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Recommendations for radon in dwellings in the Nordic countries: Background

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Introduction

Radon is a naturally occurring radioactive gas without odour, colour or taste. It is produced from radium in the decay chain of uranium, an element found in varying amounts in all rocks and soil in the Nordic countries. Radon gas from the ground enters houses through cracks and openings in the floor of the building. Building material and household water are other possible sources for indoor air radon. In Sweden, radon from a specific building material (alum shale-based lightweight concrete) is a major radon source. The average radon concentrations in dwellings in Finland, Sweden and Norway are among the highest in the world due to high uranium concentrations in the bedrock and soil formations such as eskers. A low air exchange rate due to cold climate is an important contributing factor.

The short-lived radon progeny, which emits heavily ionising alpha particles, can be electrically charged and attach to aerosols, dust and other particles in the air people breathe. As a result, radon progeny may be deposited in the cells lining the airways where the alpha particles can damage the DNA and potentially cause lung cancer.

In the Nordic countries, large parts of the populations use groundwater sources (springs, wells and boreholes). Underground water often moves through rock containing natural uranium and radium that produce radon. This is why water from deep-drilled wells in bed-rock normally has much higher concentrations of radon than surface water from rivers, lakes and streams.

Radon levels in the Nordic countries

Radon in dwellings

National surveys of the radon concentration in randomly chosen dwellings have been made in all the Nordic countries except Iceland. Finland has a mean radon level in dwellings of about 100 Bq/m^3. The average level in Swedish dwellings is about 110 Bq/m^3 and in Norway and Denmark 90 and 50 Bq/m^3, respectively. Indoor radon levels can range from about 10 Bq/m^3 to more than 80 000 Bq/m^3. Due to its volcanic bedrock Iceland has low radon levels and only a limited number of indoor radon measurements have been performed.

In Sweden the estimated number of dwellings exceeding the national action level (200 Bq/m^3) is about 450 000. In Finland more than 200 000 dwellings have radon levels exceeding 200 Bq/m^3 and 60 000 have levels above the national action level of 400 Bq/m^3. In Denmark about 65 000 dwellings have radon concentrations above the recommended action level for simple improvements (200 Bq/m^3) and 5 000 dwellings above the recommended action level for more effective improvements (400 Bq/m^3). In Norway an estimated number of 170 000 dwellings have radon levels above 200 Bq/m^3. Measurements carried out in dwellings in Iceland indicate low levels of radon and it is estimated that no dwellings in Iceland have radon levels above 200 Bq/m^3 due to the Icelandic bedrock being primarily composed of basalt. A summary of results from the national surveys is given in Table 1.

Table 1. Radon levels in dwellings in the Nordic countries determined from national surveys, and percentage of dwellings exceeding certain radon levels (SIS 2001, STUK 2006-2007, StrålevernRapport 2001:6, Swedjemark 1993).

Country	**Arithmetic mean Bq/m^3**	Percentage exceeding 200 Bq/m^3	Percentage exceeding 400 Bq/m^3
Denmark	53[1]	2.7	0.2
Finland	96[1]	12.1	3.0
Iceland	-		
Norway	89[2]	8.9	3.3
Sweden	108[3]	9.8	3.3

[1] Danish and Finnish measurements are from random surveys with a total of a whole year measurement period

[2]The Norwegian measurements have been corrected for season. The average level during winter is about 115 Bq/m^3

[3] Swedish measurements are performed mainly during the winter period, without correction for season

Radon in workplaces

Indoor radon is not only a problem in dwellings. In many buildings used for schools, day-care centres, offices, workshops etc. the radon concentrations can be high. Investigations of radon concentrations in workplaces have been made in Finland, Sweden, Norway and Denmark. The results show that schools and day-care centres may have radon concentrations that exceed the national action levels. Recent measurements at Swedish workplaces (not random sampling) showed a mean of about 80 Bq/m^3 with 2 % of the measured premises exceeding the national action level for ordinary workplaces (400 Bq/m^3) and 8 % exceeding 200 Bq/m^3. For schools and child care centres the estimated part of premises exceeding 200 Bq/m^3 (national action level) is 16 %.In Finland a random survey of indoor radon concentration at 367 workplaces was carried out in 2001. The mean concentration was 60 Bq/m^3 and 3.6% and 0.9% exceeded 200 Bq/m^3 and 400 Bq/m^3. Indoor radon concentration during working hours was estimated to be 30 Bq/m^3. A survey in new Finnish day-care centres was carried out in 2006. Some of these buildings were built using radon safe practices. The mean radon concentration was 52 Bq/m^3. In 2% of the buildings the mean value of two measurements exceeded 200 Bq/m^3. Spaces exceeding 400 Bq/m^3 were observed in 0.8% of the buildings measured. On the other hand previous measurements in over 400 day-care centres - mainly in 66 municipalities with highest indoor radon concentration in dwellings - showed that 400 Bq/m^3 was exceeded in 13% of the buildings.

In Norway, in the period 1996-98 measurements of radon were made in 3660 kindergartens; nearly 60% of the kindergartens in Norway. The mean radon concentration was calculated to 88 Bq/m^3, and 9.2 % and 2.7 % exceeded 200 and 400 Bq/m^3, respectively.

Radon in household water

Radon concentrations in household water from wells drilled into bedrock are significantly higher than in water from wells dug in soil. Radon from drilled wells can be an important source for radon in dwellings. In Sweden about 800 000 people use a drilled well as their daily water source. In Finland and Norway the corresponding number is about 300 000 and 200 000 respectively. In Denmark close to 100 percent of the household water is ground water, from drilled wells. In Sweden about 8 percent of the drilled wells have radon concentrations exceeding 1 000 Bq/l, and the corresponding proportion in Finland is around 10 percent and in Norway 15 percent. In Denmark a very small number of wells have high radon levels. The mean levels of radon in drinking water for the entire population have been calculated to about 50 Bq/l in Finland, 40 Bq/l in Sweden, 30 Bq/l in Norway and less than 1 Bq/l in Denmark

Risk estimation

Radon in indoor air

Long term exposure to radon increases the risk of lung cancer. This has been verified in many epidemiological studies in dwellings and of uranium miners. A pooled analysis of 13 case-control studies in dwellings from Europe (including more than 7 000 lung cancer cases and 14 000 controls) estimated that the risk of lung cancer increases by 16 % per 100 Bq/m^3 (Darby et al. 2005). Similar results have been achieved from pooled studies from North America (Krewski et al. 2005) and China (Lubin et al. 2004). 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. The recent estimates of the proportion of lung cancers attributable to radon in different countries range from 6 to 15 percent. The pooling studies all agree on the magnitude of the risk estimates. A practical conclusion of the results is that the risk doubles in the case of long term exposure to a radon concentration of 600 Bq/m^3.

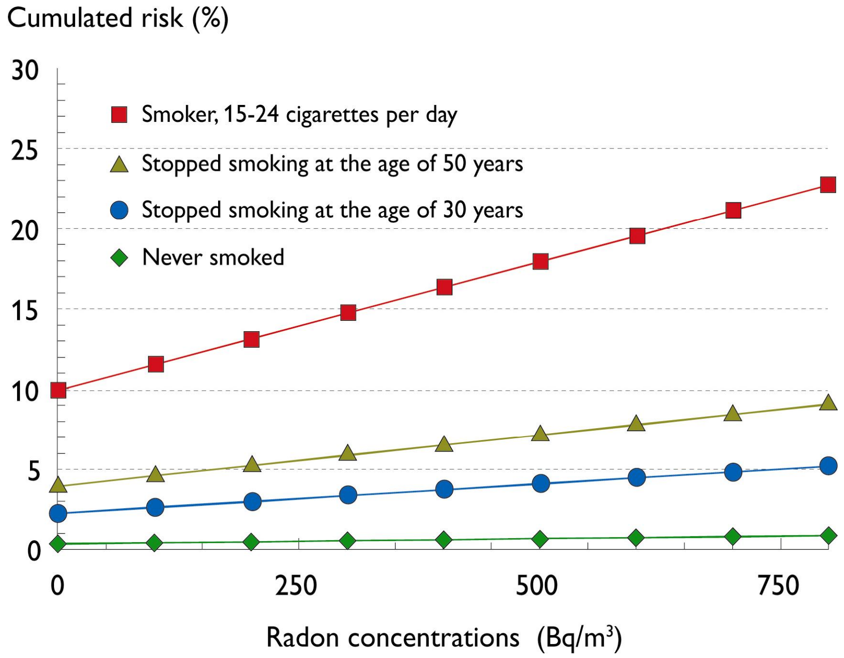

Figure 1. Cumulated life-time risk for lung cancer as a function of radon exposure for smokers and life-long nonsmokers. (Darby et al. 2005).

Most of the radon-induced lung cancer cases occur among smokers. The risk of lung cancer is about 25 times greater for a smoker than for a lifelong non-smoker! The risk of lung cancer decreases substantially if smoking is avoided. See Figure 1. For a smoker the most effective measure to reduce the risk of lung cancer from radon is to quit smoking. Simultaneously, risks of a number of other smoking-related diseases are reduced. At the same time it is important to stress that the risk for non-smokers is not negligible. The life-time risk for lung cancer increases from about 0.5 percent (at a low radon level) to about 1 percent at 600 Bq/m^3. At very high indoor radon levels, thousands of Bq/m^3, the lung cancer risk is high also for non-smokers.

The estimated number of lung cancer deaths caused by radon each year in the Nordic countries has been based on calculations by Darby and colleagues (not yet published) see Table 2.

Table 2. Estimated number and percentage of lung cancer deaths in the Nordic countries. The mean values differ from those presented in Table 1 based on corrections by Darby et al. (from Darby et al. not yet published).

Country	Mean radon Bq/m^3	Estimated number of lung cancer deaths per year	Percentage of all lung cancer deaths
Denmark	59	300	8.1
Finland[1]	120	280	15
Iceland	-	-	-
Norway[2]	89	280	14
Sweden	110	420	14

[1]Based on the results of the 1991 national survey

[2]Based on data from Norwegian Radiation Protection Authority

A large number of the lung cancer cases attributed to indoor radon occur in dwellings with radon concentrations below the national action levels. New buildings should therefore be planned and constructed in such a way that the annual average radon concentration will be as low as reasonably achievable. Similarly radon reducing measures in existing buildings should aim at an efficient reduction to low radon concentrations.

The International Agency for Cancer Research, IARC, has classified radon as a human carcinogen (the highest classification) together with, among other agents, tobacco smoking and X- and gamma radiations. The US National Toxicology Programme has made a similar classification. Next to smoking radon is the leading cause of lung cancer. The currently available epidemiological evidence indicates that risks other than lung cancer from exposure to radon (and decay products) are likely to be small.

Radon in household water

The basis for the risk assessment from consumption of radon in drinking water is much more uncertain than for radon in indoor air. More research in this field is desirable in order to obtain a more reliable risk assessment.

The best available risk estimation for radon in household water comes from a report in 1999 of a committee of the National Academy of Sciences in the United States (NRC 1999). The committee made a thorough summary of the field of knowledge for radon in water. Although they did not perform any new experiments or new measurements, they presented two new theoretical models for dose calculations, one for the diffusion of radon in the stomach and one for the behaviour of radon dissolved in the blood and other tissues. The report confirms earlier knowledge, for instance that the average transfer coefficient from radon in household water to indoor air is 10^{-4}, which means that if the radon concentration in the water is 1 000 Bq/l, the average contribution to the indoor air is 100 Bq/m^3.

The most important risk with radon in household water is that the indoor radon concentration is increased by radon emitted from the water that is used in the household. The ingestion dose from radon in drinking water seems to be of less importance. However, the estimated number of lung cancer cases due to waterborne radon is of the same order of magnitude as the number of stomach cancer cases due to ingested radon.

Risk management

International recommendations

For radon in dwellings the International Commission on Radiological Protection (ICRP) has recommended action levels to initiate intervention in the range of 3-10 mSv per year (ICRP 65). The corresponding rounded value for radon concentration in dwellings is 200-600 Bq/m^3 calculated for an annual occupancy of 7 000 hours. For radon at workplaces ICRP recommends action levels in the range 500-1,500 Bq/m^3 based on an annual occupancy of 1 800 hours.

In the latest recommendations from 2007 ICRP has retained the upper value of 10 mSv for the individual dose reference level and the corresponding activity concentrations as given in Publication 65 (ICRP 103). Consequently the upper level of reference levels for radon in homes is 600 Bq/m^3 and 1 500 Bq/m^3 for workplaces. The new ICRP recommendtions emphasizes that all reasonable efforts should be made to reduce radon exposures in homes and at working places to below the reference levels that are set at the national level and to a level where protection can be considered optimized.

The European Commission has issued a specific recommendation for radon in dwellings with a recommended action level of 400 Bq/m^3 for existing buildings and a planning level for future constructions of 200 Bq/m^3 (EC 1990). The International Atomic Energy Agency (IAEA) has an upper value of 1 000 Bq/m^3 for workplaces in their Basic Safety Standards (IAEA 96).

Estimation of potential life savings and costs from different risk management strategies

In the Nordic countries the estimated number of annual lung cancer deaths attributed to radon exposure in dwellings is almost 1 300 (1280) per year. This is more than 10 percent of the total number of lung cancers in the Nordic countries (10 100). Most of the lung cancer cases occur at radon levels under the recommended action levels. In the Nordic countries almost two thirds (63 percent) of the lung cancer deaths attributed to radon occur among people exposed to less than 200 Bq/m^3, see Table 3 (Darby et al personal communication, 2007).

Table 3 Estimated number of lung cancer deaths in the Nordic countries at different levels of radon in dwellings (Darby et al personal communication 2007)

Average radon concentration Bq/m^3	% of homes	Estimated number of lung cancer deaths, %	Estimated number of lung cancer deaths[1]
0-49	46	15	190
50-99	27	23	290
100-199	17	25	320
200-399	6.4	16	200
400+	3.1	21	270

[1]Based on the estimated sum of lung cancer deaths per year (table 2)

If all dwellings with radon concentrations exceeding 200 Bq/m^3 in the Nordic countries had the radon levels reduced to 100 Bq/m^3, 360 lung cancer deaths could be avoided each year, see Table 4.

Table 4: Estimated number[1] of avoided lung cancer cases in the Nordic countries at different action levels for radon in dwellings (Darby et al personal communication 2007)

Action level Bq/m^3	Percent avoided cases	Number of avoided cases
400	18	230
200	28	360
100	31	400

[1]If all dwellings above the action level are reduced to 100 Bq/m^3

If the long-term population average in the Nordic countries were reduced by 10 percent about 130 lung cancer cases could be avoided annually.

The Swedish Radiation Protection Authority (SSI) has estimated that if all dwellings in Sweden with radon levels exceeding 400 Bq/m^3 were mitigated to a level of 100 Bq/m^3, 150 lung cancer deaths could be avoided each year. If all dwellings between 200 and 400 Bq/m^3 also were mitigated down to 100 Bq/m^3 another 50 deaths could be avoided annually. The Swedish Radon Commission 2000 (SRC 2000) has calculated that this would save approximately 4 700 lives in a 50-year period to a cost of about 2 800 million SEK (300 million €).

Results of a cost-effect analysis from Norway was published in 2003 (Stigum, Strand and Magnus 2003). The main conclusion was: reducing the radon concentration in present and future homes to below 200 Bq/m^3 will cost $ 0.27 million per life saved. The mean life extension was assumed to be 14 years and therefore the cost per life year saved was estimated to $19 000.

In Finland the estimated number of life savings for a programme where all houses exceeding 400 Bq/m^3 are mitigated to below 100 Bq/m^3, is approximately 20% of all lung cancer deaths due to radon. The Radiation and Nuclear Safety Authority (STUK) estimated in 1994 that the cost of life saved through this programme would be 40 000 euros, corrected to the price level of 2007, roughly 100 000 € (Arvela and Castren 1994).

Examples on national programmes

The Swedish Parliament has decided on 16 national environmental-quality objectives. In 2002 the Swedish Parliament approved a national goal for radon in dwellings, schools and preschools. The goal is part of a larger environmental-quality objective called “A Good Built Environment”. The radon goal implies that all schools and preschools should have radon levels below 200 Bq/m^3 in 2010 and all dwellings should have levels below 200 Bq/m^3 before 2020. This in turn means that remedial actions should be taken in 450 000 dwellings before 2020. The cost to achieve the radon goals has been estimated by the Swedish government to about 10 000 million SEK (1 000 million €).

In Finland local health authorities and STUK have activated citizens to indoor radon measurements and radon mitigation since 2003 through a new campaign called “Radontalkoot”. Already more than 22 000 indoor radon measurement have been carried out. In 3000 of these houses the action level of 400 Bq/m^3 was exceeded. Training directed to companies and authorities is included in the campaign programme. The campaign continues. The campaign has increased the number of radon measurements also outside of the campaign areas.

Risk communication

It is recommended that the national authorities provide regional and local authorities with information material on radon in dwellings that could be distributed to the general public.

To communicate the risk from radon exposure to the general public is a challenging task, because one cannot see, smell or taste radon. Experience from many countries has shown that local communication efforts are the most effective. Radon campaigns at a national level have in several countries turned out to be less effective.

Most of the radon-induced lung cancer cases occur among smokers. The risk of lung cancer is about 25 times greater for a smoker than for a lifelong non-smoker! For smokers the greatest reduction in risk is obtained if they both stop smoking and reduce the radon concentration. Therefore efforts should be made to spread this information to the population.

However, experience from the US shows that mixing radon and stop smoking messages can lead to optimistic bias by non-smokers causing them to discount or underestimate the radon risk.

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