Action levels for indoor radon: different risks for the same lung carcinogen?

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Indoor radon and lung cancer

Assessment of the various risk factors for lung cancer has found that indoor radon exposure is the primary risk factor for lung cancer in never-smokers and the second ranked risk factor in ever-smokers [1, 2], following tobacco. Radon exposure is responsible for approximately half of the total ionising radiation that the average human being receives in a lifetime (followed in magnitude by medical radiation) and is the largest source of natural ionising radiation [3]. Radon is a colourless, odourless and tasteless gas that comes from the bedrock of the Earth's crust. Radon 222 is the most dangerous and the most common form of radon, from an epidemiological point of view, as 80% of all radon is radon 222. Indoor radon is usually measured in becquerels per cubic metre, and 1 becquerel per cubic metre is equivalent to one nuclear disintegration per second in such a volume. One nuclear disintegration releases one alpha particle.

Radon 222 is present in the decay chain of uranium 238 and therefore indoor radon concentration depends directly on the uranium 238 content of the bedrock in which a house or workplace has been built. Radon 222 has a half-life of 3.8 days and is therefore not risky by itself. The true risk is due to short-lived decay elements (sometimes called "radon daughters"), which are polonium 218 and polonium 214. The chain ends with a stable lead isotope (lead 206). These two elements (along with radon 222) release alpha particles when they decay in other elements. The continuous exposure to alpha particles may cause lung cancer through a series of molecular changes in epithelial cells of the lungs and bronchus following chronic exposure to alpha radiation. Radon exposure has also been recently associated with epidermal growth factor receptor mutations and may be related to the occurrence of the now well-characterised ALK translocation [4].

Radon was declared a human carcinogen by the International Agency for Research on Cancer (1988) [5] and the US Environmental Protection Agency (1987) [6]. Since then, many countries have issued recommendations protecting people from radon exposure. As radon concentration varies between and

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TABLE 1 Action levels for residential radon enforced by different countries and organisations

Country/ organisation	Current action level (year established)	Former reference level (year established)
USA (USEPA)	148 Bq·m^{-3} (1988)	
WHO	100 Bq·m^{-3} (300 Bq·m^{-3} if 100 Bq·m^{-3} cannot be achieved) (2009)	N/A
EU	300 Bq·m^{-3} (2014)	200 Bq·m^{-3} for new dwellings and 400 for dwellings already built (1993)
ICRP	300 Bq·m^{-3} (2011)	600 Bq·m^{-3} (2007)
UK	200 Bq·m^{-3} (target level 100 Bq·m^{-3})	200 Bq·m^{-3} (no target level)
Ireland	200 Bq·m^{-3} (2007)	N/A
Canada	200 Bq·m^{-3} (2007)	800 Bq·m^{-3} (1988)
Spain	N/A	N/A
Germany	N/A	N/A

USEPA: United States Environmental Protection Agency; WHO: World Health Organization; EU: European Union; N/A: not available; EU: European Union; ICRP: International Commission on Radiological Protection.

within countries, depending on bedrock characteristics, preventive measures differ between countries depending on indoor radon probability. New guidelines or recommendations should tailor protective actions to the expected radon levels.

As previously noted, exposure to indoor radon is a very well-characterised significant risk factor for lung cancer in nonsmokers as well as in ex- and current smokers. Its relative risk exceeds that associated with exposure to environmental tobacco smoke. The first studies on radon and lung cancer were performed in miners [7, 8] and were followed by studies in the general population [9, 10]. Practically all these studies observed a higher risk of lung cancer in participants with higher residential radon concentrations at home compared to those with lower exposures. Two seminal studies on radon and lung cancer have been performed in the general population. These were data pools of residential case-control studies performed in North America and Europe, respectively. The North-American data pool included >8000 participants from seven case-control studies, and observed that there was a linear and statistically significant association between residential radon and lung cancer. For each 100 Bq·m^{-3} increase in residential radon concentration, there was an 11% (95% CI 0–28%; $p<0.05$) increase in the risk of lung cancer [11]. The European data pool included 13 case–control studies, with >21 000 participants. It observed a linear and statistically significant increase in the risk of lung cancer of 16% for each 100 Bq·m^{-3} (95% CI 5–31%) [12]. These results encouraged the World Health Organization (WHO) to start the International Radon Project, which concluded in 2009 with the release of the *WHO Handbook of Indoor Radon*, which established a recommended action level of 100 Bq·m^{-3} [2].

Action levels on residential radon: who is right?

The available epidemiological evidence pushed many countries to establish action levels for residential radon; however, similar regulatory action levels for radon at work have lagged behind. Some countries, such as Spain, do not currently have an action level for residential radon nor do they have regulations regarding radon protection in new buildings. Table 1 shows the action levels of different countries and organisations for residential radon. In Europe, the recent Directive 2013/59/EURATOM ("Basic Safety Standards for Protection Against the Dangers Arising from Exposure to Ionising Radiation"), released in December 2013, established 300 Bq·m^{-3} as the action level for dwellings and workplaces [13]. According to the WHO report on radon [2], 300 Bq·m^{-3} are equivalent to 10 mSv per year, which is equal to receiving approximately an annual full chest CT. This action level contrasts with the 200 Bq·m^{-3} action level enforced by other countries, such as the UK [14], Ireland [15] and Canada [16] or the 148 Bq·m^{-3} action level enforced by the United States Environmental Protection Agency (USEPA) since 1988 (half of that proposed by the new European Directive) [6].

The first striking observation made by consulting table 1 is that disparities between the action levels are the norm, with differences that are up to two-fold. This is the case between the USEPA action level and the action level mandatory in Europe in 2018. A second conclusion that can be drawn from table 1 is that some countries and institutions have lowered their action levels due to new scientific evidence. The International Commission on Radiological Protection [17] and Canada [16] have lowered their action levels in this way but other countries have not acted and do not yet have a radon action level for residential settings.

There are also differences between countries regarding who should perform the radon testing, which radon measurement devices should be used, and finally, who will carry out remediation activities in dwellings that exceed recommended action levels. Homogeneous guidance on these aspects would be highly recommended. Although radon measurement and remediation is not usually expensive, cost may be a challenge in some places.

Radon action levels and risk of lung cancer

The use of different action levels clearly results in acceptable lung cancer risk levels that vary depending upon the country in which people live. For example, the risk of lung cancer due to radon amongst Americans would be half of that of Europeans. This information does not consider exposures other than radon, *e.g.* the demonstrated interaction between residential radon and tobacco smoking in enhancing lung cancer risk [10, 12, 18]. Residential radon has been found to produce lung cancer at radon concentrations below the action level of 100 $Bq \cdot m^{-3}$ [10, 18], supporting the theory that no radon level is safe. Even amongst never-smokers, residential radon has been observed to double the risk of lung cancer in those exposed to $\geqslant$200 $Bq \cdot m^{-3}$ compared to those exposed to <100 $Bq \cdot m^{-3}$ [19]. This risk is quite far below the 300 $Bq \cdot m^{-3}$ proposed by the new European Directive [13].

Indoor radon: a call for awareness

There is a real need for scientific societies to provide leadership through enhanced communication on this topic. Indoor radon risk awareness could be most effectively tackled using a multidisciplinary approach, which includes pneumologists, epidemiologists, oncologists, architects, industrial hygienists and others. But the key role remains for pneumologists and public health authorities, because indoor radon is related to lung cancer. Indoor radon at work is an important source of lung cancer risk in certain workplaces. Fortunately, this issue has been addressed by the new European Directive [13]. Health professionals should lobby and educate health authorities as well as the general public about radon exposure, as lung cancer is an environment-borne disease. Radon exposure carries significant lung cancer risks that are too often hidden in the residence or at work; these risks need renewed public health efforts (in concert with the increasingly successful smoking cessation efforts) to raise awareness and thereby decrease exposure. These efforts should also include smoking cessation programmes (for those who are exposed and who are not exposed to indoor radon, given the interaction between tobacco consumption and radon exposure in the risk of lung cancer). A consensus is also clearly needed regarding which radon exposure should be considered safe and should make a difference between what is considered a target ideal level and an admissable threshold. This consensus would avoid misperceptions from the general public on the radon concentration that is the safest.

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