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MEASUREMENT PROTOCOLS FOR RADON IN DWELLINGS IN SWEDEN; THIRTEEN YEARS OF EXPERIENCE

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ABSTRACT

Sweden has had compulsory limits for radon in buildings since 1980. From that time measurement protocols providing technological guidance for measurement of radon in dwellings have been in use. In 1988 new protocols, completely revised, were issued by the Swedish Radiation Protection Institute. The new protocols included formal requirements on regular calibration, measurement conditions, device location and documentation. To be legally valid measurements have to comply with the protocols. The measurement protocols have significantly contributed to a high quality of radon measurements in Sweden. They have had an important impact in making all those involved more aware of the quality assurance aspects of radon measurements. For instance, most measurements for comparison with the limits are nowadays made with alpha track detectors over periods of one to three months. These longer measurement periods have resulted in better estimates of the annual averages. A new, updated version of the protocols is planned for 1994, where new experience and new information will be considered.

INTRODUCTION

Radon in Swedish dwellings was first studied in the beginning of the 1950's when Bengt Hultqvist, inspired by Rolf Sievert, made a survey of radon concentrations in 300 dwellings in four cities in central Sweden (Hultqvist 1956). This investigation also included measurements of gamma radiation in about 1,000 dwellings. Hultqvist found rather high radon concentrations in houses built from lightweight concrete based on alum shale, up to 600 Bq m^{-3} (16 pCi l^{-1}). This building material, which has rather high contents of radium, between 600 and 2,600 Bq kg^{-1}, was used extensively in Sweden from about 1930 to 1975. In the 1975 building stock about 10% of the building material used was lightweight concrete based on alum shale (Mjönes 1986).

In 1956, when Hultqvist published his results, the radiation protection authorities of that time estimated that the relatively low radiation doses caused by gamma radiation and radon in dwellings constituted only a moderate health hazard. It was not until later, in the end of the 1960's, that a correlation between lung cancer in miners and high radon levels could be established. Therefore, the results published by Hultqvist did not lead to any particular protective measures apart from recommendations regarding the importance of good ventilation in dwellings.

After Hultqvist's investigations there was an intermission in the radon measurements in Sweden. At the end of the 1960's and the beginning of the 1970's measurements in dwellings were taken up again partly as a result of the reports on the correlation between lung cancer among miners and radon exposure. In the 1970's the Swedish Radiation Protection Institute (SSI) ran a rather extensive measurement program on radon in dwellings. The interest at this time was again focused on dwellings built from lightweight concrete based on alum shale. In 1979 a sample survey with statistical significance of radon levels in Swedish dwellings was initiated (Swedjemark and Mjönes 1984).

THE SWEDISH RADON PROGRAM AND HOW IT STARTED

In 1978 high radon levels, up to 10,000 Bq m^{-3} (270 pCi l^{-1}), were found in dwellings built on tailings of burnt alum shale, with radium contents of 3,000 to 6,000 Bq kg^{-1}, in a small town, Tidaholm, in the southeastern part of Sweden. This created extensive public concern and widespread publicity in Swedish newspapers, radio and television. On the initiative of SSI a governmental commission with instructions to investigate protective measures

against radiation hazards in buildings, called the Radon Commission, was appointed in 1979. The Radon Commission presented a preliminary report later the same year (SCM 1979). Based on this report the Swedish government decided that the national authorities should establish restrictions and issue recommendations principally according to the recommendations of the commission. As a result compulsory limits for existing and new dwellings were introduced in 1980 by the national authorities (National Board for Health and Welfare 1980, National Board for Physical Planning 1980), Table 1.

Table 1. Limits for ionizing radiation in Swedish dwellings in 1980.

	Radon[a] concentration		Gamma radiation		Building materials	
	Bq m^{-3}	(pCi l^{-1})	μSv h^{-1}	(μR h^{-1})	Gamma[b] index	Radium[b] index
New buildings	140	(4)	0.5	(50)	1	1
Reconstruction	400	(11)				
Existing buildings	800	(22)				

[a] The limits in Sweden are expressed as annual averages of the Equilibrium Equivalent Concentration of radon, EER. Here the values have been converted into radon concentrations by dividing EER by the equilibrium factor F = 0.5.

[b] Gamma index = $C_K/10{,}000 + C_{Ra}/1{,}000 + C_{Th}/700$ and Radium index = $C_{Ra}/200$ where C_K, C_{Ra} and C_{Th} are the concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Bq kg^{-1} of the material.

In 1983 the Radon Commission presented its final report (SCM 1983). The results of the commission's studies were summarized and a program to reduce the radon levels in buildings was suggested. The program included an action level for existing buildings corresponding to 800 Bq/m^3 (22 pCi l^{-1}) radon gas concentration and a design level for future buildings so that the majority of buildings should have radon levels well below 200 Bq/m^3 (5.4 pCi l^{-1}). (The limits were given as annual averages of the Equilibrium Equivalent Concentration of radon, EER.) The commission also recommended restrictions on building materials and keeping the radon levels as low as reasonably achievable.

In 1985 the government stated that SSI should have the overriding responsibility for following the development regarding radiation in dwellings, including risk assessment and measurement techniques. The National Board for Housing and Planning should establish the limits for planned buildings and the National Board for Health and Welfare should issue limits and recommendations for existing buildings. The direct responsibility to reduce the radon levels was decentralized to the local authorities. Sweden is divided into 286 municipalities. Some of these are big, Stockholm for instance is a municipality with about 700,000 inhabitants, while some municipalities are very small with a population of only a couple of thousand people. Each municipality, whether it is big or small, has a health authority with the responsibility for the health of the general public in their homes and a building authority with the responsibility, among other things, to issue building permits for new buildings and for extensive reconstruction.

The local health authorities have the responsibility to identify buildings with high radon levels and to arrange measurements in buildings where high radon levels could be expected, except in workplaces where the public has no admission. When the limit for existing buildings is exceeded, they can declare the house as unsanitary with regard to the radon concentration and demand that remedial actions are taken. They also help the homeowners with recommendations on how to reduce the radon levels. If the limit is exceeded, the homeowners can get financial aid from the government to mitigate the house. Today the owner can get half the cost for approved installations, maximum 15,000 SEK (about 2,000 USD). The local building authorities are responsible for assuring that the radon levels in all new buildings are lower than 140 Bq m^{-3} (4 pCi l^{-1}). They grant building licenses after consideration of the risk for radon inflow from the ground into the building. Building licenses are compulsory for almost all new

buildings in Sweden. The local authorities are further recommended to classify the ground to determine the probability of high radon levels indoors.

In 1990 the limit for existing buildings was lowered from 800 Bq m^{-3} (22 pCi l^{-1}) to 400 Bq m^{-3} (11 pCi l^{-1}). The present limits for ionizing radiation in buildings in Sweden are shown in Table 2 (National Board for Health and Welfare 1990, National Board for Housing and Planning 1988).

Table 2. Present limits for ionizing radiation in Swedish buildings. The limits are compulsory.

	Radon[a] concentration		Gamma radiation		Building materials	
	Bq m^{-3}	(pCi l^{-1})	µSv h^{-1}	(µR h^{-1})	Gamma[b] index	Radium[b] index
New buildings	140	(4)	0.5	(50)	1	1
Reconstruction	400	(11)				

[a] The limits in Sweden are expressed as annual averages of the Equilibrium Equivalent Concentration of radon, EER. Here the values have been converted into radon concentrations by dividing EER by the equilibrium factor F = 0.5.

[b] Gamma index = $C_K/10{,}000 + C_{Ra}/1{,}000 + C_{Th}/700$ and Radium index = $C_{Ra}/200$ where C_K, C_{Ra} and C_{Th} are the concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Bq kg^{-1} of the material.

The radon proficiency of the local authorities differ very much between the municipalities. Some have ambitious radon programs and the officials have a very good knowledge and long experience of radon and the problems involved, while in others they have no radon program at all and the knowledge is very poor.

THE 1980 PROTOCOLS

As part of the overall scheme to reduce radon levels indoors in Sweden, measurement protocols were introduced in 1980. The directions from the national authorities prescribed that measurements should be made according to the protocols if the results were to be compared with the limits. The protocols provided method-specific technical guidance about how to make the measurements with the method in question and how to assess the annual average to be compared with the required limits. They also included detailed information for the calculation of the combined uncertainty in the annual average. Protocols for three methods were presented during 1980-1981. The protocols covered measurements with unfiltered alpha track detectors, grab sampling Working Level devices and thermoluminescence ion chambers. In 1983 an additional protocol was introduced for measurements with activated charcoal adsorption devices. These first protocols were worked out in collaboration between the Swedish National Testing and Research Institute and SSI.

The protocols prescribed measurements in at least two rooms, one of which should be a bedroom and the other the room where the residents spend most of their time. The air exchange rate should be normal, therfore measurements in periods with exceptional temperature or wind conditions or in the summertime (when windows and doors are often open) were not recommended. Rules were given for how to calculate the annual average for the dwelling and how to report the uncertainty of the measurement results. The protocols also stated what should be included in the measurement report and contained simple examples of the above-mentioned calculations.

THE 1988 PROTOCOLS

In 1985 SSI was instructed by the government to work out new measurement protocols in consultation with the Boards for Health and Welfare, Planning and Housing and the Board for Technical Accreditation. Due to the

Chernobyl accident in 1986, which for some time engaged almost the entire staff of SSI, the work with the new protocols was delayed. Eventually the new, completely revised, measurement protocols were issued in 1988.

As an introduction to the new measurement protocols a booklet containing general information on radon and radon measurements as well as recommendations from the national authorities (SSI 1988b) was published together with the specific protocols for each method. Protocols for nine different methods have been issued (SSI 1988a), see Table 3. New methods are added continually.

Table 3. Measurement protocols for radon in dwellings in Sweden issued 1988 and later.

Nr	Method
1	Filtered alpha track detectors
2	Unfiltered alpha track detectors
3	Activated charcoal adsorption devices
4	Activated charcoal adsorption devices including thermoluminescence dosimeters
5	Thermoluminescence ion chambers
6	Continuous Working Level monitors
7	Continuous radon monitors
8	Simultaneous grab sampling-Working Level and radon
9	Electret ion chambers

The protocols require that the measurement devices should be calibrated regularly, at least every 12 months. As part of its quality assurance efforts SSI participates regularly in international intercomparison and intercalibration programs. Between 1978 and 1982 intercomparisons with the other Nordic countries, NRPB in England and EML in the United States were undertaken on several occasions. After 1982 SSI has regularly participated in radon intercomparisons organized by EML and several European organisations (Falk et al. 1993). SSI has also organized intercalibrations between the commercial companies that provide measurement services with alpha track detectors on the Swedish market. Routine instrument performance checks, for instance with an instrument check source, are recommended in the protocols as well as checks of other important components, such as pumps and batteries.

The measurements should be performed during the heating season, normally from the beginning of October to late April for most of the country. In the north of Sweden the heating season can be longer and in the southern parts shorter than October to April. To define "heating season" the protocols state that measurements can be performed if the average outdoor temperature during the measurement period is less than 10°C (50°F). Measurements are required in at least two rooms in each dwelling, normally in a bedroom and the living-room and in at least one room on each dwelling floor. The basement should be included in the calculation of the annual average only if it is used for normal living. It is rather common in Sweden to have bedrooms for teenagers, a TV-room or an extra living-room in the basement.

In general long term measurements are recommended, at least one month, preferably three months, to smooth out the diurnal and seasonal variations and give a good assessment of the annual average. Minimum measurement periods are given for each method. The shortest measurement period accepted is 24 hours in each room. This is valid for continuous radon and Working Level monitors. For short term measurements, less than three days, restrictions exist regarding airing and vacuum cleaning and for climate conditions such as wind speed and outdoor temperature. The ventilation system should be working and the ventilation ducts should be open during the measurement period. No corrections are made for seasonal effects.

The protocols also include detailed instructions on how the results should be reported with regard to for instance quantities and units, rounding off, accuracy etc. and what should be included in the measurement report. Some examples on how to calculate the annual average and random and systematic uncertainties and references to original papers on the method in question are included as well as an appendix showing an example of how a measurement report could be designed. An example of the contents of a measurement protocol is shown in Table 4.

Table 4. An example of the contents of a measurement protocol.

MEASUREMENT PROTOCOL
Radiation in dwellings
Assessment of the annual average of the radon progeny concentration with **filtered alpha track detectors**

1. Purpose

2. Definitions

3. Method
3.1 Description of the method
3.2 Limitations in the use of the method

4. Calibration

5. Measurement criteria
5.1 Length of the measurement period
5.2 Timing of the measurement period
5.3 Deployment of detectors
5.4 Information to the occupants

6. Calculation of the average for the measurement period

7. Accuracy
7.1 Calculation of random and systematic uncertainties
7.2 The magnitude of the random uncertainties
7.3 The magnitude of the systematic uncertainties

8. Calculation of the annual average

9. How to report the results

10. Measurement report

11. Examples

12. References

THE SIGNIFICANCE OF THE MEASUREMENT PROTOCOLS

Before 1979 almost all radon measurements in dwellings in Sweden were made by SSI. After the discovery of the high levels in Tidaholm and the publishing of the Radon Commission's preliminary report in 1979 the number of measurements increased rapidly. In the beginning of the 1980's radon consultants and measurement companies were formed and many local health authorities started to measure radon. Radon measurement training courses were organized by different organizations, often with SSI personnel as instructors and teachers. In this situation the first measurement protocols were very useful. They were used as teaching materials in the training courses and as handbooks in the field and in the laboratories. Between 1979 and 1986 the local authorities made about 60,000 measurements in dwellings and measurement companies and consultants made perhaps 10,000 or 15,000 (SSI 1993). Thanks to the measurement protocols most of these measurements were made with acceptable methods and in an acceptable way. Even if the early protocols had their shortcomings they contributed significantly to a good quality of the radon measurements in Sweden between 1980 and 1988.

The 1988 protocols included new methods, some of which were already in use, as filtered alpha track detectors, continuous Working level monitors and continuous radon monitors. Grab sampling methods were excluded except for some very special cases. The new protocols prescribed regular calibration and put more emphasis on quality assurance. They included a strong recommendation in favour of long term measurements, one to three months. Short term measurements, less than three days, were recommended only when longer measurement periods could not be used, for instance measurements in connection with buying or selling homes.

In principle all measurements in Sweden for comparison with the limits have to be made according to the measurement protocols. To be legally valid measurements have to comply with the protocols. The courts of law don't accept any other measurements.

Once a year SSI issues a catalogue of companies that have calibrated their instruments according to the requirements in the measurement protocols.

Radon measurements training

There are no formal requirements of proficiency for radon measurement companies or local authority officials in Sweden. However, most companies and many officials have attended the training courses organized by SSI and other organisations. SSI has radon measurement training courses in two steps, all in all five days of training. Step II includes a theoretical and practical proficiency test. The individuals that have passed the test are listed in a catalogue that is distributed to national and local authorities along with potential customers. The proficiency test and the catalogue serve as a simple form of certification. Plans are to formalize the system in the future.

From 1991 Swedish companies can be accredited for measurements of radon in indoor air. The accreditation is issued by the Swedish Board for Technical Accreditation, SWEDAC, and based on the requirements in the measurement protocols. The system for accreditation complies with the system in the European Communities.

FUTURE PLANS

The 1988 protocols have now been in use for five years. During this time much has happened in the radon field, also regarding measurement methods. The measurement protocols need to be revised and perhaps simplified. SSI has received many suggestions from consultants and local authority officials on improvements and modifications. The next version of the measurement protocols will probably include prescriptions for longer measurement periods, a minimum of one month and a recommendation for three months have been discussed. This would imply that a number of methods with short measurement periods no longer could be used for comparison with the limits, for instance charcoal adsorption devices and continuous radon and Working Level monitors. This in turn leads to problems with measurements concerning buying or selling homes. Such tests usually require measurement periods less than a week. This might be taken care of by working out special protocols for this kind of measurements. It is also the ambition of SSI that the next set of protocols will include more requirements regarding quality assurance.

The present protocols are only applicable to measurements in dwellings. However, an increasing number of measurements are made in workplaces, schools and daycare centers. Therefore, it is important to also produce measurement protocols for these kinds of premises. Protocols for measurements in mines are also planned.

In May 1993 SSI submitted a proposal for a new radon program to the government. The proposal included some minor changes in the limits and that the quantity of the limits should be changed from radon progeny concentration, EER, to radon gas concentration. This change is motivated by the fact that radon gas measurements seem to give a better measure of the radiation dose (Vanmarke et al. 1989) and that most other countries have their limits and action levels in radon gas units. If the new radon program is approved, the publication of the revised measurement protocols will be coordinated with the introduction of the new limits.

The new radon program further suggests that 80% of all buildings with radon concentrations exceeding 400 Bq m^{-3} (11 pCi l^{-1}) should be located and mitigated within 10 years. The present work with preventive actions against radon in new buildings should continue. The long term goal of the program is to decrease the average radon concentration in the Swedish building stock to 50 Bq m^{-3} (1.4 pCi l^{-1}) which is about half the average radon level from the 1980s.

CONCLUSIONS

The measurement protocols have significantly contributed to a good quality of the radon measurements made in Swedish dwellings. The fact that they were introduced early, before the number of measurements started to increase, has certainly prevented many bad and erroneous measurements. The revised protocols issued in 1988 have

further raised the quality. Before 1988 grab sampling was common practice among many radon measurement consultants and local authorities. Many measurements were made with activated charcoal devices with short measurement periods. Today most measurements for comparison with the limits are made with alpha track detectors over periods of one to three months. The longer measurement periods have resulted in better estimates of the annual averages. The protocols have also made the officials at the local authorities and the consultants more aware of the quality assurance aspects of radon measurements. After 1988 all measurement devices used for comparison with the radon limits have to be calibrated at SSI at least once a year.

The quality of the measurements is of great significance, not in the least from an economic point of view. Up to 1992 about 240,000 dwellings and workplaces had been measured in Sweden, most of these measurements were made in dwellings. Since Sweden has about four million dwellings this means that 5-6 % of the dwelling stock has been measured. The majority of the measurements, about 150,000, have been administrated and paid for by the local authorities in the different municipalities. About 16,000 dwellings have been measured in different research projects. The total cost for all these measurements is approximately 300 million SEK, about 40 million USD. Based upon the results of these measurements preventive measures for more than 200 million SEK (30 million USD) have been made (SSI 1993).

For the future it is an important task for SSI to maintain and improve the quality of the radon measurements. One way to achieve this is to have good measurement protocols and to make sure that they are followed.

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