SWEDISH PERSPECTIVES ON RADON

G.A. Swedjemark
Swedish National Institute
for Radiation Protection
Box 60204
S-10401 Stockholm

Although research in the 1950s on radon and γ-exposure in Swedish homes showed that the absorbed dose in the lungs could be as much as 0.01 Sv per week, no regulations were introduced at that time. In 1980 general limits for radon in homes, schools, etc, were established in Sweden. A decrease of the existing limits and an extension to all working places above ground is presently discussed. The experiences in Sweden show that it is possible to decrease the radon concentrations in most existing houses to below 200 Bq m^{-3}. New houses can be built so that the average is about 50 Bq m^{-3} for all new construction and that most individual houses have levels below the limit established for newly built houses, 140 Bq m^{-3}.

INTRODUCTION

It has been a tradition in Sweden since the days of professor Rolf Sievert to study naturally occurring radiation. He initiated the study of gamma radiation and radon in dwellings (1). Sievert pointed out in 1956 (2) that the radiation dose in the lungs from radon in dwellings could be up to 1 rem (0.01 Sv) per week.

However, no regulations for radon or γ-exposure were introduced at that time. The reasons were several: (I) the radon concentration depended on ventilation and good ventilation was needed for other hygienic reasons, (II) natural radiation was excluded from the international recommendations at that time and (III) the limit for the general population from artificial radiation recommended by the International Commission on Radiological Protection, ICRP, was higher than now. Already in the 1950s it was clear that the ground was one source to the radon concentration indoors. However, before the 1970s no measurement was made of the high radon levels indoors as attained at a later date.

Nowadays, building technique measures to decrease radon concentrations have been checked. It is easy to measure the radon concentration and we know more about the health risks. It is therefore easier to defend regulations governing the exposure of radon indoors.

In Sweden, in contradiction to the other Nordic countries, about 10% of the dwellings are built of a concrete containing more radium-226 than normal, alum-shale based aerated concrete. The country-wide average for Swedish homes is, despite this, not much higher than for the neighbouring countries Finland and Norway. This depends on the ground for which the risk of high radon exhalation is high in all the three countries. Moreover, there is the cold climate which encourages energy conservation, often by decreasing air exchange rates. In a few regions the contribution from deep-bored wells is significant. Denmark and Iceland have in general no problems with radon indoors.

The arithmetic mean of the radon concentration for the Swedish homes in the 1975 building stock measured during 1980-82 was 100 Bq m^{-3}, 10% exceeding 200 Bq m^{-3} and 1% above 800 Bq m^{-3} (3), see Fig 1.

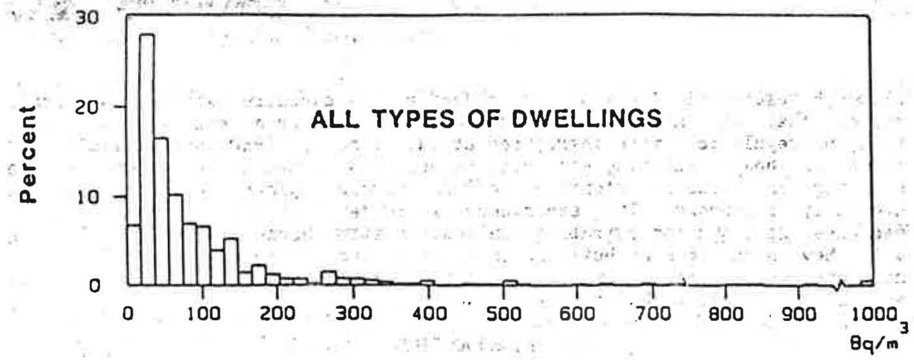

Figure 1 . Distribution of radon concentrations in the Swedish dwelling stock 1975. Indicated in the figure are also three values exceeding 1000 Bq/m^3 (1312, 1537 and 3306 Bq/m^3).

There are many indications that the average radon concentration in Swedish homes has increased since the 1950s. The average from the measurements 1980-82 were six times higher than the average from the measurements 1953-54 for approximately the same regions. The air exchange rates have been decreased and the underpressure indoors has been increased in the efforts to save energy. During the 1950s and 1960s about half of the newly built houses were built of alum-shale concrete containing more radium-226 than usual.

REGULATIONS

Radon is different from other indoor air quality problems. It is for example not possible to feel with our senses, but rather easy to measure. Also there is an existing international radiation protection policy and much work has been done on the estimation of health risks from ionizing radiation. This made it easier to state a regulation system for radon indoors than for other air pollutants, a possibility used in Sweden.

One experience since the Swedish limits for radon indoors were established in 1980 is that it is a tedious process making the politicians and the population so aware of the health risks that they are ready to decrease the levels when they are high. Financial implications are mostly more important. For example, a special clause stipulating lower housing taxes when the radon concentration exceeded 140 Bq m^{-3} resulted in that the local health authorities and the measuring companies were overwhelmed with questions about measurements and certifications.

The individual Nordic countries have tried to solve the radon problem in different ways, depending on different administrative routines. Hitherto, Sweden and Finland (4) have promulgated limits to decrease the radon concentrations in homes. Norway has recommendations and Denmark and Iceland have no regulations on radon. Recommended action levels are voluntary to follow, whereas a limit has to be met independent of the costs. However, the usage is to recommend, not to order, mitigation of the effects of radon, when the owner and family live in the home. The national authorities for radiation protection in the Nordic countries have agreed about basic recommendations (5).

Table 1 gives a summary of the limits and recommendations used in the Nordic countries. The original figures have been transferred to the concentration of radon in Bq m^{-3}. An equilibrium factor of 0.5 is used for the ratio between the equilibrium equivalent concentration of radon, EER, and the total potential α-energy of the daughters which would be in equilibrium with the radon concentration. EER is defined as 'that activity concentration of radon in radioactive equilibrium with its short-lived daughters which has the same potential α-energy concentration as the actual non-equilibrium mixture' (1 Bq m^{-3} = 2.7×10^{-4} WL = 5.6×10^{-9} J m^{-3}) (6). For the figures given in the following the radon concentration is used.

Table 1. Regulations and recommendations for the whole housing stock in the Nordic countries, radon concentration in Bq m^{-3}.

	Existing Bq m^{-3}	Design Bq m^{-3}
- Sweden (1980)	800	140
- Finland (1986)	800	200
- Norway (1987)	800	200
- Nordic radiation protection authorities (1986)	800	200
Recommendations <u>when simple measures</u>		
- Sweden	200	
- Norway (1987)	200	
- Finland (1986)	200	
- Nordic radiation protection authorities (1986)	200	

The Swedish limit for the radon concentration in existing homes, schools etc has been 800 Bq m^{-3} since 1980 (7). A decrease to 400 Bq m^{-3} and an extension to all working places above the ground is presently discussed. Homeowners are recommended to decrease the level to below 200 Bq m^{-3} when it is possible to do so with simple measures. The design level has been 140 Bq m^{-3} since 1980 (8). A decrease in the limit for rebuilding from 400 to 140 Bq m^{-3} is under discussion. The earlier limits for building materials and for γ-exposure indoors have recently been changed into recommendations.

The reasons for the decrease of these limits are (I) a better basis for the risk estimate, (II) a lower lifetime limit for radiation protection of Swedish workers established in 1988, and (III) better documentation of mitigation.

The early recommendations on mitigation from the beginning of the 1980s have now been revised and completed. A detailed handbook (9) and a brochure de-scribing mitigation methods have been published.

The purpose of the limits is to reduce the population dose and the dose to individuals. The reduction of the population dose is based on the ALARA-principle, one of the main principles of the ICRP recommendations (10), 'All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account.'

The possibility for owners of detached houses to receive governmental financial contributions to decrease concentrations has been improved since 1988. A governmental subside covering half of the cost, not exceeding SEK 15000 (~USD 2400) can be given to the owner when the radon concentration exceeds 800 Bq m^{-3}.

The Swedish local authorities are responsible for decreasing the radon concentration in homes in each municipality (11). The health authorities are responsible for the search of houses with high levels, measurements, decisions on if the level has to be decreased and for giving general advice on mitigation. They also approve proposals of mitigation as a basis for decisions on financial contribution. The local building authorities have to take the risk for high radon exhalation from the ground into account in their planning for building and also in their building permits.

CRITERIA FOR MEASUREMENTS

Measurements of radon and radon progeny concentrations and comparisons to the required limits are made by the local authorities or by private measuring companies. They are recommended to follow measurement protocols for the measurements and calculation of the annual averages. Furthermore, they can check their calibration at the National Institute for Radiation Protection after which they will be placed on a list available from the Institute. The measurement protocols, established since 1980, have recently been revised.

Several techniques are permitted as the basis for calculating annual averages; short-term, integrating, and continuous recording measurements. At least two rooms should be measured, such as a bedroom and a living room during normal living conditions (except for short-term measurements). In detached houses at least one measurement should be carried out on each floor. Basements should be included when calculating the annual average only if they are used for normal living. The ventilation should be working properly and the ventilation ducts should be open during the measurement period. Measurements are permitted only during the heating season. No corrections are made for seasonal effects.

Special restrictions are recommended regarding airing of the houses, vacuum cleaning and climatic conditions before and during short-term measurements. Since 1989 instantaneous measurements are only permitted in dwellings without contact with the ground, for example dwellings in the upper floors of apartment houses.

Protocols for searching of houses with high concentrations are presently being devised. These measurements can be done using simpler and quicker measurement methods. Such a searching method has already been practised in several municipalities. When the radon concentration is found to exceed a reference level, a new or repeated measurement should be carried out for comparison with the limit. Measurements in basements may be recommended.

The length of the measurement period is presently discussed in Sweden. The following considerations have to be taken:

- A measurement during a whole year would seem at a first glance to be the best measure of the annual average. This is, however, not true for countries with a combination of a cold climate, houses with natural draught ventilation systems and most of the holiday periods in the summer months, as in the Nordic countries. When the temperature difference between indoors and outdoors and the wind speed is low, natural draught ventilation systems do not work. If such houses are closed during a large part of the summer the radon levels may be very high in houses where the major radon source is the building materials. When the radon comes from the ground the radon concentration indoors may be lower in the summer although the ventilation does not work.

- In Sweden some houses have very high radon concentrations. In such houses it is important to decrease the levels as soon as possible. The measurement period should therefore not be too long. About 1% of the homes have radon concentrations exceeding 800 Bq m^{-3} and 3-4% levels above the discussed limit 400 Bq m^{-3}.

- The measurement period should not be too short because of the time variations indoors.

- For newly built houses it may entail considerable financial consequences to have to wait a long time for the measuring result. Later official approval of the building will cause later change to long-time loans with lower interest.

- For selling and buying, it is usually not possible to wait for several months for the results.

- One problem is the possibility of manipulation of the measurement. Simultaneous measurements of the radon progeny and the radon gas can make it easier to evaluate the results. Another way is to measure continuously and study the long time records. This method can, however, only be used for a few days due to the costs.

The measurement requirements differ between the Nordic countries. In Finland a minimum period of two months is required and in Norway 7 days. In both countries the measurements should be made in the heating season, but the stipulated months differ between the countries; for Finland during November - March, for Norway mid October - mid April and for Sweden, the heating season, which is different in the climatic zones.

That a measurement method is approved in one country is not a reason to approve it in another country. One example is electret based counters which can not be used without simultaneously measured γ-radiation in a country where some building materials contain enhanced concentrations of uranium and thorium, as in Sweden.

Also the requirements of certification of the measuring companies differ between the Nordic countries. In Finland the national radiation protection authority has performed the majority of measurements. Services of other organizations may be used but they must be submitted to the quality control performed by the radiation protection authority (12). Norway has, like Sweden a voluntary check of the calibration of the detectors used commercially (13). In Sweden work is in progress with the basis for accreditation of laboratories.

RADON RISK MAPS

The Swedish national authorities have recommended the local authorities to classify the ground for the probability of high levels indoors (14), so called radon risk maps. These maps should be a help to achieve the aim of having radon concentration below the limit, 140 Bq m^{-3}, in newly built houses, and as one basis for the searching of existing houses with high radon concentration. The principles for the classification are summarized elsewhere (15,16) and a very short summary of the principles are given in Table 2. The ground is classified after determining the radon concentration in the soil air, the permeability of

Table 2. A summary of the recommendations issued by the Swedish National Board of Physical Planning and Building (14) regarding classification of ground according to the risk for radon gas and types of protective measures (15).

Classification of risk	Percentage of the Swedish surface	Types of ground	Building technical requirements
High risk areas	10%	Uranium rich granites, pegmatites and alum shale. Higly permeable soils, for example gravel and coarse sand. Rn concentration in soil gas >50,000 Bq m^{-3}	Radon safe construction, such as thicker, reinforced concrete foundation or ventilation below the foundation
Normal risk areas	70%	Rocks and soil with low or normal U content and average permeability. Rn concentration in the soil gas 10,000-50,000 Bq m^{-3}	Radon protective construction. No open holes in the foundation
Low risk areas	20%	Rocks with very low U content for example limestone, sandstone and basic igneous and volcanic rocks. Soils with very low permeability, for example clay and silt or soils where the Rn concentration in the soil gas is <10,000 Bq m^{-3}	Traditional

the soil, the concentration of radium-226 in the soil, etc. Results from measurements in houses are also a help. A handbook describing how to classify the ground has been published (17). In addition to the ground conditions, the construction of the house is significant for the radon concentration indoors.

Depending on the ground classification and associated indoor radon risk from the ground, construction design is established. The Board of Physical Planning and Building has given examples of radon safe or radon protective building methods (14). Detailed mitigation methods are described in a handbook (9).

Also in the work with prognosis for future homes there are differences between the Nordic countries. For example, in Finland one does not classify the ground, but provide radon risk maps based on measuring results from an extensive data base and geological maps (12).

MITIGATION

Our experiences of mitigation come from the work in the municipalities (18,19,20,21,22) and from experimentals (23). Long-term follow-up of the effects have been studied, but more results are needed from longer follow-up periods. The experiences hitherto show that radon concentrations have not significantly increased during a five year follow-up period (23). It is also important that mitigation does not result in other problems in the houses such as moisture, freezing of the water pipes or the ground under the house etc. No certification of mitigation consultants or companies is planned, although it would have served as an extra security for the houseowners.

CONCLUSIONS

Experiences of local authorities and results from experimental building show that it is possible to decrease radon concentrations in most existing houses to below 200 Bq m^{-3}. Sometimes, however, several measures have to be taken. The homeowners which are responsible for the mitigation need adequate information in order to successfully mitigate. The effectiveness of the methods depends on the major radon source.

The air exchange rates in Swedish homes are in general lower than the building code limit, 0.5 changes per hour. The basic recommendation is therefore to improve the ventilation in homes in these cases, irrespective of elevated radon concentrations.

It is possible to build new houses so that their average is about 50 Bq m^{-3}, and so that all houses have levels below the limit for newly built houses, 140 Bq m^{-3}.

The local authorities are responsible for the administration of the safety standards in the homes and the public health. The homeowners are responsible for the mitigation. Many people have to be informed - this is the most difficult obstacle in solving the indoor radon problem.

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