WORKPLACES WITH ELEVATED LEVELS OF EXPOSURE TO NATURAL RADIATION: THE SITUATION IN SWEDEN

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1 ABSTRACT

Because of the geological conditions, with an abundance of granites and pegmatites rich in uranium and thorium together with large areas of uranium-rich alum shale, exposure to natural radiation is not unusual in certain types of industries and other work activities in Sweden. Although no representative survey of radon at regular workplaces has been carried out in Sweden, smaller surveys and the high radon concentrations in dwellings indicate that workplaces with elevated radon levels are common in Sweden. Very high levels of indoor radon have been found at waterworks. Radon in mines has been regulated in Sweden since 1972 and radon in other workplaces since 1990. The situation in schools and day-care centres was thoroughly investigated in 2000. The estimated number of school and child-care buildings with radon concentrations exceeding the action level, 400 Bq/m^3, is 800; about 200 of these have been identified and in about 100 buildings remedial measures have been taken. Regulations on natural radioactivity in building materials (for new buildings) have been in force since 1980. Lightweight concrete produced from uranium-rich alum shale was in use between 1929 and 1975. Almost 400,000 dwellings, 10 per cent of the Swedish building stock, contain this material. The situation at NORM (Naturally Occurring Radioactive Material) industries is currently being investigated. Since the beginning of the 1950s, it has been known that residues from several industrial activities contain enhanced levels of natural radioactivity. Some examples are burnt alum shale from lime burning, radium-rich slag from metal production and waste gypsum from sulphuric acid production. The impact of the exposure from these residues is now being reinvestigated. So far no systematic search for hitherto unknown work activities, where substantial exposures from natural radiation could occur, has been initiated. For the protection of aircrew from cosmic radiation, the responsible Swedish authorities have recommended an international solution according to a proposal made by the Joint Aviation Authorities.

2 INTRODUCTION

Sweden, and also Finland and Norway, have problems with elevated natural radioactivity in the ground and in some building materials. This is because of the geological conditions with an abundance of granites and pegmatites rich in uranium and thorium. Moreover, Sweden and Norway have large areas of uranium-rich alum shale. An overview of natural radiation in the Nordic countries is presented in “Naturally Occurring Radioactivity in the Nordic countries – Recommendations” (1).

About 75 per cent of Sweden has been covered by airborne measurements of natural radioactivity, mostly as part of the search for uranium between 1956 and 1984. Most municipalities have produced local radon risk maps, based primarily on geological information.

Maps are also available of areas with enhanced uranium and thorium concentrations and of areas where the ground has a high permeability, e.g. deposits of gravel and coarse sands. High permeability soils, for instance gravel in eskers, present an enhanced risk for radon in buildings. Recently, a preliminary risk map was produced for radon in water from drilled wells based on a combination of geological information and measurement results.

The most important problem with occupational exposure from natural radiation is radon at workplaces. Sweden has a mean radon level in dwellings of 108 Bq/m^3. Using the dose conversion convention recommended by the ICRP, 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. The most important source of indoor radon is the ground. Other sources are building materials and radon-rich household water. Between 1929 and 1975, a type of lightweight concrete based on alum shale was manufactured and it was used as a building material in nearly 400,000 dwellings and an unknown number of other buildings in Sweden. The contribution to indoor radon levels from this material can be up to about 1,000 Bq/m^3 if the air exchange rate is low. The gamma radiation levels in these buildings are usually between 0.3 and 1.2 µSv/h. Sweden has about 200,000 drilled wells utilised all the year round by permanent residents. It is estimated that as many as 10,000 to 15,000 of these wells have radon levels exceeding 1,000 Bq/l and 80,000 – 100,000 exceeding 100 Bq/l.

3 SUPERVISION OF EXPOSURE FROM NATURAL RADIATION AT WORKPLACES

In Sweden, indoor radon and gamma radiation in new buildings have been regulated since 1980 (2). Joint recommendations for natural radiation were first published by the Nordic radiation protection authorities in 1986 (3). A new, totally revised version of these recommendations was published in 2000 (1).

3.1 Supervision of radon

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 action level is expressed as an exposure limit of 2.5 MBq h m^{-3} per year which corresponds to 1,500 Bq/m^3 for 1,600 working hours per year. All the action levels are compulsory. The regulatory body is the Swedish Work Environment Authority, the SWEA. Inspections are carried out by the Work Environment Inspectorate, an integrated part of the SWEA.

3.2 Supervision of gamma radiation

There is no action level in Sweden for gamma radiation in existing buildings. For new buildings the planning level is 0.5 μSv/h. For building materials, two exemption levels are recommended by SSI: The activity concentration of ^{226}Ra should not exceed 200 Bq/kg (as a source of indoor radon) and the gamma index, m_{μ} should be less than 2, where $m_{\mu} = C_K/3000 + C_{Ra}/300 + C_{Th}/200$. C_K, C_{Ra} and C_{Th} are the activity concentrations in Bq/kg of ^{40}K, ^{226}Ra and ^{232}Th of the material. For outdoor areas in frequent use, such as playgrounds, it is recommended that the gamma radiation does not exceed 1 μSv/h (1).

4 RADON AT WORKPLACES

For ordinary above-ground workplaces, only a couple of smaller surveys have been carried out, but the authorities involved have judged the situation to be fairly well under control. Measurement protocols for radon in dwellings have been in use since 1981, the last edition was issued in 1994. A proposal for a measurement protocol for workplaces is being discussed with the SWEA.

4.1 Above-ground workplaces

No representative survey of radon in ordinary, above-ground workplaces has been conducted in Sweden. The SWEA made an investigation of about 150 workplaces in 1996. The investigated premises (not randomly selected) were chosen in buildings where high radon levels could be expected primarily due to radon from the ground, but measurements were also performed at workplaces built from alum shale-based lightweight concrete. About 10 per cent of the investigated workplaces had radon levels exceeding 400 Bq/m^3 (4). The conclusion must be, although the sampling was not representative, that several tens of thousands of workplaces in Sweden have radon levels exceeding the action level of 400 Bq/m^3.

Most Swedish municipalities have made extensive measurements in schools and day-care centres. The number of buildings for schools and day-care centres in Sweden is estimated to be 25,000 with a total of about 125,000 premises. Roughly 25,000 of these premises have been measured for radon. The estimated number of buildings with radon concentrations exceeding 400 Bq/m^3 is 800 (but 2,800 exceeding 200 Bq/m^3). About 200 buildings with radon levels exceeding 400 Bq/m^3 have been identified and remedial measures have been taken in about 100 of them. About 1,000 buildings with premises exceeding 200 Bq/m^3 have been identified. It is not known how many of those have been mitigated (5).

4.2 Mines

Radon measurements have been performed in Swedish mines since the end of the 1960s. When the measurements started, the radon levels in some of the mines were quite high. At that time Sweden had 55 mines and the number of miners was approximately 5,000. After four years of intensive work with remedial measures, the radon levels had been reduced significantly. Today, the radon situation in the Swedish mines is satisfactory. The exposure to radon is normally well below the exposure limit. The number of underground mines is about 25 and the number of miners 3,500.

4.3 Other underground installations

Radon levels in other underground installations such as hydroelectric power stations, telecommunication installations etc. is supervised by the SWEA and the Work Environment Inspectorate. Defence installations are supervised by a special unit of the defence authorities. Most of these premises are sufficiently well ventilated, but continuous supervision is necessary. Many of the premises are only used irregularly.

4.4 Waterworks

In Sweden, many waterworks, especially the smaller ones, use ground water from drilled wells or surface water that has been filtered through deposits of sand or gravel. In water from drilled wells, the radon concentration can be very high, up to 85,000 Bq/l has been found. The radon levels in filtered groundwater are generally lower, but activity concentrations of up to 200 Bq/l are not uncommon. When water with elevated radon concentrations is processed in a waterworks, radon is released into the air. If the water is processed inside a building the indoor radon concentrations can be very high. In surface water originating directly from a lake or a river the radon concentrations are normally too low to cause problems. Several waterworks have been investigated by local authorities in co-operation with the SWEA and SSI. In a number of waterworks, very high indoor radon levels have been found. In central Sweden, mean radon levels of up to 18,000 Bq/m^3, with peaks exceeding 50,000 Bq/m^3, have been found in waterworks using ground water with radon concentrations of about 100 Bq/l (6). It is quite possible that employees of waterworks can receive doses exceeding 20 mSv per year (calculated according to the ICRP dose conversion convention). On the initiative of SSI and the National Food Administration, the SWEA has started a more extensive study of indoor radon at workplaces using large volumes of ground water, including public baths, the food industry, laundries and certain processing industries, for instance paper mills. The study will be made during 2001.

5 NORM INDUSTRIES

A survey for further identification of industries with potential problems with enhanced natural radiation is in progress. However, the types and numbers of such industries are already fairly well known to SSI and the SWEA .

5.1 Sulphuric acid production

This is probably no problem today. The activity concentrations in the ores that are used today are low. In southern Sweden several hundreds of thousands of tons of waste gypsum from a big plant for sulphuric acid production were deposited on a small island, from the 1940s until 1992. The activity concentration of ^{226}Ra in the waste gypsum is 400 to 650 Bq/kg. The gamma radiation level above the deposited gypsum is 0.3 to 0.4 µSv/h with some local maxima of 0.5 µSv/h.

5.2 Metal production

The ores used nowadays for metal production in Sweden normally have low levels of natural radioactivity. Radium-rich slag from metal production (100-200 Bq/kg) has sometimes been used as filling material for building construction and this can cause high radon levels indoors. In earlier years, slag was also used as a building material, for example in wall tiles, and this can cause gamma radiation levels of 1-2 µSv/h.

5.3 Foundry sands

Sweden has about 10 large foundries. Measurements have been made at a company importing zircon sand. The measured gamma radiation levels in the warehouse in the vicinity of the stored sacks were 2-3 µSv/h. The activity concentrations of ^{232}Th and ^{226}Ra in the sand were about 500 and 4,300 Bq/kg respectively. This area will be investigated further.

5.4 The oil and gas industry

Sweden has no oil production of its own. There are two large refineries, one on the west coast and one on the east coast that can have problems with radium-rich scales in tubes and pumps. More knowledge is needed in this field. The use of natural gas is probably no problem. Radon and radon progeny concentrations have been measured in pipes and filters and no high levels have been found.

5.5 Thoriated welding rods

This is a potential problem during welding and grinding of the rods. If the working rules are followed the doses are low. SSI has dealt with the problems that have been recognised so far, but this area will be further investigated.

5.6 Natural stone

Quarrying is an important industry in Sweden. The Swedish granites, acid gneisses and porphyries are hard rock types that are extremely durable. The quarried rock is used for construction material, ornamental stones, gravestones etc. Some of the best granites have considerably higher activity concentrations of uranium and thorium than most other rock types. Concentrations of ^{238}U of 120-450 Bq/kg, ^{232}Th 120-360 Bq/kg and ^{40}K of 1200-2000 are not uncommon. There are probably no radiation protection problems in the working environment at the quarries. The estimated maximum annual dose during quarrying is 0.6 mSv. Some granites with elevated contents of uranium and thorium can cause problems with enhanced gamma radiation levels when used as building material (7).

5.7 Peat ash

Peat is used as a bio-fuel in Sweden, so far on a rather small scale. Peat excavation is controlled by the Swedish Geological Survey and sampling of uranium is required before a concession is granted. For this reason the peat that is used in Sweden usually contains low levels of uranium and the occupational doses from natural radiation to excavation workers are not a significant problem.

5.8 Paper mills and waterworks

Large volumes of water are processed in paper mills and waterworks. Apart from the problems with high indoor radon levels due to radon escape from the water, radium-rich scales can form on the inside of tubes and pumps. This is hardly a major radiation protection problem at the workplace, although further investigation is needed, but rather a problem when the tubes and pumps eventually appear at the entrance to the scrap yard.

5.9 Residues of burnt alum shale

At about a hundred places in Sweden there are deposits of burnt alum shale. Alum shale has been used for the extraction of alum, $KAl(SO_4)_2$, used for tanning, for burning limestone in the field and for a short period, during the Second World War, as a raw material for oil production. These deposits are in some places very large, several hundred metres in both directions and up to 20 metres high. The estimated quantity of deposited burnt alum shale is several million tons. The gamma radiation above these deposits is about 0.5 to 1.2 µSv/h. The radon levels in the soil air in these deposits can be very high, up to 2,000,000 Bq/m^3. In some places in Sweden large numbers of residential buildings have been built on such deposits (7).

6 BUILDING MATERIALS

Light-weight concrete based on uranium-rich alum shale was produced in Sweden between 1929 and 1975. Because of its bluish colour it is often called “blue concrete”. The activity concentration of ^{226}Ra in the material varies between 700 Bq/kg and 2,600 Bq/kg, depending on where it was produced. Nearly 400,000 dwellings in Sweden (about 10 percent of the building stock) have been built using blue concrete. The gamma radiation levels in the dwellings are usually between 0.3 µSv/h and 1.2 µSv/h, depending on the activity concentration in the material and the amount included in the building. The indoor radon levels in such buildings can reach 1,000 Bq/m^3 if the air exchange rate is low. More than 20 million tons were produced until the production was discontinued in 1975. People living in houses built from “blue concrete” can receive an annual effective dose from the building material of up to 4 mSv.

7 PROTECTION OF AIR CREWS

For the protection of aircrews from cosmic radiation the responsible Swedish authorities have recommended an international solution in accord with the proposal made by the Joint Aviation Authorities (8).This proposal is in accord with the EU recommendations (9).

The Nordic Radiation Protection and Civil Aviation authorities have discussed common Nordic recommendations for the control of exposure of aircrew to cosmic radiation. The recommendations discussed follow the EU recommendations (9). Some of the points that are discussed are:

- The operators of commercial air transports shall inform the aircrew of the risks from occupational exposure to cosmic radiation. Female aircrew shall know of the need for early declaration of pregnancy.
- Estimation of effective doses to the aircrew shall be based on generic route doses published by the Nordic Radiation Protection Authorities or on route doses calculated with special computer programmes.
- The operator shall estimate the dose to each individual crew member annually and inform them about the dose and report to the national authorities a summary of the estimated effective doses to the crew members. A list of crew members with an estimated annual effective dose equal to or exceeding 6 mSv shall be submitted.
- Working schedules shall be organised in such a way that estimated doses exceeding 6 mSv per year are avoided. When a pregnant crew member has informed the operator of her condition, her working schedule should be organised in a way that the dose will not exceed 1 mSv during the remainder of the pregnancy.

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