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

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Radon is the second leading cause after smoking related to lung cancer occurrence. In 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 Câmpeni, Bâiţa, Fânaţe and Nucet - Bâiţa-Ştei area). Based on these integrated measurements, were identified in a first stage 40 locations with radon values between 600 and 6000 Bq m\textsuperscript{-3}. From these homes those that have fulfilled the main selection criterion (values of indoor radon concentrations higher than 800 Bq m\textsuperscript{-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 Bq m\textsuperscript{-3} to an average of 160 Bq m\textsuperscript{-3}.
Radon ($^{222}\text{Rn}$) is present in both indoor and outdoor air because the parent radionuclide of it ($^{226}\text{Ra}$) from the $^{238}\text{U}$ decay series occurs in trace amounts throughout the Earth’s crust [1]. After forming, $^{222}\text{Rn}$, (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.
Methods and results

To select the houses for remediation were made in the area Băița-Nucet-Fânațe-Câmpani (see fig.1) two campaigns for installing track detectors in 303 houses were performed. In each house were installed 3-4 detectors which gives a total number of 303x2x3.5 = 2121 track detectors used. The first campaign was in winter period from 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 close 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 hydroxide of 6.25 molarity at 90\(^{\circ}\)C and read by automatic microscope [13] Radosys producer declares that the reproducibility of the data falls in the range of \(\pm\) 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 step 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 ($\Phi = 120$ mmm) which cross the loft and the roof of the house having the end at 2-3 m above the roof. Usually a fan is intercalated on this pipe inside the lofts;

- Pressurisation and depressurisation of sub-slab, where perforated pipes ($\Phi = 55$ mm) were mounted under room floor and connected 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 efficieny. Preliminary measurements about this suggestion showed a small difference between the two kinds of fans (see fig.3)

![Verification of depressurization system working in the pilot house](image-url)
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. Usually 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.
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.) (%)

<table>
<thead>
<tr>
<th>Village No.</th>
<th>Baita 6</th>
<th>Baita 75A</th>
<th>Baita 75 B</th>
<th>Baita 76</th>
<th>Baita 119</th>
<th>Baita 127</th>
<th>Baita 138</th>
<th>Baita 204</th>
<th>Baita 206</th>
</tr>
</thead>
<tbody>
<tr>
<td>room. 1</td>
<td>74</td>
<td>44</td>
<td>80</td>
<td>2</td>
<td>18</td>
<td>38</td>
<td>40</td>
<td>-</td>
<td>92</td>
</tr>
<tr>
<td>room. 2</td>
<td>78</td>
<td>-</td>
<td>-</td>
<td>60</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>72</td>
</tr>
</tbody>
</table>

Average remedial index 47.4 %

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

$$Eff = \frac{(C_i - C_f)}{C_i}$$

where, $C_i$ and $C_f$ 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 Czech Republic, Finland, France, Norway, Suisse and United Kingdoms. 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 (column 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]:

\[ C_a = C_m \left[ \left( \frac{n_{Sp,A}}{n} + r \frac{n_{S,W}}{n} \right) \right] \]  

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>
<thead>
<tr>
<th>House adress</th>
<th>Room</th>
<th>Annual CRn (Bq/m(^3))</th>
<th>Eff. (%)</th>
<th>Average Eff. (%)</th>
<th>Variation domain Eff. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before remediation</td>
<td>After remediation</td>
<td>all rooms</td>
<td></td>
</tr>
<tr>
<td>1. Baita 6</td>
<td>bedroom</td>
<td>1554</td>
<td>159</td>
<td>88.3</td>
<td>79.0</td>
</tr>
<tr>
<td>2. Baita 75 A</td>
<td>bedroom</td>
<td>982</td>
<td>143</td>
<td>85.4</td>
<td>85.3</td>
</tr>
<tr>
<td>3. Baita 75 B</td>
<td>Living</td>
<td>872</td>
<td>107</td>
<td>87.7</td>
<td>87.7</td>
</tr>
<tr>
<td>4. Bâța 76</td>
<td>Living</td>
<td>1062</td>
<td>100</td>
<td>90.6</td>
<td>89.5</td>
</tr>
<tr>
<td>5. Baita 119</td>
<td>Bedroom</td>
<td>761</td>
<td>137</td>
<td>82.0</td>
<td>84.5</td>
</tr>
<tr>
<td>6. Bâța 127</td>
<td>Bedroom</td>
<td>948</td>
<td>92</td>
<td>90.3</td>
<td>90.3</td>
</tr>
<tr>
<td>7. Baita 138</td>
<td>Bedroom</td>
<td>534</td>
<td>113</td>
<td>78.8</td>
<td>78.8</td>
</tr>
<tr>
<td>8. Bâța 204</td>
<td>Living</td>
<td>771</td>
<td>152</td>
<td>80.4</td>
<td>78.3</td>
</tr>
<tr>
<td>9. Baita 206</td>
<td>Bedroom</td>
<td>1557</td>
<td>91</td>
<td>94.2</td>
<td>93</td>
</tr>
<tr>
<td>10. Baita 213</td>
<td>Bedroom</td>
<td>1205</td>
<td>112</td>
<td>90.7</td>
<td>79.1</td>
</tr>
<tr>
<td>11. Baita 215</td>
<td>Bedroom</td>
<td>1010</td>
<td>117</td>
<td>88.4</td>
<td>81.9</td>
</tr>
<tr>
<td>12. Baita 228</td>
<td>Bedroom</td>
<td>1059</td>
<td>155</td>
<td>85.3</td>
<td>86.4</td>
</tr>
<tr>
<td>13. Campani 57</td>
<td>Bedroom</td>
<td>530</td>
<td>91</td>
<td>82.8</td>
<td>82.8</td>
</tr>
<tr>
<td>14. Campani 71</td>
<td>Bedroom</td>
<td>548</td>
<td>86</td>
<td>84.3</td>
<td>77.0</td>
</tr>
<tr>
<td>15. Câmpănî 103</td>
<td>Living</td>
<td>560</td>
<td>122</td>
<td>78.2</td>
<td>78.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>867</td>
<td>74.4</td>
<td>70.6</td>
</tr>
<tr>
<td>---</td>
<td>----------</td>
<td>----------</td>
<td>-----</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>16.</td>
<td>Fânaţe 23</td>
<td>Kitchen*</td>
<td>3389</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Fânaţe 59</td>
<td>Bedroom*</td>
<td>1177</td>
<td>214</td>
<td>81.8</td>
</tr>
<tr>
<td>18.</td>
<td>Fânaţe 118</td>
<td>Bedroom</td>
<td>1127</td>
<td>77</td>
<td>93.2</td>
</tr>
<tr>
<td>19.</td>
<td>Fânaţe 189</td>
<td>Bedroom</td>
<td>834</td>
<td>219</td>
<td>73.7</td>
</tr>
<tr>
<td>20.</td>
<td>Nucet 9</td>
<td>Bedroom</td>
<td>1958</td>
<td>96</td>
<td>95.1</td>
</tr>
<tr>
<td>21.</td>
<td>Pilot house</td>
<td>Bedroom</td>
<td>1395</td>
<td>174</td>
<td>87.5</td>
</tr>
</tbody>
</table>

AVERAGE 85.4 81.4 65.4-95.1

Min 73.7 65.2
Max 95.1 95.1

* measured by continuous measurement

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

<table>
<thead>
<tr>
<th>Method</th>
<th>Summary</th>
<th>AT</th>
<th>BE</th>
<th>CZ</th>
<th>FI</th>
<th>FR</th>
<th>NO</th>
<th>CH</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-slab depressurization</td>
<td>60-95</td>
<td>80</td>
<td>90</td>
<td>85-95</td>
<td>65-95</td>
<td>89</td>
<td>50-95</td>
<td>90</td>
<td>89</td>
</tr>
<tr>
<td>Improving natural ventilation in living spaces</td>
<td>10-50</td>
<td>&lt;30</td>
<td>15-55</td>
<td>49</td>
<td>10-50</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving mechanical ventilation in living spaces</td>
<td>10-60</td>
<td>5-55</td>
<td>61</td>
<td>10-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacing the existing natural room air ventilation by a mech. exhaust ventilation</td>
<td>10-40</td>
<td>15-45</td>
<td>10-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation of a new mech. supply and exhaust ventilation with heat recovery system</td>
<td>30-60</td>
<td>60</td>
<td>30-60</td>
<td>30-65</td>
<td>10-80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving ventilation in cellar</td>
<td>20-60</td>
<td>50</td>
<td>25-50</td>
<td>20-55</td>
<td>47</td>
<td>10-50</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreasing under-pressure in the house</td>
<td>20-70</td>
<td>50</td>
<td></td>
<td>10-50</td>
<td>25</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sealing entry routes</td>
<td>10-60</td>
<td>10</td>
<td>10-40</td>
<td>10-55</td>
<td>55</td>
<td>10-60</td>
<td>25</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Improving crawl space ventilation</td>
<td>40-60</td>
<td>50</td>
<td>40-65</td>
<td>47</td>
<td>10-80</td>
<td>75</td>
<td>47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions**

A number of 20 houses and a pilot house were selected for radon remediation in Bâiţa-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 ventilation, cave ventilation, 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.

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