CONTROL OF HIGH NATURAL ACTIVITY BUILDING MATERIALS AND LAND AREAS IN THE NORDIC COUNTRIES

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Abstract

Enhanced levels of natural radioactivity in the ground can cause problems with high concentrations of indoor ^{222}Rn, elevated levels of gamma radiation and natural radioactive elements in drinking water. Of the Nordic countries it is essentially Finland, Norway and Sweden that have problems with enhanced natural radioactivity in the ground and in building materials. Finland and Sweden have among the highest mean ^{222}Rn concentrations in dwellings in the world, 123 Bq m^{-3} and 108 Bq m^{-3}, with a corresponding mean annual effective dose of about 2 mSv. In Sweden about 500 000 and in Finland and Norway about 200 000 persons get their drinking water from wells drilled in bedrock. The water from a large number of these wells contain elevated levels of naturally occurring radioactive elements, primarily ^{222}Rn. The action levels for ^{222}Rn in dwellings and above-ground workplaces are essentially the same in Finland, Norway and Sweden: 200 Bq m^{-3} for new buildings and 400 Bq m^{-3} for existing buildings. For mines and underground excavations, however, there are some differences. The treatment of gamma emitting natural radionuclides in building materials etc. is similar, although there are differences in the degree of control. The action levels for ^{222}Rn in drinking water differ from 100 Bq l^{-1} to 500 Bq l^{-1}. The action level in Finland has the form of an activity index that restricts also other radioactive nuclides. Denmark has not adopted a formal radon policy and has no recommended or legally binding action levels for ^{222}Rn or any other naturally occurring radionuclides.

1. INTRODUCTION

Enhanced levels of natural radioactivity in the ground can cause problems with elevated levels of ^{222}Rn in buildings and underground workplaces as well as elevated levels of gamma radiation, both indoors and outdoors. Furthermore it can cause high levels of natural radioactive elements in drinking water from wells drilled in the bedrock.

Of the five Nordic countries it is essentially Finland, Norway and Sweden that have problems with enhanced natural radioactivity in the ground and in building materials. This is because of the geologic conditions with great abundance of granites and pegmatites rich in uranium and sometimes in thorium in all three countries and large areas of uranium-rich alum shale in Sweden and Norway. In Denmark and Iceland the concentrations of naturally radioactive elements in the bedrock are much lower and consequently these problems are much less pronounced.

1.1. ^{222}Rn levels

^{222}Rn causes the highest radiation doses to the population of the Nordic countries. The most important source for indoor radon is the ground. Other sources are building materials and radon-rich household water. Finland and Sweden have the highest mean radon levels in dwellings, 123 Bq/m^3 [1] and 108 Bq/m^3 [2] respectively. Using the dose conversion convention recommended by the ICRP in its ICRP 65 [3] report this implies a mean annual effective dose from radon in dwellings of about 2 mSv, roughly half of the total mean annual effective dose to the population in these countries. The radon levels and the calculated mean effective doses in the Nordic countries are shown in Table 1.

TABLE 1. LEVELS OF ^{222}Rn IN DWELLINGS IN THE NORDIC COUNTRIES AND THE CORRESPONDING CALCULATED MEAN ANNUAL EFFECTIVE DOSES [1,2,4,5,6,7]

Country	^{222}Rn concentration, Bq m^{-3}	Annual effective dose[1], mSv a^{-1}
Denmark	47	0.8
Finland	123	2.1
Iceland	8	0.1
Norway	75	1.3
Sweden	108	1.8

[1] Calculated using the dose conversion convention recommended by the ICRP [3]. 80 percent occupancy has been assumed.

The levels of ^{220}Rn and its progeny have been investigated in Norway and Sweden. The estimated mean concentration of ^{220}Rn progeny (EET) in Norway is 0.3 Bq/m^3 [8] and in Sweden 0.5 Bq/m^3 [9] which according to UNSCEAR 1993 [4] would give an annual effective dose of about 0.1 mSv. ^{220}Rn gas would give less than 0.01 mSv per year.

1.2. Terrestrial gamma radiation

1.2.1. Outdoor gamma radiation

The gamma radiation outdoors in the Nordic countries vary from an absorbed dose rate in air of about 30 nGy h^{-1}(cosmic radiation at sea level) up to about 150 000 nGy h^{-1} over small areas of uranium mineralisations [10]. In Sweden the mean outdoor gamma radiation level has been calculated from air-borne measurements. In Finland and Norway the outdoor gamma radiation has been surveyed by measurements from cars, while the levels in Denmark and Iceland have been estimated from point measurements in different parts of the countries. In Sweden about 1 % of the surface area consists of alum shale with a gamma radiation level from 100 nGy h^{-1} to 300 nGy h^{-1}. In the Bohus granite area in the western part of Sweden the gamma radiation in quite large areas is between 150 nGy h^{-1} and 250 nGy h^{-1}, locally up to about 400 nGy h^{-1} [10]. Finland has a rather large area of uranium-rich Rapakivi granite in the south-eastern part of the country with gamma radiation levels from 150 nGy h^{-1} to more than 200 nGy h^{-1} [11]. The mean terrestrial outdoor gamma radiation levels in the Nordic countries are shown in Table 2.

1.2.2. Indoor gamma radiation.

Surveys of the levels of gamma radiation indoors have been conducted in Denmark, Finland, Norway and Sweden. For Iceland the levels have been estimated. Due to the geological conditions the levels are highest in Finland, Norway and Sweden. In Sweden lightweight concrete based on uraniferous alum shale was used extensively as a building material between about 1930 and 1975. This material, called "blue concrete" in Sweden because of its dark bluish-grey colour, contains between 600 and 2 600 Bq kg^{-1} of ^{226}Ra [12]. The gamma radiation in dwellings built from this material varies from about 200 nGy h^{-1} to more than 1 000 nGy h^{-1} depending on the concentration of ^{226}Ra and the number of walls containing the material. In the 1975 building stock about 10 % of the building material used was "blue concrete". The mean levels of indoor gamma radiation in the Nordic countries are shown in Table 2.

TABLE 2. MEAN TERRESTRIAL OUTDOOR AND INDOOR GAMMA RADIATION LEVELS IN THE NORDIC COUNTRIES [4,5,6].

Country	Outdoors Absorbed dose rate in air, nGy h^{-1}	Indoors Absorbed dose rate in air, nGy h^{-1}
Denmark	38	63
Finland	65[1]	80[1]
Iceland	28	23
Norway	73	95
Sweden	56[2]	110

[1]Population weighted mean
[2]A population weighted mean has not been calculated but would probably be as high or higher as in Finland and Norway

1.3. Naturally occurring radionuclides in drinking water

In water from wells drilled in bedrock the concentrations of naturally occurring radionuclides such as ^{222}Rn, ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{210}Po, ^{238}U and ^{234}U can be high. Drinking water from waterworks using surface water usually contain very low levels of natural radionuclides. The levels of natural radionuclides in water from dug wells are on the average considerably lower than in drilled wells. The use of drilled wells is becoming increasingly popular in the Nordic countries, especially in Finland, Norway and Sweden. Private wells are common in sparsely populated areas without common water supplies. Drilled wells are also used for small municipal waterworks and as water supplies for small villages, schools, hospitals etc. According to UNSCEAR 1993 the annual effective dose to an infant in a household with a radon concentration of 1 000 Bq l^{-1} in the drinking water is 7 mSv. For a ten year old child the effective dose would be 1.5 mSv and for an adult 0.5 mSv (with an assumed annual consumption of untreated water of 100 l for an infant, 75 l for a ten year old child and 50 l for an adult) [4].

A survey of ^{222}Rn and ^{226}Ra from waterworks and a random sample of 500 private drilled wells in Sweden was conducted in the 1980's. The levels of ^{222}Rn were low for water from waterworks, the mean ^{222}Rn concentration was about 20 Bq l^{-1}, while the mean concentration for drilled wells was 212 Bq l^{-1} [13]. The highest concentration found so far in Sweden is 57 000 Bq l^{-1}. In total there are about 200 000 drilled wells in Sweden utilised all year round by permanent residents and 200 000 - 300 000 drilled wells utilised by non-permanent recreational residents. An estimated number of 20 000 - 30 000 permanently used wells, about 10 percent, have radon levels exceeding 500 Bq l^{-1}, and about 10 000 exceeding 1 000 Bq l^{-1}.

In Finland about 200 000 people use water from drilled wells. More than 7 000 private wells have been studied. Half of these wells have ^{222}Rn levels exceeding 500 Bq l^{-1}. The average ^{222}Rn concentration in water from drilled wells is 930 Bq l^{-1} and from wells dug in soil 76 Bq l^{-1}. The highest concentrations of ^{222}Rn (maximum 77 000 Bq l^{-1}) and uranium (maximum 12.4 mg l^{-1}) have occurred in southern Finland in uraniferous granite areas [14].

In Norway about 120 000 of the homes use ground water from drilled wells in bedrock. Samples from about 3 500 drilled wells have been analysed for radon. The average concentration was between 100 and 200 Bq l^{-1}. About 13 percent of the wells had radon levels exceeding 500 Bq l^{-1} [15]. In Denmark measurements on natural radioactivity were made in the 1980's. Only in one case was the radon concentration elevated [25].

2. CONTROL OF INDOOR RADON

2.1. Sweden

2.1.1. Dwellings

The strategy for the Swedish radon programme was drawn up by the governmental Radon Committee in 1979 and was finally decided by the Government in 1985. The long term goal for this programme is to reduce the mean radon concentration in dwellings to 50 Bq m^{-3}, about half the present mean level. In this context radon concentration means the annual average of the radon concentration.

For new buildings high radon levels should be avoided by taking preventive measures before and during the building of the house. The action level for new buildings, set by the central building authorities, is 200 Bq m^{-3}. Existing homes with radon concentrations exceeding the action level (today 400 Bq m^{-3}) should be located and the levels reduced by remedial measures. Also in homes with levels between 200 and 400 Bq m^{-3} the concentrations should be reduced if it can be done with relatively simple measures. If the radon concentration in a home exceeds 400 Bq m^{-3} it can be declared as unsanitary and the owner can be forced to take countermeasures. The owner of a detached house can get financial support from the Government for half the cost of the remedial measures up to a maximum contribution of 15 000 Swedish Crowns (equivalent to about 2 000 USD).

The Swedish Radiation Protection Institute, SSI, has the overall responsibility to follow the development of radiation in dwellings, particularly for measurement techniques and risk estimation. SSI has estimated that radon in dwellings could cause between 300 and 1 500 lung cancer deaths each year in Sweden. This estimation is based primarily on epidemiological studies of miners and the Swedish national epidemiological study of radon in dwellings and lung cancer. SSI has also issued protocols for measurements of radon in dwellings for the purpose of quality assurance. In the protocol is stated that measurements should be conducted during the heating season and that the measuring period should be at least two months. The National Board of Health and Welfare is responsible for setting the action level for radon in existing homes. The action level for new buildings is included in the building code issued by the National Board for Housing and Planning.

The local health authorities at the municipal level are responsible for searching for homes with elevated radon levels and for making measurements in homes suspected to have high radon levels. They are also responsible for general information and advice to the public about the health risks involved with radon. The local building authorities are responsible for control of radon from the ground. The ground should be classified into three different categories of risk, as shown in Table 3. Technical building requirements to prevent high radon levels in new buildings are associated to each risk category.

Before a building permit is granted the local building authorities are responsible for checking that the risk for high indoor radon concentrations has been taken into consideration. The builder is responsible for that the radon concentration in the new building is below 200 Bq m^{-3}. The local building authorities also have the responsibility for information and advice to the public about suitable remedial measures [18]. Today Sweden has about 150 000 homes with ^{222}Rn concentrations exceeding the action level 400 Bq m^{-3} and about 500 000 exceeding 200 Bq m^{-3}.

TABLE 3. SUMMARY OF RECOMMENDATIONS REGARDING CLASSIFICATION OF THE GROUND IN SWEDEN ACCORDING TO THE RISK FOR INDOOR RADON AND THE TYPES OF PROTECTIVE MEASURES [17].

Classification of risk	Percentage of the Swedish surface	Types of ground	Technical building requirements
High risk areas	10 %	Uranium-rich granites, pegmatites and alum shale. Highly permeable soils, for example gravel and coarse sand. Radon 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 soil gas 10 000 - 50 000 Bq m^{-3}	Radon protective construction. No apparent fissures or leaks 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 gas concentration in the soil gas is < 10 000 Bq m^{-3}	Traditional

2.1.2. Workplaces

For existing above ground workplaces the action level is the same as for dwellings, 400 Bq m^{-3} and for new workplaces the planning level is the same as for new dwellings, 200 Bq m^{-3}. For mines and underground excavations the exposure limit from 1 July 1997 will be 2.5 MBq h m^{-1} per year which corresponds to 1 500 Bq m^{-3} at 1 600 working hours per year.

2.2. Finland

2.2.1. Radon in dwellings

Finland has new legislation since 1992. In the Radiation Act the Ministry of Social Affairs and Health was authorised to set limits for radon in homes. The Finnish Centre for Radiation and Nuclear Safety, STUK, is the competent authority. The action level for existing houses is 400 Bq m^{-3}. Future buildings should be planned and constructed in such a way that the radon concentration does not exceed 200 Bq m^{-3}. As in Sweden radon concentration here means the annual average radon concentration. Measurements must be carried out using a method approved by STUK.

The local health authorities are responsible for defining areas with high indoor radon concentrations and for providing information on remedial measures. STUK helps the local authorities with measurement plans [19]. For remedial measures it is possible to get financial support with 20 percent of the total cost or at maximum 7 500 Finnish Marks, equivalent to about 1 500 USD.

Radon-prone areas for monitoring of radon at workplaces have been identified on the basis of radon concentration measured in 25 000 detached one-family homes. The 455 municipalities in Finland have been classified into four risk categories [20], see Table 4. Finland also have radon risk maps where geologic parameters have been combined with results from measurements in dwellings.

TABLE 4. CLASSIFICATION OF RADON-PRONE AREAS IN FINLAND FOR MONITORING OF RADON AT WORKPLACES [20].

Risk category	Percentage of measured homes exceeding 400 Bq m^{-3}	Number of municipalities
I	More than 25 % of the measured homes exceeding 400 Bq m^{-3}	14
II	10 - 25 % exceeding 400 Bq m^{-3}	68
III	1 - 10 % exceeding 400 Bq m^{-3}	154
IV	< 1 % exceeding 400 Bq m^{-3}	224

2.2.2. Radon in workplaces

Workplaces of different kinds are divided into two categories:

- Underground mines and other underground excavations
- All other workplaces

For mines and other underground excavations the action level is 400 Bq m^{-3} as an annual average (radon exposure 600 000 Bq h m^{-3}). If the action level is exceeded and remedial measures not successful or possible, the work should be classified as radiation work and personal monitoring of doses and health surveillance of the workers shall be arranged [20].

The action level for radon at workplaces above ground is set by STUK to 400 Bq m^{-3}, averaged over the total number of annual working hours. The same limit also applies to public buildings. The monitoring of radon at above-ground workplaces has been focused on the radon prone areas. STUK has measured the radon concentration in more than 5 000 private and municipal workplaces in municipalities in categories I and II. 10 percent of the measured workplaces had radon levels exceeding 400 Bq m^{-3}. The mean concentration was estimated to be 260 Bq m^{-3} [20].

2.3. Norway

2.3.1. Radon in dwellings

The Norwegian recommendations for radon in dwellings were given in 1995 by the Norwegian Radiation Protection Authority, NRPA. It is recommended that remedial measures should be taken at levels above 200 Bq m^{-3}. At levels above 400 Bq m^{-3} even more extensive measures are justified. There is no financial support for remedial measures. The radon levels in new buildings should not exceed 200 Bq m^{-3}.

2.3.2. Radon in workplaces

For above-ground workplaces the recommended action levels are the same as for dwellings. For mines and other underground facilities (hydroelectric power stations, defence installations, tunnels etc.) the action level is 1 000 Bq m^{-3} [22].

2.4. Denmark

Denmark has no formal radon policy. The recommendation to build airtight against the ground has been adopted in the building code. So far Denmark has no recommended or legally binding action level for remedial measures in existing dwellings and no limit for the allowed radon concentration in new dwellings. The National Institute of Radiation Hygiene has proposed that the discussions of establishing a Danish limit for new dwellings should be based on a radon gas concentration of 200 Bq m^{-3} [16].

3. CONTROL OF GAMMA RADIATION

3.1. Sweden

There is no action level in Sweden for gamma radiation in existing buildings. For new buildings the planning level is 0.5 μSv h^{-1}. For building materials two exemption levels are recommended: The activity concentration of ^{226}Ra should not exceed 200 Bq kg^{-1} and the gamma index, m_γ, should be less than 1, where $m_\gamma = C_K/10\,000 + C_{Ra}/1\,000 + C_{Th}/700$. C_K, C_{Ra} and C_{Th} are the activity concentrations in Bq kg^{-1} of ^{40}K, ^{226}Ra and ^{232}Th of the material. For often used outdoor areas such as playgrounds it is recommended that the gamma radiation does not exceed 1 μSv h^{-1} [18].

3.2. Finland

In Finland STUK has issued requirements on radioactivity in construction materials and fuel peat and peat ash [23]. A set of activity indices are used to assess whether or not the requirements are met, see Table 5. If the value of the activity index exceeds 1 the responsible party is required to show that the safety requirements have been met. If the value is 1 or less the material can be used without restriction. The basis for the requirements is that the additional effective dose from gamma radiation should not exceed 1 mSv per year from building materials, 0.1 mSv per year from materials used in roads, playgrounds etc. The same is valid for landfill materials or if peat ash is used in construction materials. The effective dose to a worker handling fuel peat or peat ash should not exceed 1 mSv per year.

TABLE 5. ACTIVITY INDICES FOR CONSTRUCTION MATERIALS, FUEL PEAT AND PEAT ASH IN FINLAND [23] .

Type of material	Activity index
Building materials	$I_1 = C_{Th}/200 + C_{Ra}/300 + C_K/3\,000$
Materials used in roads, playgrounds etc.	$I_2 = C_{Th}/500 + C_{Ra}/700 + C_K/8\,000 + C_{Cs}/2\,000$
Landfill materials	$I_3 = C_{Th}/1\,500 + C_{Ra}/2\,000 + C_K/20\,000 + C_{Cs}/5\,000$
Fuel peat and peat ash	$I_4 = C_{Th}/3\,000 + C_{Ra}/4\,000 + C_K/50\,000 + C_{Cs}/10\,000$

C_{Th}, C_{Ra}, C_K and C_{Cs} are the activity concentrations of ^{232}Th, ^{226}Ra , ^{40}K and ^{137}Cs of the material in Bq kg^{-1}.

3.3 Norway

Norway uses the same gamma index for building materials as Finland, see index I_I in Table 5. For filling materials to be used under or around buildings the activity concentration of ^{226}Ra should be less than 300 Bq kg^{-1} [22].

3.4. Denmark

Denmark has no specific regulations for radioactivity in building materials.

A system of environmental labelling has been established between the Nordic countries for boards and tiles, the "Swan Label". The indices $m_{Ra} = C_{Ra}/100$ and $m_\gamma = C_{Th}/200 + C_{Ra}/300 + C_K/3\,000$ are used. The criteria are only applicable for materials used indoors. Similar criteria for concrete are on its way.

4. CONTROL OF NATURAL RADIOACTIVE ELEMENTS IN DRINKING WATER

4.1. Sweden

The Swedish Food Administration has proposed limits for radon in drinking water in 1995, see Table 6. If accepted, the limits will be mandatory for public waterworks but will only be regarded as recommendations for private wells.

TABLE 6. PROPOSED LIMITS FOR RADON IN DRINKING WATER IN SWEDEN.

^{222}Rn concentration, Bq l^{-1}	Subject to limits	Comments
100	Public water supplies	Mandatory action level for water delivered from public waterworks
500	Private water supplies	Recommended action level. Concerns the maximum concentration in water given to children under 5 years of age
1 000	All drinking water	Unfit for consumption

4.2. Finland

In Finland STUK has issued safety requirements for household water. The basis is that the effective dose due to radioactivity in water should not exceed 0.5 mSv per year. ^{222}Rn released from the water to indoor air is not taken into account when assessing the dose. The activity index $I = C_\alpha + C_\beta + C_{Rn}$ is used to assess if the safety requirement is met, where C_α, C_β, and C_{Rn} are the gross alpha activity, gross beta activity and the ^{222}Rn concentration of the water. Provided no other radionuclides are present in the water the maximum radon concentration would be 300 Bq l^{-1}. If the value of the index exceeds 1, the concentrations of the different radionuclides should be determined and used to calculate a new activity index. If this index still exceeds 1 remedial measures must be taken to reduce the radioactivity of the water. The safety requirements are not applied in connection with private wells, but only to waters supplied by waterworks and professional producers of beverages [24].

4.3 Norway

Norway has a limit of 500 Bq l^{-1} for ^{222}Rn concentration in drinking water, issued by the NRPA [22].

4.4. Denmark

Measurements have been conducted of ^{222}Rn and ^{226}Ra in water [25] but Denmark has no explicit limits for natural radioactivity in drinking water.

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