The presence of radon in dwellings is an important indicator of the exposure of the population at the beginning and in the course of the process of reducing indoor radon. Considering the linear exposure/response relationship between radon and lung cancer risk, the arithmetic mean is the most relevant indicator to assess the impact on public health.

The radon action levels of 200 and 400 Bq.m$^{-3}$ allow for international comparisons, since most of the countries comply with the European guideline of 400 Bq.m$^{-3}$ for existing houses and 200 Bq.m$^{-3}$ for future dwellings.

Average radon levels in dwellings vary widely within and between countries. In most countries the world average of 40 Bq.m$^{-3}$ is exceeded (1). Countries with mainly sedimentary soils (e.g. Germany, the Netherlands, Poland and the United Kingdom) present lower or equivalent averages, whereas those with old granite soils (e.g. Austria, the Czech Republic and Finland) are more prone to radon emissions. If a common action level of 200 Bq.m$^{-3}$ were to be defined, Austria, the Czech Republic and Finland would have to take remedial measures for more than 10% of the houses, as against under 3.5% in countries with sedimentary soil.

This summary presents an assessment of the estimated radon levels and proportion of dwellings with annual mean levels of radon above 400 Bq.m$^{-3}$ for existing dwellings and above 200 Bq.m$^{-3}$ for future dwellings in 11 European countries.

### KEY MESSAGE

Average radon levels in dwellings vary widely within and between countries. In most countries the world average of 40 Bq.m$^{-3}$ is exceeded (1). Countries with mainly sedimentary soils (e.g. Germany, the Netherlands, Poland and the United Kingdom) present lower or equivalent averages, whereas those with old granite soils (e.g. Austria, the Czech Republic and Finland) are more prone to radon emissions. If a common action level of 200 Bq.m$^{-3}$ were to be defined, Austria, the Czech Republic and Finland would have to take remedial measures for more than 10% of the houses, as against under 3.5% in countries with sedimentary soil.

### RATIONALE

The presence of radon in dwellings is an important indicator of the exposure of the population at the beginning and in the course of the process of reducing indoor radon. Considering the linear exposure/response relationship between radon and lung cancer risk, the arithmetic mean is the most relevant indicator to assess the impact on public health.

The radon action levels of 200 and 400 Bq.m$^{-3}$ allow for international comparisons, since most of the countries comply with the European guideline of 400 Bq.m$^{-3}$ for existing houses and 200 Bq.m$^{-3}$ for future dwellings.

The 200 Bq.m$^{-3}$ measurement enables a reliable comparison of the proportion of houses that exceed this level in different geographical areas since it is less sensitive to variability from the size of the samples than the 400 Bq.m$^{-3}$ measurement.
PRESENTATION OF DATA

Figure 1 shows the estimated arithmetic mean of indoor radon in each country, based on a review of national surveys carried out by the European Commission Joint Research Centre (JRC). There is almost 10 times the difference between the minimum (20 Bq.m⁻³), found in the Netherlands and the United Kingdom, and the maximum (120–140 Bq.m⁻³) reported for the Czech Republic and Finland. The maps also display those countries with insufficient or unreliable data.

Figures 2 and 3 show the percentage of radon measurements higher than 200 Bq.m⁻³ and 400 Bq.m⁻³. The countries with the highest mean radon levels also have the highest percentage of housing stock above these levels, indicating a higher proportion of houses requiring remedial action.

HEALTH – ENVIRONMENT CONTEXT

Radon is a radioactive gas coming from soils (mainly granites) and accumulating in houses. Radon concentration in air is measured as the number of transformations per second in a cubic metre of air (Bq.m⁻³). One Becquerel corresponds to the transformation (disintegration) of one atomic nucleus per second.

Radon contributes up to 40% of the dose of ionizing radiation received by the population. Studies of cohorts of uranium miners clearly show a linear relation between exposure to radon and risk of lung cancer (3,4). This relation is modified by age, time since exposure and duration of exposure. Pooled analyses of key studies in China, Europe and North America have confirmed that radon in homes contributes substantially to the occurrence of lung cancers worldwide. On the basis of these studies, the International Agency for Research on Cancer (IARC) and the US National Toxicology Program have classified radon as a human carcinogen. There is also discussion of plausible leukemogenicity of radon (5).

Recent findings from case-control studies on lung cancer and exposure to radon in homes completed in many countries allow for substantial improvements in risk estimates and, by pooling the studies, for further consolidation of knowledge. The consistency of the findings from the latest European and North American pooled studies clearly points to a need for global action (6,7). The recent pooled analysis of key European studies estimated that the risk of lung cancer increases by 16% per 100 Bq.m⁻³ increase in radon concentration. The dose–response relation seems to be linear without evidence of a threshold, meaning that the lung cancer risk increases proportionally with increasing radon exposure. Furthermore, the new results show that if a threshold exists, it should not be higher than 150 Bq.m⁻³. With these results and an estimated exposure mean for 29 European countries of 59 Bq.m⁻³, 9% of deaths from lung cancer per year in Europe were estimated to be attributable to exposure to indoor radon. The pooling studies agree on the magnitude of the risk estimates.

In order to reduce the disease burden associated with radon, it is important that national authorities use methods and tools based on solid scientific evidence and sound public health policy. Mapping and distribution indicators can help to assess the level of burden yet to be expected for radon effects. Most countries have adopted national radon programmes to identify zones of higher concentration and provide information to the public. On the base of the new epidemiological results, WHO has developed a programme on public health aspects of radon exposure (8). This project is one of the high priority activities of the WHO radiation programme.

POLICY RELEVANCE AND CONTEXT

There is no regulation or directive in Europe concerning radon. Instead, in 1990 the European Commission issued recommendation 90/143/Euratom on the protection of the public against indoor exposure to radon. This recommendation defined 400 Bq.m⁻³ as the level for considering remedial action in existing dwellings and 200 Bq.m⁻³ as the reference level for new dwellings (9). It has served as a reference for the development of policies against radon exposure in many countries. Although the recommendation sets the framework policy on indoor radon, there are diverse approaches in Europe: some countries do not have any regulations and many others have adopted an indoor radon level within the range 200–400 Bq.m⁻³ as the level for action or the reference level for new buildings. Only a few responsi-
ble authorities have developed detailed legislation specifying levels above which financial support for mitigation can be provided. Radon levels in indoor air can be lowered in a number of ways, from sealing cracks in floors and walls to increasing the ventilation rate of the building. Under-floor sump and extraction methods are considered to be the most efficient. Prevention of radon exposure in new buildings can be implemented through appropriate provisions in the construction phase. National building codes cover the issue of exposure to natural radiation in building construction and ventilation sections.

In addition, all European Union member states already have or are drawing up provisions for implementing basic safety standards for the health protection of the general public, and workers in particular, in case of a significant increase in exposure due to natural radiation sources (including radon) in work places, as laid down in Title VII of Council Directive 96/29/Euratom.

In 2006, the JRC launched the Radioactivity Environmental Monitoring (REM) project (11) with the aim of improving the collection, evaluation and harmonization of environmental radioactivity concentrations and the modelling of the migration of radioactivity in the environment. A central activity of REM is the monitoring and mapping of indoor radon (12).

In 1995, WHO set up the International Radon Project (8) in which over 20 countries have formed a network of partners to identify and promote programmes that reduce the health impact of radon. The Project will review recommendations for levels of action and provide evidence-based recommendations for radon policies and radon programmes in countries. The project will also develop tools for radon communication.

### ASSESSMENT

There are clearly huge differences between countries in terms of exposure to radon in dwellings. Countries with mainly sedimentary soils have low radon gas concentrations indoors. In our sample this concerns Germany, the Netherlands, Poland and the United Kingdom. Countries with large amounts of granite or uranium-rich soils generally have very high levels of radon.

The wide variations also lead to very different health impacts in countries. As mentioned before, the overall estimate of lung cancer that can be attributed to radon is approximately 9% for Europe. Based on the methodology used in the European pooling study, attributable risk estimates range from about 3% of lung cancer deaths in the Netherlands or the United Kingdom to 21% in the Czech Republic.

The public health gain due to remedial action for levels above 200 Bq·m⁻³, as well as the cost-effectiveness of such action, would also differ greatly between countries. At present it is impossible to assess the time trends of radon. Improvements in insulation techniques in the context of energy crises may have in fact led to an increase in radon levels in dwellings. Action programmes to reduce radon levels in old and new dwellings may have led to a reduction below certain guidelines, or to changes in radon distribution. The current indicator could serve as a starting point for making an initial assessment at the outset of radon programme activities. The estimated arithmetic mean in regions or countries would be a good indicator in following up modifications to buildings or other

### Table 1. Sampling table

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference survey</th>
<th>Geographical coverage</th>
<th>Survey period</th>
<th>Sampling strategy</th>
<th>No. of dwellings</th>
<th>Measuring equipment</th>
<th>Other measuring technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Austrian Radon Project</td>
<td>National</td>
<td>1991–2002</td>
<td>Random and representative</td>
<td>16 000</td>
<td>SSNTD</td>
<td>E-PERM</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>National radon programme</td>
<td>National</td>
<td>1984–2004</td>
<td>Random and then targeted</td>
<td>150 000</td>
<td>LR115, Kodak</td>
<td>–</td>
</tr>
<tr>
<td>Germany</td>
<td>Various regional surveys</td>
<td>National</td>
<td>1978–2003</td>
<td>Varied, preference for geologically specific regions</td>
<td>&gt;50 000</td>
<td>Makrofol</td>
<td>Activated charcoal LSC Activated charcoal gamma spectrometry</td>
</tr>
<tr>
<td>Spain</td>
<td>Various surveys</td>
<td>Rural regions and areas with potentially high levels</td>
<td>1990–2005</td>
<td>Various, no precision</td>
<td>9 800</td>
<td>Terradex KIK</td>
<td>Charcoal detectors</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>National survey</td>
<td>National</td>
<td>1988</td>
<td>Random</td>
<td>2 500</td>
<td>NRPB/HPA</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: In the United Kingdom, around 500 000 dwelling measurements have been taken but they were not random and are not used as reference data for the assessment of radon distribution in dwellings.
activities aimed at lowering radon levels in dwellings. Monitoring of the proportion of dwellings with radon levels above the point at which action is required will enable the effectiveness of programmes targeted at extreme levels to be evaluated.

The indicator provides a good picture of the discrepancy concerning radon problems between countries and of the proportion of dwellings with levels above the European guidelines. It thus serves a baseline reference for future comparison. Countries with continuing radon programmes can use the information as interim monitoring results.

**DATA UNDERLYING THE INDICATOR**

**Data source**
The information comes from the JRC campaign to collect nationally available information for radon mapping in 34 European countries. The focal points in the country institutions in the relevant radon areas answered a questionnaire produced by the JRC. More information about the database used for each country is available on the European Forum on Radon Mapping web site (12).

**Description of data**
The indicator consists of a presentation per country of three important key values of the distribution of annual radon level in dwellings: estimated arithmetic mean of radon concentration estimated percentage of dwellings with annual mean levels of radon above 200 Bq.m\(^{-3}\) estimated percentage of dwellings with annual mean levels of radon above 400 Bq.m\(^{-3}\).

**Method of calculating the indicator**
The estimated values are given by institutions which deal with indoor radon and maintain information about radon distribution over the country. The survey reference has been quoted as well as its period, the number of dwellings concerned and the method of sampling (Table 1).

**Geographical coverage**
Austria, the Czech Republic, Finland, France, Germany, Hungary, the Netherlands, Poland, Romania, Spain and the United Kingdom.

**Period of coverage**
The data were collected in 2005 but the results concern widely differing periods between countries.

**Frequency of update**
Not specified yet.

**Data quality**
It is important to stress that the radon measurements were not made with a standardized protocol in all countries. In some countries the sample was selected randomly on a national basis, so that the results can be directly extrapolated in order to generate estimates. In others, the samples were not randomly selected and corrections were needed to estimate the radon distribution. Some countries relied on information from regional campaigns and did not give precise descriptions of the methodology used to assess the estimated distribution. Direct comparisons between results are, therefore, to be viewed with great caution.

Radon levels are susceptible to change with modifications to buildings or the renewal of the building stock, or the efficiency of regional or national action programmes. Regular national surveys or targeted surveys of new buildings or buildings of concern are, therefore, necessary to assess the evolution or efficiency of a policy. Coordination between countries is necessary to promote the use of national (and/or regional) survey protocols with a minimum set of standard criteria allowing for direct comparisons. Furthermore, as radon levels are strongly linked to local geological characteristics, the ideal scale to assess and compare radon distribution would be the regional one. Regional mapping based on a standardized assessment protocol could be an excellent tool for making comparisons.

**References**


**Further information**

Author: Philippe Pirard, National Institute of Public Health Surveillance, Saint-Maurice, France.