Introduction

Reference level for radon concentration in workplaces was introduced in several countries, including Hungary from 01. January 2003, following the EU suggestion [1]. The determination of average radon concentration could present a problem considering, for example, that the monthly values measured in a hospital cave showed 24 times difference depending of the chosen month [2]. In cases like this only the year-long measurements give reliable results [3]. There is a difference between the averages measured during the working hours and during the total time (including nights and weekends), mostly in the cases of rooms with frequent air change like the schools and kindergartens and the ventilated workplaces.

Materials and methods

a.) The effect of measuring duration. To find out the ideal measuring length of time the radon concentration was measured continuously (hourly averages) in the hospital cave of Tapolca for three years long. The device was a Dataqua apparatus with semiconductor detector, which keeps the hourly averages in the memory.

b.) The effect of considering the actual working time. The ratio of the average radon concentrations measured during the actual working time and during the a whole time period were investigated in cases of schools, kindergartens, a uranium tailing pond and the hospital cave above mentioned. The measuring devices were: a PYLON-AB5 with CPRD scintillation detector.
Experimental results

\textit{a.) The effect of measuring duration.} The monthly average radon concentrations during three years in the hospital cave can be seen on the Fig. 1. It can be seen that in the hospital cave the variation of radon concentration with the seasons is considerable. The average radon concentrations as a function of measuring duration (1, 3, 6 or 12 months) and measuring date can be seen in the Table 1.

<table>
<thead>
<tr>
<th>Measuring duration (month)</th>
<th>Average radon concentration (kBq/m$^3$)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.51 ± 0.03</td>
<td>0.51</td>
<td>12.4</td>
</tr>
<tr>
<td>3</td>
<td>0.67 ± 0.23</td>
<td>0.67</td>
<td>11.54</td>
</tr>
<tr>
<td>6</td>
<td>1.11 ± 0.38</td>
<td>1.11</td>
<td>8.23</td>
</tr>
<tr>
<td>12</td>
<td>4.67 ± 0.12</td>
<td>4.67</td>
<td>5.7</td>
</tr>
</tbody>
</table>

The ± values mean the differences of the certain year averages from the 3 years average. It can be seen that at the one-month-long measurement in December the average was 0.51 kBq/m$^3$ and in August 12.4 kBq/m$^3$, which means 24 times difference. Even when one measures in, 7 times differences could be resulted. If the six-months-long period measurements executed from the first and second part of the year (01. January – 30. June, and 01. July – 30. December) the averages are 3.64 ± 0.37 kBq/m$^3$ and 5.7 ± 0.40 kBq/m$^3$ consequently. These differ from the yearly average (4.67 ± 0.12 kBq/m$^3$) with approximately 20 %, which is acceptable. Consequently, in workplaces where the expectable changes of radon concentration considerable with the seasons should be measure for 12 months long. If it is not possible, the chosen six months period should contain summer and winter months as well.

\textit{b.) The effect of considering the actual working time.} Analysing the results of measurements in the hospital cave, it was found that the yearly average radon concentration was 17 % lower than the all day average in the morning hours, when the treatments happened, but 16 % higher for ones who spend 8 hours in the treatment
rooms of cave. This means that the average is higher during the working hours, but the difference is not considerable. The monthly average radon concentrations (in 2001) during the working hours and the total time in a case of a uranium tailing pond when recultivation works happened, can be seen in the Fig. 2. The yearly average for the whole time was 625 Bq/m$^3$, which is high considering that this is an open-air place. Analysing the certain months the differences are well-marked. The ratio of the averages of the working time and the total time (Figure 3.) are changing with 40 %. The works connected with intensive radon exhalation and the meteorological circumstances causes this. This was the reason that in September the average for working hours was higher than the average for whole month. At the uranium tailing pond was find that the personal dosimeters showed two times higher dose than the detectors placed to the workplace. The reason was that the personal detectors were stored in the changeroom where the radon concentration was higher than the on the workplace. This also point out that consider the exact working hours could present a problem at the integrated measurements. Analysing the results of measurements in schools other differences were found. The Fig.4. shows the results of measurements happened in a school. It can be seen that the radon concentrations increase during the nights and weekends, so the average is 497 Bq/m$^3$. During the time when the children are inside, the averages are 125 Bq/m$^3$. Consequently, the average radon concentration during the effective time is only half of the most rigorous regulation (150-200 Bq/m$^3$) while the averages concerning the whole time exceed that. Similar results were found in the other cases as well. So, it would be unnecessary to mitigate in these cases because the levels for the effective time, usually, considerable less than the levels for the whole time. Basing on our experiences it can be stated that it would be
advisable to execute short time (a week) continuous measurements parallel with the long time (some months) ones to find out the variation of the radon concentration as well. At workplaces where the ventilation is effective or there is intensive air change due to the frequent opening the doors and/or windows, the averages for the working hours considerable differ from the averages of whole time. The Fig.5. shows the change of radon concentration in a mine tunnel. The ventilation works only during the working hours, so the levels increase at nights and in the weekends while during the working hours considerable lower. For a month track detectors were placed to the different locations of the mine and some miners wore the same detectors during work, which were keep in a place with low radon concentration (< 12 Bq/m$^3$) after the working hours. The average radon concentration in the mine was 3690 Bq/m$^3$, in working time was 815 Bq/m$^3$ which means 4.5 times difference. The artificial ventilation effects strongly the radon concentration during working hours so, mitigation action should be done knowing the actual levels during the effective work time.

**Conclusion**

The facts above detailed show that much more disturbing effects emerge at the determination of average radon concentration in workplaces than in cases of homes. It can be stated that the one month long measurements means very high variation (as it is obvious in the cases of the hospital cave and the uranium tailing pond). Consequently, in workplaces where the expectable changes of radon concentration considerable with the seasons should be measure for 12 months long. If it is not possible, the chosen six months period should contain summer and winter months as well. The average radon concentration during working hours can be differ considerable from the average of the whole time in the cases of frequent opening the doors and windows or using artificial ventilation.

**References**

