IMPLEMENTING REMEDIAL TECHNIQUES AGAINST RADON IN DWELLINGS FROM THE URANIUM AREA OF BAITA-STEI (ROMANIA)

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*Radon is the second leading cause after smoking related to lung cancer occurrence. In the the framework of IRART Project 2010 (European funds) have been selected 21 homes for the remediation from 2 complete integrated measurements campaigns (in different seasons), from a batch of 303 homes (58% of all houses from Câmpani, Băiţa, Fânaţe and Nucet - Băiţa-Ştei area). Based on these integrated measurements, were identiffied in a first stage 40 locations with radon values between 600 and 6000 Bqm^{-3}. From these homes those that have fulfilled the main selection criterion (values of indoor radon concentrations higher than 800 Bqm^{-3}) as a result of discussions with residents have been selected 20 houses and also a pilot house for effective remediation. The remedial measures and obtained results are presented in this paper showing a mean efficiency of 80.9% (*65.2 - 95.1*%). In average the radon concentration was reduced from 992 Bqm^{-3} to an average of 160 Bqm^{-3}.*

Keywords: indoor radon, track detectors, remediation, depressurisation, eolian ventilation.

Radon (^{222}Rn) is present in both indoor and outdoor air because the parent radionuclide of it (^{226}Ra) from the ^{238}U decay series occurs in trace amounts throughout the Earth's crust [1]. After forming, ^{222}Rn, (half-life of about 3.82 days), because it is chemically inert, can migrate through soil or basement material, to reach the indoor atmosphere. Radon applications in geological science are very interesting subject as in fractures identification [2], in earthquake prediction [3] also in annual dose estimation for luminescence dating [4].

The radon presents also a wide interesting subject in radioprotection because it contributes over than 50 % to the natural radiation dose received by the people and it is considered as responsible between 3 and 14 % of lung cancer death, being proved the second main cause for this illness after smoking [5]. In radon risk areas (radon prone areas) this contribution can be much higher to 90-95 %, increasing the natural dose exposure of 5-10 times [6].

The area of Băiţa-Ştei is located in the Bihor Mountains (NW part of Romania) in the neighborhood of "Avram Iancu" and "Băiţa" uranium mines. This includes the town Ştei and few villages (Băiţa-Plai, Băiţa-Sat, Nucet, Fânaţe, Cîmpani etc.), with a total of approximately 15.000 inhabitants (see fig.1).

The mine deposit of Băiţa-Ştei was the largest surface uranium deposit in the world (open pit mine) and represented the largest uranium reserve in Romania [7]. The average uranium content was 1-5 % in the radiometric sorted material but in some samples the uranium content reached 30-40 %. Two ways of uranium dissemination were used over time, and during the exploitation period [8]. The first was the natural way represented by Crişul-Băiţa River that crosses the Băiţa surface deposit. Sediment transport by water course during geological time increased the uranium and radium content in the river meadow. The building material from Crişul-Băiţa River bed (stone, gravel, sand) was used as construction material for houses in this area. The second way was related to people living in this valley and in the surroundings, who used uranium waste from this mine as building material. Preliminary indoor radon measurements suggested that this zone is a radon prone area [9,10]. A focused radon survey of the area (in the frame of the IRART project) facilitated the selection of 20 houses with the highest indoor radon concentration and these houses were proposed for remediation. To find the radon sources in these houses, a systematic investigation on radon was performed. The remedial measures applied for these 20 selected houses were firstly tested on a chosen pilot house. During the period 2010-2013 with the financial support from IRART Project [see Acknowledgement] all these 20 houses were remediate and this work presents the results obtained.

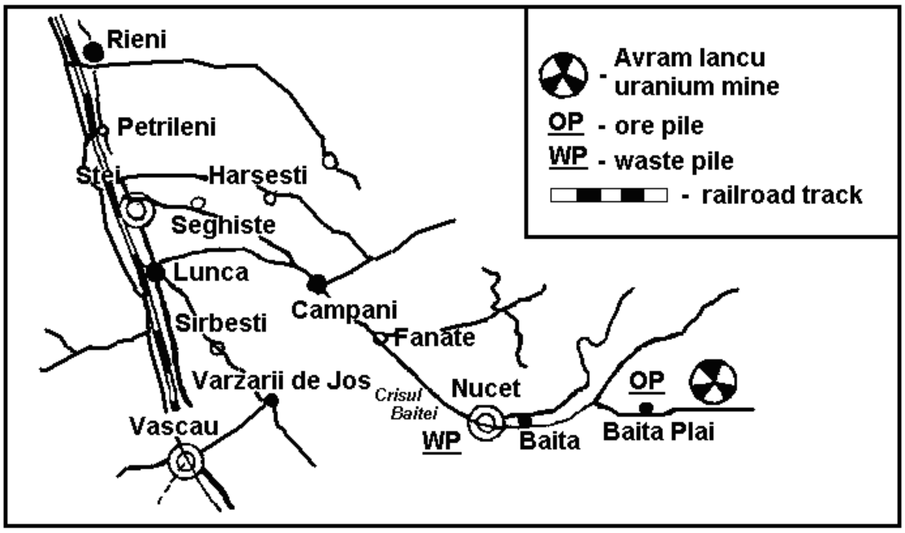

Fig. 1. *Băiţa-Ştei area with the locations included in this study*

Methods and results

To select the houses for remediation were made in the area Băiţa-Nucet-Fânaţe-Câmpani (see fig.1) two campaigns for instaling track detectors in 303 houses were performed. In each house were instaled 3-4 detectors were installed, which gives a total number of 303x2x3.5 = 2121 track detectors used. The first campaign was in winter period fom December of 2010 to February 2011 and the second one, during the spring time from April to June 2011). In a first stage, 40 locations with radon concentration values between 600 and 3000 Bqm^{-3} were selected. Placement, etching and reading of these detectors were made in our laboratory (Environmental Radioactivity and Nuclear Dating Center) and in respect with the international standards regarding indoor radon measurement [11]. In 2011 May our research group participated at an important intercomparison exercise at Saelices el Chico (Salamanca, Spain) and the results proved that our measurements were very closed to the real values used in this intercomparison [12].

For these long term measurements, CR-39 track etched detectors were used. After exposure for a period of two-three months, the radon concentration was determined using Radosys system [9]. First time the CR-39 detectors were etched for 4.5 hours using sodium hidroxyde of 6.25 molarity at 90^oC and read by automatic microscope [13] Radosys producer declares that the reproducibility of the data falls in the range of ± 8% and this fact was confirmed at International Intercomparisons [14].

From these homes that have fulfilled the main selection criterion (values of indoor radon concentrations higher than 800 Bqm^{-3}) and after preliminary discussions with the residents have been selected 20 houses and also a pilot house for effective remediation. Following this selection the next steep was to find the radon entry source for each house. For this, continuous measurements were made using active radon monitors, namely Alpha-Guard, Radim 3A, Radon-Scout, RAD 7 and Ramon 2.2.

The main remedial techniques applied for the 20 houses, firstly were tested on the pilot house. These techniques were:

- Soil depressurisation and pressurisation near the house using four collectors inside the soil, very closed of the house foundation. Each collector is connected at a vertical pipe (Φ = 120 mmm) which cross the loft and the roof of the house having the end at 2-3 m above the roof. Usualy a fan is intercalated on this pipe inside the lofts;
- Pressurisation and depressurisation of sub-slab, where perforated pipes (Φ = 55 mm) were mounted under room floor and conected to the fan by main pipe;
- Applying an eolian extraction mounted at the end of the pipe which is joints with the collector or to the sub-slab system;
- Testing together simultaneously the fan and eolian extraction;
- Using anti-radon membranes;
- Using in combination anti-radon membranes and depressurization system coupled to eolian and/or fan extraction;

During the scientific audit of the project mentioned above (May 2013) the European expert ascertains a good function of the depressurization system, as it can be seen in fig.2. The depressurization system efficiency (was verified in the three rooms (living, bedroom 1 and bedroom 2) under accumulation condition in the first part and after starting the fan extraction. The radon concentration begins to decrease immediately after the depressurization system started to work. These results were presented by auditor (Prof. Andre Poffijn) at the Boullion workshop [15] and he suggested try the extraction with centrifugal fan, instead axial fan in order to increase depressurisation and remedial effiency. Preliminary measurements about this sugestion showed a small difference between the two kinds of fans (see fig.3)

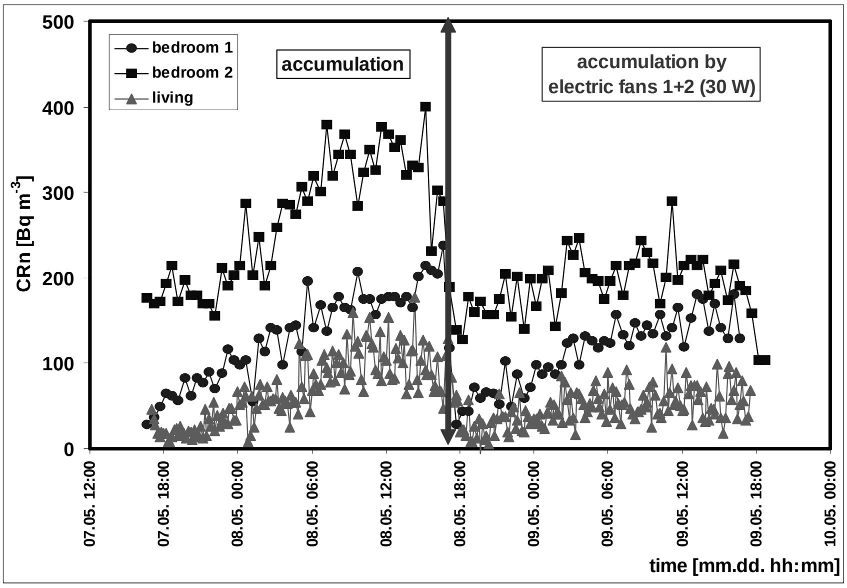

Fig.2. *Verification of depressurization system working in the pilot house*

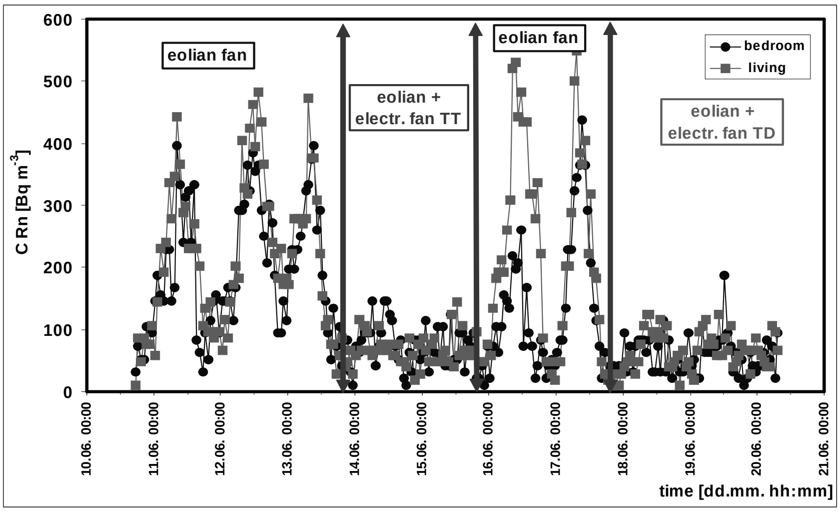

Fig.3. *Axial and centrifugal depressurization in a remediate house*

Testing of the remedial technique by depressurisation using only eolian extraction shows a moderate efficiency (47.4 %) as it can be seen in Table 1. Similar value was obtained by using anti-radon membrane only. Usualy the depressurisation was obtain by simultan extraction with eolian and electric fan, as is shown in fig.4a,b.

(a) (b)

Fig. 4. *Eolian extraction a) fan mounted in the loft and b) fan on outdoor wall.*

In fig.5 and fig.6 it can be seen some aspects during remedial actions, respectively were can be see the principal components of remedial implementation: collector, sub-slab extraction sytem and anti-radon membrane instalation.

(a) (b) (c)

Fig. 5. *Soil radon collector near foundation (a); Pipe extraction connected to soil collector and to sub-slab extraction (b); Sub-slab extraction (c).*

Fig. 6. *Membrane installing above sub-slab depressurisation system*

Table 1. Testing of eolian depressurisation efficiency (Eff.) *(%)*

Village No.	Baita 6	Băiţa 75A	Băiţa 75 B	Băiţa 76	Băiţa 119	Băiţa 127	Băiţa 138	Băiţa 204	Băiţa 206
room.1	74	44	80	2	18	38	40	-	92
room. 2	78	-	-	60	22	-	-	3	72

Village No.	Baita 213	Baita 215	Baita 228	Campani 57	Campani 71	Campani 103	Fanate 23	Fanate 118
room.1	38	7	85	78	18	53	45	74
room.2		-	73	-	22	-	-	-

Average remedial index 47.4 %

After remediation, the efficiency of intervention (Eff.) were controlled both by integrated (2 months) and continous indoor measurements, and this index is:

$$Eff = (Ci - Cf)/ Ci \tag{1}$$

where, *Ci* and *Cf* are the radon annual average concentration before and after remediation. These final results for all remediated houses (21) are presented in Table 2.

Discussions

Table 2 presents the best room results obtained in 21 houses (column 6) and the average efficiency in each house is present in column 7. In Table 3 are present the results obtained in the frame of European RADPAR Project [16] for following countries: Austria, Belgium Czekh Republik, Finland, France, Norway, Suisse and United Kindoms. As it can be seen from this table the best method for remediation is sub-slab depressurisation with the efficiency between 65 and 95 %. Our results for average houses efficiency shown in Table 2 (coulumn 7) is 81.4 % and ranged in the interval 65.4-95.1 % (column 8). If we consider the best result obtained in each house our result is still better, by 85.4 % (73.7 - 95.1 %) as can see in column 6.

The columns 3 and 4 from the Table 2 are the annual mean radon concentration in these houses (*Ca*) measured by integrated CR-39 track detectors in two seasons (winter and spring) and averaged for annual value using relation [17]:

$$C_a = C_m[(n_{Sp,A}/n + r(n_{S,W}/n)] \quad (2)$$

where, C_m is measured concentration and n_{Sp}, n_A, n_S, n_W are the month number of detector exposure in each season (Spring, Autumn, Summer, Winter) and *r* is a factor correcting exposure in Winter (r=0.67) and in Summer (r=1,35). The measurements of radon concentration after remediation were made both by integrated or / and continuous measurements during the 2013 Spring and then calculated as annual values using equation (2). Also, it must be noticed that in some cases, when using 30 W electric fan the obtained values were high (over 250 Bqm^{-3}). In these cases the fan was replaced with a fan of 60W. This is the case of positions 7, 9 and 14 from Table 2.

Table 2. Final results of efficiency (Eff.) for the radon remediated rooms in 21 houses from Băiţa-Ştei area

	House adress	Room	Annual CRn (Bq/m3)		Eff. (%)	Average Eff. (%) all rooms	Variation domain Eff. (%)
			Before remediation	After remediation			
1.	Baita 6	bedroom	1354	159	88.3	79.0	71.1 - 88.3
2.	Baita 75 A	bedroom	982	143	85.4	85.3	85.3 - 85.4
3.	Baita 75 B	Living	872	107	87.7	87.7	87.7
4.	Băiţa 76	Living	1062	100	90.6	89.5	88.3 - 90.6
5.	Baita 119	Bedroom	761	137	82.0	84.5	80.5 - 82
6.	Băiţa 127	Bedroom	948	92	90.3	90.3	90.3
7.	Baita 138	Bedroom	534	113	78.8	78.8	65.6
8.	Băiţa 204	Living	771	152	80.4	78.3	75.9 - 80.4
9.	Baita 206	Bedroom	1557	91	94.2	93	83.5-94.2
10.	Baita 213	Bedroom	1205	112	90.7	79.1	67.5-90.7
11.	Baita 215	Bedroom	1010	117	88.4	81.9	75.5-88.4
12.	Baita 228	Bedroom	1059	155	85.3	86.4	79.1 - 85.3
13.	Campani 57	Bedroom	530	91	82.8	82.8	82.8
14.	Campani 71	Bedroom	548	86	84.3	77.0	72.6 - 84.3
15.	Câmpani 103	Living	560	122	78.2	78.2	78.2

16.	**Fânaţe 23**	**Kitchen***	**3389**	**867**	**74.4**	**70.6**	**66.7 - 74.4**
17.	**Fânaţe 59**	**Bedroom***	**1177**	**214**	**81.8**	**65.2**	**65.4 - 81.8**
18.	**Fanate 118**	**Bedroom**	**1127**	**77**	**93.2**	**90.8**	**88.4-93.2**
19.	**Fanate 189**	**Bedroom**	**834**	**219**	**73.7**	**72**	**70.3-73.7**
20.	**Nucet 9**	**Bedroom**	**1958**	**96**	**95.1**	**95.1**	**95.1**
21.	**Pilot house**	**Bedroom**	**1395**	**174**	**87.5**	**76.9**	**68.7-87.5**
				AVERAGE	**85.4**	**81.4**	**65.4-95.1**
				Min	**73.7**	**65.2**	
				Max	**95.1**	**95.1**	

*** measured by continuos measurement**

Tabel 3. Remedial efficiency obtained in RADPAR Project using different method [16].

	Reduction factor (%), Typ. range								
Method	**Summary**	AT	BE	CZ	FI	FR	NO	CH	UK
Sub-slab depressurization	**60-95**	80	90	85-95	65-95	89	50-95	90	89
Improving natural ventilation in living spaces	**10-50**			< 30	15-55	49	10-50		33
Improving mechanical ventilation in living spaces	**10-60**				5-55	61	10-20		
Replacing the existing natural room air ventilation by a mech. exhaust ventilation	**10-40**				15-45		10-20		
Installation of a new mech. supply and exhaust ventilation with heat recovery system	**30-60**	60		30-60	30-65		10-80		
Improving ventilation in cellar	**20-60**	50		25-50	20-55	47	10-50	75	
Decreasing under-pressure in the house	**20-70**	50					10-50	25	60
Sealing entry routes	**10-60**	10		10-40	10-55	55	10-60	25	41
Improving crawl space ventilation	**40-60**	50			40-65	47	10-80	75	47

Conclusions

A number of 20 houses and a pilot house were selected for radon remediation in Băiţa-Ştei prone area following two radon measurement campaigns using integrated CR-39 track detectors. In the pilot house some remedial techniques for radon mitigation were tested (membrane, pressurisation, depressurisation, colector and sub-slab ventillation, cave ventillation, etc). The best results were obtained by using sub-slab depressurisation.

The new method using „eolian ventilation" to reduce the costs have only a limited acceptance, respectively the radon is in average reduced only by two times (Eff. ~ 50 %). The average result of efficiency equal to 81,4 % for all houses is in the range of the best results obtained in the International RADPAR project where values of 60-95 % were reported.

Acknowledgement. This work was supported by the Sectoral Operational Programme "Increase of Economic Competitiveness" co-financed by The European Regional Development Fund under the project with title

"IMPLEMENTATION OF RADON REMEDIATION TECHNIQUES IN DWELLINGS OF BĂIŢA URANIUM MINE AREA / IRART" POSCCE 586-12487, and by a National Program "Radon Map (residential, geogenic, water) for Center, West and North-West regions from Romania / RAMARO", PN-II-PT-PCCA-2011-3.2-1064.

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