAMS DESCRIPTION: written successive executing Fortran 90 programmes are such as follows: **The first** programme called **DOZAV_AUT.F90** calculates absorbed fraction, AF, of alpha particles energy in sensitive cells of human respiratory tract. According to ICRP 66, AF is defined as an average fraction of alpha particle energy absorbed in the layer containing the sensitive cells. Alpha particles loose their energy in the layer of mucus and in deeper layers of the airway wall. One part of energy is deposited in sensitive cells. According to ICPR 66 [7] and NRC [8] two kinds of cells, basal and secretory cells, have been considered as sensitive. The structure of airway wall, thickness of different layer and relevant dimensions have been accepted as it was described in ICRP 66 report. To calculate AF a semi empirical approach [9] was used. **The second** programme **ICRP66_DEPOS.F90** calculates deposition of aerosol in different deposition filters of respiratory tract, from oral- and naso-cavities to the terminal alveolus. It follows algebraic deposition model through five regions of respiratory tract, given in ICRP 66, and gives deposited fraction as a function of aerosol equivalent diameter. **The third** Program **LOGAR_SAB_3M.F90** performs summation of deposited activity calculated by previous program according to three modal log-normal distribution (for attached progeny). Unattached fraction is treated separately. Aerosol parameters, thermodynamic diameter (AMTD), aerodynamic diameter (AMAD), dispersions of distribution, density of aerosols, aerosol shape factor, equilibrium factor between radon and its progeny have been taken according to their the best estimation (ICRP, 1994). Concerning the inhalation parameters, DCF was firstly calculated for typical standard inhalation values, (ICRP 66, 1994, Table 15 and Table B.6), which corresponds to the referent Caucasian male man, age 20–30 years, 176 cm tall, with the mass of 73 kg, who lives in temperate climate (this description fit well to the City of Niš population). These parameters are as follows: functional residual capacity FRC=3301 ml, tidal volume V_{TIDAL}=1250 ml, breathing rate=1.5 m^3/h, volumetric air flow V=833 ml, dead spaces in extratoracic ET, bronchial BB and bronchiolar bb regions are, respectively: V_D(ET)=50 ml, V_D(BB)=49 ml and V_D(bb)=47 ml. These values are corresponding to the light exercise. Later, these parameters have been varied according to the sex, age, and assumed physical activity. Random sampling of an individual was performed from the age population distribution given in Table 1. Then, based on ICRP 66 report (Table 15, page 50, and Table B.15, B.16A, B.16B, B.B17, page 194–198) lung volume and level of physical activity were sampled.

The number of simulation was 10^5, which is order of the population of the City of Niš. **The forth** programme **CLEARANCE (CISCENJE).F90** treats clearance and translocation of deposited aerosol. Separated clearance mechanisms are: radioactive decay, mucocillar transmission and transfer to blood. This program calculates equilibrium activity of all progeny in all regions of human respiratory tract. Multiplication of equilibrium activity with exposure time, with starting alpha particle energy (6 MeV for ^{218}Po and 7.69 MeV for ^{214}Po) and with absorbed fraction (AF), gives the energy absorbed in sensitive cells (secretory and basal cells). The ratio of absorbed energy and the mass of sensitive tissue is dose absorbed in these cells. Weighting procedure is the next step. The average dose D_{BB} in BB region (first 8 generation of branching) is found as $D_{BB}=(D_{BB,bas}+D_{BB,sec})/2$, where $D_{BB,bas}$ is absorbed dose in basal cells, and $D_{BB,sec}$ is absorbed dose in secretory cells in the bronchial region (BB). Absorbed dose in the tracheo-bronchial (T-B) tree of respiratory tract is: $D_{T\text{-}B}= 0.333\ D_{BB} + 0.333\ D_{bb,sec}$, where $D_{bb,sec}$ is absorbed dose in secretory cells in bronchiolar (bb) region (basal cells don't exist in this region). Weighting factors, 0.333 were applied to BB and bb region according to ICRP 66 recommendation. Thus, the effective dose was found as: $E = 20 \times 0.12 \times D_{T\text{-}B}$, with 20 as radiation weighting factor for alpha particles, and, 0.12 tissue weighting factor for lung. Then the effective dose was divided with the assumed exposure condition in WLM and DCF was obtained in [mSv/WLM]. Based on the programs described above, DCF was calculated for referent man with standard parameters of anatomy, morphology and inhalation (ICRP 66 [7], Table 15 and Table B.6). The value of DCF obtained in this trial was 16 mSv/WLM and it is close to 15 mSv/WLM obtained by ICRP 66 and Birchall and James [7, 10].

3. RESULTS

Radon concentration found in Kalna dwellings are given in Table 2. First column gives number of a house, second column is a number of a room in a given house. For example, in house No1 radon was measured only in one room, while in house No7, detectors were placed in two rooms. L means living room, B is for bedroom, L/K is living and kitchen adjoined. Results are given for four seasons in the third column, and arithmetical mean in fourth. Room ratio (in respect to the total indoor occupancy) is given in the last column. Radon concentrations are in the range between 29 and 666 Bq/m^3 with arithmetical mean AM=187 Bq/m^3, and standard deviation of ASD=127 Bq/m^3.

Effective dose calculation was conducted for each room where the radon concentration was measured. DCF was calculated with abovementioned programs, for specific persons who live in that room. Relevant input parameters that were available are gender, age of subject and level of physical activity. ICRP 66 recommended parameters of inhalation based on age and physical activity. Population which live in Kalna is mostly between 15 years to 65 years, equally male to female. It has been assumed light exercise in daily rooms and kitchens, while in bedroom it was sitting and sleeping. Parameters for mentioned population groups and physical activities were taken from ICRP 66 recommendation. Other parameters which are not available as aerosol distribution, equilibrium factor, thickness of tissue level in respiratory tract were taken at their best estimation. DCFs were calculated for each person who spent some time in the rooms where radon concentration was measured. Effective dose, *E*, was calculated with formula:

$$E = \frac{C_{Rn}\,(\mathrm{Bq/m^3})}{3700} \cdot F \cdot \frac{t}{170} \cdot (\mathrm{room\quad ratio}) \cdot \mathrm{DCF} \tag{1}$$

where, C_{Rn} is radon concentration given in Bq/m^3, *F* is equilibrium factor, that was taken as 0.4 (because there were no better information), t=8760 h/year is number of hours per year, 170 h/M is number of hours per M (mount), DCF is dose conversion factor obtained by our programs for specific person. Based on calculated DCF, the annual effective dose ***E*** for male and female in 78 houses was estimated. The annual range of effective dose between 0.47 mSv up to 10.81 mSv. Arithmetical average is 2.73 mSv/a. Table 2 presents value of respiratory ventilation for various levels of physical activities.

3.1. (III) DETERMINATION OF EFFECTIVE DOSE ACCORDING TO ICRP 65

The effective dose, *E* was calculated according to the Equation 1, but DCF was taken to be equal in all cases and amounted as DCF=4 mSv/WLM. Indoor occupancy was taken 0.8 and equilibrium factor 0.4 (the same as above). Obtained results are in the range between 0.5 up to 11.9 mSv/a, with average value 3.4 mSv/a. Results of effective dose calculation according to ICRP 65 and ICRP 66 and comparison between them are given in Table 3.

Table 1

Dose conversion coefficient (DCF) for adult, according to the different levels of physical activity: V_T Tidal volume, amount of inhaled air in ml per one inhalation; f_R respiratory frequency, number of inhalation per one minute; V_U_S inhalation rate; FRC functional residual capacity and DCF dose conversion coefficient.

Sex	Physical activity	V_T [ml]	f_R [min]$^{-1}$	V_U_S [ml/s]	FRC [ml]	DCF [mSv/WLM]
Male	Light exercise	1250	20	833	3301	15.85
Female	Light exercise	992	21	694	2681	14.18
Male	Sitting-sleeping	750	12	300	3301	10.82
Female	Sitting-sleeping	464	14	217	2681	6.56

Table 2

Radon concentrations (C_{Rn}) in Kalna houses: Code is number of house; Room is number of room in a given house; L living room; B bedroom; L/K living room and kitchen adjoined

Code	Rm No		C_{Rn} [Bq/m^3] I (Spring)	II(Aut)	III(W)	IV(Sum)	C_{Rn} [Bq/m^3]	Room ratio
1	1	L	63	55	197	75	98	1.0
2	1	B	44	99	106	32	70	1.0
3	1	L	120	44	42	42	62	1.0
4	1	B	93	394	127	53	167	1.0
5	1	L	131	230	226	135	181	1.0
6	1	L	78	206	258	93	159	1.0
7	1	L	181	342	332	185	260	0.5
7	2	B	42	78	122	43	71	0.5
8	1	L	32	53	87	26	50	1.0
9	1	L	48	114	198	54	104	1.0
10	1	L	248	234	436	174	273	0.5
10	2	b	99	112	205	95	128	0.5
11	1	L	267	50	454	147	230	1.0
12	1	L	114	95	64		84	1.0
13	1	L	98	96	138		118	1.0
14	1	L	168	251	219		214	1.0
15	1	L	148	90	140	30	102	1.0
16	1	L	98	120	212	69	125	1.0
17	1	L	160	212	216	96	171	0.5
17	2	B	147	75	92	43	89	0.5
18	1	L	77	80	147	40	86	0.5
18	2	B	44	76	31	21	43	0.5
19	1	L	1736	153	344	146	595	1.0
20	1	L	2218	115	176	61	643	1.0
21	1	L	55	100	71		75	0.5
21	2	B	59	52	104		72	0.5
22	1	L	47	79	86	75	72	0.5
22	2	B	154	1500	68	34	439	0.5
23	1	L	1050	73	167	46	334	0.5
23	2	L/K	818	103	103	36	265	0.5
24	1	L	193	202	126	51	143	1.0
25	1	L	82	112	154	41	97	1.0
26	1	L	114	127	237	59	134	1.0
27	1	L	201	185	253	123	191	0.5
27	2	B	210	173	364	138	221	0.5
28	1	L	33	93	104	49	70	1.0
29	1	L	64	69	136	34	76	1.0
30	1	L	63	71	106	38	70	1.0
31	1	L	50	94		41	70	1.0
32	1	L	88	160			136	1.0
33	1	L	111	153	173	75	128	0.5
33	2	B	99	58	216	96	117	0.5

Table 2 (Continued)

34	1	L	121	180	329	96	182	0.5
34	2	B	188	135	337	136	199	0.5
35	1	L	117	122	102	51	98	0.5
35	2	B	126	83	137	62	102	0.5
36	1	L	41	46	150	29	67	0.5
36	2	B	74	63	133	48	80	0.5
37	1	L	192	152	184	76	151	0.5
37	2	B	128	137	177	80	131	0.5
38	1	L	166	61	127	18	93	0.5
38	2	B	46	80	89	49	66	0.5
39	1	L	33		24		29	1.0
40	1	L/K	83	114	53		303	0.5
40	2	L	104	83	42		271	0.5
41	1	L	95	175	107	54	108	1.0
42		L	201	237	190	130	190	1.0
43	1	B	314	255	381	216	292	0.5
43	2	L	119	173	202	191	171	0.5
44	1	L	271	207	280	130	222	0.5
44	2	B	233	131	230	152	187	0.5
45	1	L	256	382		124	286	1.0
46	1	L	102	161	189		160	1.0
47	1	L	115	139	150	63	117	0.5
47	2	B	232	93	546	206	269	0.5
48	1	L	144	122	42		108	0.5
48	2	B	72	319		69	195	0.5
49	1	L	135	126	142	97	125	1.0
50	1	L	200	235	209	102	187	1.0
51	1	L	279	289			286	0.5
51	2	B	95	171			146	0.5
52	1	L	210	248	452	272	296	0.5
52	2	B	463	179	141	126	227	0.5
53	1	L	746	346	283	198	393	0.3
53	2	L	105	190	316	76	172	0.3
53	3	B	392	771	544	214	480	0.3
54	1	L	228	227	357	108	230	1.0
58	1	L	350	352	662	254	405	1.0
59	1	L	188	195	403	177	245	1.0
60	1	L	150	130	542	200	256	1.0
61	1	L	374	320	787	347	457	1.0
62	1	L	78	106	105	46	84	1.0
63	1	L	269	226	478	135	277	1.0
64	1	L	163	186	295	98	186	0.5
64	2	B	97	63	121	80	90	0.5
65	1	B	81	58	119	33	73	0.5
65	2	L	65	47	124	30	67	0.5

Table 2 (Continued)

66	1	L	102	42	329	47	130	1.0
67	1	L	90	152	221	81	136	1.0
68	1	L	69		122	48	77	1.0
69	1	L	148	151	291	96	172	1.0
70	1	L	249	2012	317	86	666	1.0
71	1	B	67		171	77	158	1.0
72	1	B	127	125	127	38	104	1.0
73	1	L	86	95	744	64	247	0.5
73	2	B	173	495	267	132	267	0.5
74	1	L	142	150	197	117	152	0.5
74	2	B	96	1339	140	85	415	0.5
75	1	L	120	135	181	87	131	1.0
76	1	L	183		165	63	137	1.0
77	1	L	160	219		133	256	1.0
78	1	L	101	150		56	154	0.5
78	2	B	196	544			434	0.5

4. DISCUSSION

As it might be seen from Table 2, arithmetical mean values of radon concentration are 219 Bq/m^3 in winter, 94 Bq/m^3 in spring season. Winter/spring ratio is 2.33. Arithmetical mean of radon concentration in autumn (208 Bq/m^3) is slightly larger than in spring season (197 Bq/m^3), refering to the similar indor ventilation conditions during these two seasons. The range of values is very wide; the lowest result is 18 Bq/m^3 in location 38 in summer season, while the largest is about 2218 Bq/m^3 in location 20 during the spring period.

By inspection of Tables 3 and 4, one might easily observe that effective dose calculated by ICRP 66 is much larger than those obtained by ICRP 65. The reason for so large discrepancy is much larger DCF, up to 4 times obtained by ICRP 66 dosimetric model. This is well known scientific gap between epidemiological and dosimetric approach. In ICRP 66 report itself in page 101, in paragraph No 356 was written the following:

"*In the case of exposure to radon progeny, since estimates of lung cancer risk for workers (and for members of the public) can be made reliably from epidemiologic studies relating lung cancer in miners to radon exposure, the Commission does not recommend the assessment of risk from calculations of equivalent dose to respiratory track tissues. In its report on radon exposure, an approach that relies more directly on an application of the epidemiologic data, and a risk projection model for specific exposure situation, is applied (ICRP, 1994). However, the use of the respiratory track model to calculate equivalent doses to lungs may be helpful in comparing those lung doses that result from different exposure conditions*."

Table 3

Effective doses calculated according to ICRP 65 and ICRP 66

By ICRP 65			By ICRP 66				
Room ratio	*E* [mSv/a] rooms	*E* [mSv/a] average	*E* (male)	*E* (male_total)	*E* (female)	*E* (female_total)	*E*_average
			[mSv/a]				
1.0	1.7	1.7	6.93	6.93	6.20	6.20	6.56
1.0	1.2	1.2	3.38	3.38	2.05	2.05	2.71
1.0	1.1	1.1	4.38	4.38	3.92	3.92	4.15
1.0	3.0	3.0	8.06	8.06	4.89	4.89	6.47
1.0	3.2	3.2	12.79	12.79	11.45	11.45	12.12
1.0	2.8	2.8	11.24	11.24	10.05	10.05	10.65
0.5 0.5	2.3 0.6	3.0	9.19 1.71	10.90	8.22 1.04	9.26	10.08
1.0	0.9	0.9	3.53	3.53	3.16	3.16	3.35
1.0	1.9	1.9	7.35	7.35	6.58	6.58	6.96
0.5 0.5	2.4 1.1	3.6	9.65 3.09	12.74	8.63 1.87	10.50	11.62
1.0	4.1	4.1	16.26	16.26	14.54	14.54	15.40
1.0	1.5	1.5	5.94	5.94	5.31	5.31	5.62
1.0	2.1	2.1	8.34	8.34	7.46	7.46	7.90
1.0	3.8	3.8	15.13	15.13	13.53	13.53	14.33
1.0	1.8	1.8	7.21	7.21	6.45	6.45	6.83
1.0	2.2	2.2	8.84	8.84	7.90	7.90	8.37
0.5 0.5	1.5 0.8	2.3	6.04 2.15	8.19	5.41 1.30	6.71	7.45
0.5 0.5	0.8 0.4	1.2	3.04 1.04	4.08	2.72 0.63	3.35	3.71
1.0	10.6	10.6	42.06	42.06	37.62	37.62	39.84
1.0	11.5	11.5	45.45	45.45	40.66	40.66	43.05
0.5 0.5	0.7 0.6	1.3	2.65 1.74	4.39	2.37 1.05	3.42	3.91
0.5 0.5	0.6 3.9	4.6	2.54 10.59	13.14	2.28 6.42	8.70	10.92
0.5 0.5	3.0 2.4	5.3	11.80 9.37	21.17	10.56 8.38	18.94	20.05
1.0	2.6	2.6	10.11	10.11	9.04	9.04	9.58
1.0	1.7	1.7	6.86	6.86	6.13	6.13	6.50
1.0	2.4	2.4	9.47	9.47	8.47	8.47	8.97
0.5 0.5	1.7 2.0	3.7	6.75 5.33	12.08	6.04 3.23	9.27	10.68
1.0	1.2	1.2	4.95	4.95	4.43	4.43	4.69
1.0	1.4	1.4	5.37	5.37	4.81	4.81	5.09
1.0	1.2	1.2	4.95	4.95	4.43	4.43	4.69
1.0	1.2	1.2	4.95	4.95	4.43	4.43	4.69

Table 3 (Continued)

1.0	2.4	2.4	9.61	9.61	8.60	8.60	9.11
0.5 0.5	1.1 1.0	2.2	4.52 2.82	7.35	4.05 1.71	5.76	6.55
0.5 0.5	1.6 1.8	3.4	6.43 4.80	11.23	5.75 2.91	8.67	9.95
0.5 0.5	0.9 0.9	1.8	3.46 2.46	5.92	3.10 1.49	4.59	5.26
0.5 0.5	0.6 0.7	1.3	2.37 1.93	4.30	2.12 1.17	3.29	3.79
0.5 0.5	1.3 1.2	2.5	5.34 3.16	8.50	4.77 1.92	6.69	7.59
0.5 0.5	0.8 0.6	1.4	3.29 1.59	4.88	2.94 0.97	3.91	4.39
1.0	0.5	0.5	2.05	2.05	1.83	1.83	1.94
0.5 0.5	2.7 2.4	5.1	10.71 9.58	20.29	9.58 8.57	18.15	19.22
1.0	1.9	1.9	7.63	7.63	6.83	6.83	7.23
1.0	3.4	3.4	13.43	13.43	12.01	12.01	12.72
0.5 0.5	2.6 1.5	4.1	7.04 6.04	13.09	4.27 5.41	5.41	9.25
0.5 0.5	2.0 1.7	3.6	7.85 4.51	12.36	7.02 2.74	9.75	11.06
1.0	5.1	5.1	20.22	20.22	18.09	18.09	19.15
1.0	2.9	2.9	11.31	11.31	10.12	10.12	10.71
0.5 0.5	1.0 2.4	3.4	4.13 6.49	10.62	3.70 3.93	7.63	9.13
0.5 0.5	1.0 1.7	2.7	3.82 4.70	8.52	3.41 2.85	6.27	7.39
1.0	2.2	2.2	8.84	8.84	7.90	7.90	8.37
1.0	3.3	3.3	13.22	13.22	11.82	11.82	12.52
0.5 0.5	2.6 1.3	3.9	10.11 3.52	13.63	9.04 2.14	11.18	12.40
0.5 0.5	2.6 2.0	4.7	10.46 5.48	15.94	9.36 3.32	12.68	14.31
0.3 0.3 0.3	2.3 1.0 2.8	6.2	9.17 4.01 7.64	20.82	8.20 3.59 4.63	16.42	18.62
1.0	4.1	4.1	16.26	16.26	14.54	14.54	15.40
1.0	7.2	7.2	28.63	28.63	25.61	25.61	27.12
1.0	4.4	4.4	17.32	17.32	15.49	15.49	16.40
1.0	4.6	4.6	18.09	18.09	16.19	16.19	17.14
1.0	8.2	8.2	32.30	32.30	28.90	28.90	30.60
1.0	1.5	1.5	5.94	5.94	5.31	5.31	5.62
1.0	4.9	4.9	19.58	19.58	17.52	17.52	18.55
0.5 0.5	1.7 0.8	2.5	6.57 2.17	8.74	5.88 1.32	7.20	7.97

Table 3 (Continued)

0.5 0.5	0.7 0.6	1.2	1.76 2.37	4.13	1.07 2.12	3.19	3.66
1.0	2.3	2.3	9.19	9.19	8.22	8.22	8.70
1.0	2.4	2.4	9.61	9.61	8.60	8.60	9.11
1.0	1.4	1.4	5.44	5.44	4.87	4.87	5.16
1.0	3.1	3.1	12.16	12.16	10.88	10.88	11.52
1.0	11.9	11.9	47.07	47.07	42.11	42.11	44.59
1.0	2.8	2.8	7.62	7.62	4.62	4.62	6.12
1.0	1.9	1.9	5.02	5.02	3.04	3.04	4.03
0.5 0.5	2.2 2.4	4.6	8.73 6.44	15.17	7.81 3.91	11.71	13.44
0.5 0.5	1.4 3.7	5.1	5.37 10.01	15.38	4.81 6.07	10.88	13.13
1.0	2.3	6.0	9.26	9.26	8.28	8.28	8.77
1.0	2.4	4.8	9.68	9.68	8.66	8.66	9.17
1.0	4.6	4.6	18.09	18.09	16.19	16.19	17.14
0.5 0.5	1.4 3.9	5.2	5.44 10.47	15.91	4.87 6.35	11.22	13.57

Table 4

Summary of radon concentration (C_{Rn}) in Kalna area, and effective dose (E) determined according to ICRP 65 and ICRP 66

	C_{Rn} [Bq/m^3]	*E* (ICRP 65) [mSv/a]	*E* (ICRP 66) [mSv/a]
Minimum	29	0.5	1.94
Maximum	666	11.9	44.59
Arithmetic mean	187	3.4	11.26
Arithmetic SD	127	2.3	8.42

Program developed here could be used only for comparison of dose received by various subject in different exposure situation.

Acknowledgements. The Serbian Ministry of Education and Science through Projects 41028 and P 171021 supported this work.

REFERENCES

1. ICRP (International Commission on Radiological Protection), *Protection against Radon-222 at Home and Work*, ICRP Publication 65, Annals of the ICRP 23 (2), Oxford: Pergamon Press, 1993.
2. Z. S. Zunic, J. P. Mc Laughlin, C. Walsh, R. Benderac (1999**),** The use of SSNTDS in the retrospective assessment of radon exposure in high radon rural communities in Yugoslavia, *Radiation Measurements*, *Volume 31, Issues 1-6*, *June 1999*, *Pages 343-346+*
3. J. Paridaens, H.Vanmarcke, K.Jacobs, Z.Zunic (2000): Retrospective radon assessment by means of Po-210 activity measurements, *Applied Radiation and Isotopes 53, 361-364.*

4. Johan Paridaens, Hans Vanmarcke, Zora S. Zunic, James P Mc Laughlin(2001), Field Experience with Volume Traps For Assessing Retrospective Radon Exposures, *The Science of the Total Environment (2001), 272, 295-302.*
5. Z. S. Žunić, J. P. McLaughlin, C. Walsh, A. Birovljev, S. E. Simopoulos, B. Jakupi, V. Gordanic, M. Demajo, F. Trotti, R. Falk, H. Vanmarcke, J. Paridaens, K. Fujimoto, *Integrated natural radiation exposure studies in stable Yugoslav rural communities*, Science of the Total Environment, **272**, 253–259, 2001.
6. J. Paridaens, Z.S.Zunic, F. Trotti, J.P.Mc Laughlin, H.Vanmarcke (2002), Correlation between Rn exposure and Po-210 activity in Yugoslavian rural communities, *International Congress Series 1225, High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects eds: Werner Burkart, Mehdi Sohrabi and Anton Bayer, (2002) Elsevier, 87–93.*
7. ICRP (International Commission on Radiological Protection), *Human Respiratory Tract Model for Radiological Protection*, ICRP Publication 66, Annals of the ICRP 24 (1/4), Oxford: Pergamon Press, 1994.
8. NRC (National Research Council), *Comparative Dosimetry of Radon in Mines and Homes*. Panel on dosimetric assumption affecting the application of radon risk estimates, Washington, DC, National Academic Press, 1991.
9 D. Nikezić, K. N. Yu, D. Vucic, *Absorbed fraction and dose conversion coefficients of alpha particles for radon dosimetry*, Physics in Medicine and Biology, **46**(7), 1963–1973, 2001.
10. A. Birchall, A. C. James, *Uncertainty analysis of the effective dose per unit exposure from radon progeny and implication for ICRP risk-weighting factors*, Radiation Protection Dosimetry, **53**, 133–140, 1994.