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Workplaces with elevated levels of exposure to natural radiation: The situation in Sweden

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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 from 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 performed in Sweden, smaller surveys and the high radon concentrations in dwellings indicate that workplaces with elevated radon levels are frequent in Sweden. Very high levels of indoor radon have been found in 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 for 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 percent of the 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 is 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 up to now 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 the proposal made by the Joint Aviation Authorities.

Natural radioactivity in Sweden

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.

About 75 percent 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 for radon in water from drilled wells based on a combination of geological information and measurement results was produced.

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 for indoor radon is the ground. Other sources are building materials and radon-rich household water. Between 1929 and 1975 a light-weight concrete based on alum shale was manufactured and used as 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 1.0 μSv/h. Sweden has about 200 000 drilled wells utilised all year round by permanent residents. An estimated number of 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.

Control of exposure from natural radiation at workplaces in Sweden

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

Control 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 at 1 600 working hours per year. All the action levels are compulsory. The regulatory body is the Swedish Work Environment Authority, SWEA. Inspections are carried out by the Work Environment Inspectorate.

Control 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_γ, should be less than 2, where $m_\gamma = C_K/3000 + C_{Ra}/300 + C_{Th}/200$. 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 often used outdoor areas such as playgrounds it is recommended that the gamma radiation does not exceed 1 μSv/h.

Control of cosmic radiation exposure to air crew

For the protection of aircrew from cosmic radiation the responsible Swedish authorities have recommended an international solution according to the proposal made by the Joint Aviation Authorities (Notice of Proposed Amendment OPS-23).

Radon in workplaces

For ordinary above-ground workplaces only a couple of smaller surveys have been performed, but the authorities involved have judged the situation to be rather well in hand. 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 SWEA.

Above-ground workplaces

No representative survey of radon in ordinary, above-ground workplaces has been conducted in Sweden. 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 in workplaces built from alum shale-based lightweight concrete. About 10 percent of the investigated workplaces had radon levels exceeding 400 Bq/m^3. 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 altogether 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 (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.

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 5000. After four years of intensive work with remedial measures the radon levels were 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.

Other underground installations

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

Waterworks

In Sweden many waterworks, especially smaller ones, use ground water from drilled wells or surface water that has been infiltrated 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 measured. The radon levels in infiltrated groundwater are generally lower, but activity concentrations of several hundred 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 emanating 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 co-operation with SWEA and SSI. In a number of waterworks very high indoor radon levels have been found. In central Sweden mean radon levels 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. 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, SWEA has started a more extensive study of indoor radon in workplaces using large volumes of ground water, including public baths, food industry, laundries and certain processing industries, for instance paper mills. The study will be performed during 2001.

Industries with potential problems with enhanced natural radiation other than radon

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

Sulphuric acid production: Probably no problem today. The activity concentrations in the ores that are used today are low. In southern Sweden several 100 000 tons of waste gypsum from a big plant for sulphuric acid production have been deposited on a small island, from the 1940s until 1992. The activity concentration of ^{226}Ra in the waste gypsum is 400 – 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.

Metal production: The ores used for metal production in Sweden today 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 can cause high radon levels indoors. Slag has also in earlier years been used as a building material, for example as wall tiles, and can cause gamma radiation levels of 1-2 μSv/h.

Foundry sands: Sweden has about 10 big foundries. Measurements have been performed at a company importing zircon sand. The measured gamma radiation levels in the warehouse in the vicinity of the stored sacks were about 0.3 μSv/h. This area will be further investigated.

Oil and gas industry: Sweden has no oil production of its own. There are two big 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.

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.

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 can cause problems with enhanced gamma radiation levels when used as building material.

Peat ash: Peat is used as 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 concession is granted. Therefore 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.

Paper mills and waterworks: Large volumes of water are being processed in paper mills and waterworks. Apart from the problems with high indoor radon levels due to radon escape from the used water, radium-rich scales can be formed 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 of the scrap yard.

Residues of burnt alum shale: In 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 raw material for oil production. These deposits are in some places very large, several hundred metres in square 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 erected on such deposits.

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 radium-226 in the material varies between 700 Bq/kg and 2 600 Bq/kg, depending on where it was produced. Nearly 400 000 dwellings (about 10 percent of the building stock) have been built from blue concrete in Sweden. The gamma radiation levels in the dwellings are usually from 0.3 μSv/h to 1.2 μSv/h, depending on the activity concentration in the material and the amount included in the building. The contribution to the indoor radon levels can reach 1 000 Bq/m^3 if the air exchange level is low. More than 20 million tons were produced until the production was terminated in 1975. People living in houses built from blue concrete can get an annual effective dose from the building material of up to 4 mSv.

Protection of air crew

For the protection of aircrew from cosmic radiation the responsible Swedish authorities have recommended an international solution according to the proposal made by the Joint Aviation Authorities, JAA, in the Notice of Proposed Amendment OPS-23.

The Nordic Radiation Protection and Civil Aviation authorities have discussed common Nordic recommendations for the control of exposure of aircrew to cosmic radiation. The discussed recommendations follow the EU recommendations in "Radiation Protection 88". Some of the points that are discussed are:

- The operators of commercial air transports shall inform the aircrew of the risks of 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 crewmember annually and inform them about the dose and report to the national authorities a summary of the estimated effective doses to the crewmembers. A list of crewmembers with an estimated annual effective dose equal to or exceeding 6 mSv shall be reported.
- Working schedules shall be organised in such a way that estimated doses exceeding 6 mSv per year are avoided. When a pregnant crewmember 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.