Indoor radon concentrations in workplaces and dwellings in North-Western Greece

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INTRODUCTION

Radon and its decay products are significant natural sources of radiation exposure for the general population, both in the living and working environment. Thus, extensive residential and occupational radon surveys are continuously performed worldwide. In Greece, indoor radon mapping has covered mostly the north-eastern, eastern and southern part of the country (Nikolopoulos et al., 2002, Clouvas et al., 2007).

This paper presents the results from radon measurements in typical workplaces and dwellings in Ioannina, which is a major city with a municipal population of approximately 75,000 (2001 census), located in north-western Greece. The reported data aim at contributing to the assessment of radon distribution and dose estimate at the national level.

MATERIALS AND METHODS

Electret-Passive Integrating Electret Ionization Chambers (E-PERM, Rad Elec Inc., USA) were used for short-term radon measurements in 44 public workplaces, situated in the University, the University Hospital and the Ioannina Prefecture Administration buildings. In all workplaces, the E-PERM chambers were installed during both summer (May-July) and winter (November-January) periods and exposed for 8-10 days.

Radon measurements were performed during summer (May-September) and winter (October-April), in 87 randomly selected dwellings in the area of Ioannina using CR-39 nuclear track detectors, as described elsewhere (Papachristodoulou et al., 2004, Patiris et al., 2006).

RESULTS AND CONCLUSIONS

Radon in public workplaces

Radon concentrations in workplaces follow a log-normal distribution (p<0.05), as shown in Fig. 1. Descriptive statistics are listed in Table 1. The results fall within the range reported in a recent pilot study carried out in 561 workplaces in other parts of the country (Clouvas et al., 2007). All radon concentration values were found to be below 400 Bq m\(^{-3}\), which is the action level implemented for workplaces by the Greek Radiation Protection Regulations, following the EC (1997) recommendation. Summer and winter measurements were compared through a paired student’s t-test and no statistically significant seasonal variation was established (p=0.298). However, one-way analysis of variance (ANOVA) followed by Fisher’s LSD post hoc test, showed that radon concentrations measured in basement and ground floor workplaces were significantly higher than those measured in the first and upper floors (see Fig. 2a).
The annual mean effective dose $H$ (mSv y$^{-1}$) from radon and its decay products was calculated (UNSCEAR, 2000) through the equation: $H = C \times E \times F \times T \times D$, where $C$ is radon concentration (Bq m$^{-3}$), $E$ is the equilibrium factor between radon and its decay products (=0.4; ICRP, 1994), $F$ is the occupancy factor, $T = 8760$ h y$^{-1}$ and $D$ is the dose conversion factor ($9 \times 10^{-6}$ mSv per Bq m$^{-3}$; ICRP, 1994).

Using the mean value of 92 Bq m$^{-3}$ for radon concentration and assuming an occupancy factor of 0.22 (i.e. working for 1920 h per y), the annual mean effective dose in the investigated workplaces is estimated to be 0.64 mSv y$^{-1}$. The dose is higher for those working in offices located on basement and ground floors (i.e. ~0.90 mSv y$^{-1}$) than on the first and upper floors (i.e. ~0.44 mSv y$^{-1}$). It should be noted that these values are based on short term measurements that may not accurately reflect radon levels throughout the year.

**Table 1.** Summary statistics of results from the present work and from a pilot study in workplaces from other parts of Greece. AM=arithmetic mean, SD=standard deviation from the mean, GM=geometric mean.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>AM ± SD (Bq m$^{-3}$)</th>
<th>GM (Bq m$^{-3}$)</th>
<th>Range (Bq m$^{-3}$)</th>
<th>&gt;400 Bq m$^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>this work</td>
<td>44</td>
<td>92 ± 54</td>
<td>79</td>
<td>21-278</td>
<td>-</td>
</tr>
<tr>
<td>Clouvas <em>et al.</em>, 2007</td>
<td>561</td>
<td>123</td>
<td>106</td>
<td>29-695</td>
<td>5 (0.9%)</td>
</tr>
</tbody>
</table>

**Figure 1.** Frequency distribution of radon concentrations measured in workplaces. The correlation between summer and winter values is shown in the inset.
Figure 2. Box-whisker plot of radon concentrations in (a) workplaces and (b) dwellings, broken down by floor level (B=basement; G=ground floor; 1=first floor; >1=above first floor). Open squares=mean value; boxes=25-75% range; whiskers=5-95% range; open triangles=1-99% range; N=number of samples; AM=arithmetic mean (Bq m\(^{-3}\)); SD=standard deviation (Bq m\(^{-3}\)). Statistically significant differences (* p<0.001; ** p<0.0001) between floors are also indicated.

Radon in dwellings

Radon concentrations in dwellings are log-normally distributed and range between 11 and 286 Bq m\(^{-3}\) with an arithmetic mean of 86 Bq m\(^{-3}\) (Table 2). All values were below 400 Bq m\(^{-3}\) and only in two basement dwellings values exceeded 200 Bq m\(^{-3}\), while which are the action levels applying to existing buildings and future constructions, respectively (EC, 1990). No statistically significant variations were found between summer and winter radon levels and between radon levels measured in detached house or apartment dwellings. A significant variation with floor level was established, with mean radon concentrations decreasing from basement to upper floors (see Fig. 2b).

Table 2. Summary statistics of radon measurements in dwellings. AM=arithmetic mean, SD=standard deviation from the mean, GM=geometric mean.

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Type of construction</th>
<th>Measuring period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dwellings</td>
<td>Detached</td>
<td>Apartment</td>
</tr>
<tr>
<td>N</td>
<td>87</td>
<td>31 (36%)</td>
<td>56 (64%)</td>
</tr>
<tr>
<td>AM ± SD (Bq m(^{-3}))</td>
<td>86 ± 52</td>
<td>83 ± 68</td>
<td>87 ± 42</td>
</tr>
<tr>
<td>GM (Bq m(^{-3}))</td>
<td>72</td>
<td>61</td>
<td>78</td>
</tr>
<tr>
<td>Range (Bq m(^{-3}))</td>
<td>11-286</td>
<td>11-286</td>
<td>32-190</td>
</tr>
</tbody>
</table>

Radon concentrations assessed in the present study compare well with previously reported results from 18 dwellings in the city of Ioannina (Nikolopoulos et al. 2002), in which radon concentrations ranged from 26 to 600 Bq m\(^{-3}\) with an arithmetic mean of 89 Bq m\(^{-3}\). An older survey (Ioannides et al. 2000) conducted in 55 dwellings in the town of Metsovo, situated in
Ioannina prefecture, revealed higher radon concentrations ranging from 18 to 750 Bq m$^{-3}$ with an arithmetic mean of 170±132 Bq m$^{-3}$.

The annual mean effective dose from residential radon exposure is estimated to be 1.64 mSv y$^{-1}$, assuming an occupancy factor of 0.6. On a national basis, effective doses between 0.09 and 11 mSv y$^{-1}$ have been determined (Nikolopoulos et al. 2002).

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REFERENCES


