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High indoor radon concentrations in some Swedish waterworks

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Abstract
High indoor radon concentrations in buildings used for water treatment are not uncommon. When raw water is processed in an open system radon escapes from the water to the indoor air of the premises. It is not unusual that the staff of the waterworks have their offices in the building where the water is processed. If large volumes of water are processed and the evaporated radon can reach the workplaces the indoor radon concentration can be very high even if the radon concentration of the raw water is moderate. Groundwaters from aquifers in bedrock and soil and surface water that has been infiltrated through deposits of sand or gravel have the potential to cause high indoor radon levels. In surface water emanating directly from a lake or a river the radon concentrations are normally too low to cause problems. Three waterworks in central Sweden have been studied, Ludvika, Fredriksberg and Kolbäck. The radon concentrations in the raw water of these waterworks are from 85 Bq/l to 300 Bq/l. Average indoor radon concentrations exceeding 17 000 Bq/m^3 have been measured in Ludvika with peaks of almost 37 000 Bq/m^3. In Kolbäck radon concentrations up to 56 000 Bq/m^3 have been measured. It is quite possible that employees of waterworks can receive doses exceeding 20 mSv per year (calculated according to ICRP:s dose conversion convention). Measurements of radon and gamma radiation from the waterworks are reported and methods to lower the indoor radon concentrations are discussed.

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Introduction

In waterworks usually large volumes of water are treated. The water is aired, often in open systems, and chloride and other chemicals are added. Radon dissolved in the water is inevitably released into the air of the waterworks premises.

In Sweden about 50 percent of the drinking water is prepared from surface water, 25 percent from groundwater and 25 percent from artificially infiltrated groundwater (often water from lakes infiltrated in eskers). Sweden has approximately 2 100 public waterworks. A relatively small number of large waterworks, predominantly using surface water, serve the majority of the population. Use of surface water is especially common in densely populated areas. This means that most waterworks in Sweden are relatively small and a large number of them use groundwater or infiltrated water. 70 percent of the plants serve less than 1 000 consumers (Hult 1998).

The radon levels in surface waters are usually very low, less than 1 Bq/l. Normal radon concentrations in groundwater in soil aquifers in Sweden are 10 – 300 Bq/l. In drilled wells in normal bedrock typical radon levels are 50 – 500 Bq/l, in uranium-rich granites 300 – 4 000 Bq/l. The maximum radon concentration found in a drilled well in Sweden is 89 000 Bq/l (Nordic 2000).

The local health inspector of Ludvika municipality in central Sweden reported to the Swedish Radiation Protection Institute, SSI, that he had found high indoor radon levels at the waterworks in Ludvika and Fredriksberg. In May 2000 SSI visited these waterworks and the waterworks in Kolbäck to investigate the situation, study the remedial measures taken so far and make complementary measurements. At the same time the health risks were discussed with the personnel working at the waterworks. The action level for radon at workplaces in Sweden is 400 Bq/m^3. The regulatory body is the Swedish Work Environment Authority.

The personnel at the waterworks often work a couple of hours per day with surveillance of pumps and filters, cleaning reservoirs and handling the chemicals used in the water treatment processes. The same personnel very often serve several waterworks in the same area. It is common that other municipal workplaces, such as offices, are included in the waterworks buildings.

The concentrations of ^{226}Ra in groundwater in Sweden vary between 0.001 Bq/l and 0.3 Bq/l. In uranium-rich granites the levels are higher, a maximum of 8 Bq/l has been found in a drilled well. The dissolved radium often precipitates together with iron- and manganese hydroxide and can also be deposited as scales on the inside of tubes and pumps. Radon progeny will also deposited in filters containing activated charcoal and sand. Therefore elevated gamma radiation can sometimes be a problem from filters and pumps. Sometimes a filter can contain so much radium that it will act as a secondary radon source so that the radon concentration in the treated water will exceed the radon concentration in the water entering the filter.

The three waterworks studied, in Ludvika, Fredriksberg and Kolbäck are all situated in the central parts of Sweden, see map in Fig. X1.???

Inspections and measurements

Ludvika waterworks

The Ludvika waterworks serves the small town of Ludvika with water. It is situated on an esker (a postglacial formation of gravel and coarse sand, highly permeable to both air and water). The water originates from a small lake and is infiltrated in the esker. It is pumped up using cased wells and is then sprayed into small ponds in the vicinity of the waterworks in order to be re-infiltrated in the esker, Fig. X2. Trough two cased wells at the waterworks the water is pumped up into a mixing basin where the chemicals are added. The mixing basin is situated under the waterworks building. Air from the basin can reach the premises on the bottom floor of the building through an inspection opening in the floor, Fig x3. From the mixing basin the water is pumped into a 3 000 m^3 reservoir situated under the waterworks building. The treated water is pumped up into a high reservoir in the town before reaching the consumers. The waterworks has a staff of five people. The number of working hours per year have been between 200 – 800 hours.

On the average 6 000 m^3 of water passes the waterworks per day. The radon concentration in the raw water has been measured to be 85 Bq/l and in the treated water 75 Bq/l. According to the measurements performed by the municipal health authorities the average indoor radon levels in different rooms in the building varied from 1 200 Bq/m^3 to 18 000 Bq/m^3. Maximum values exceeding 35 000 Bq/m^3 had been recorded, se Table 1. The waterworks building also contains some offices and storerooms.

Table 1. Radon gas concentrations in different parts of the waterworks building in Ludvika according to measurements performed by the municipal authorities

Room	Before remedial measures, Bq/m^3	Maximum, Bq/m^3	After remedial measures, Bq/m^3
Control room	4 250	10 860	
Above mixing basin	17 870	36 900	40
Cellar outside reservoir	8 150		100
Canteen	1 200		40

The water is transported in a closed system until it reaches the mixing basin and is flushed over into the reservoir. The water flow in the mixing basin is very turbulent and radon is released from the open water surface to the air in the room situated above the mixing basin and from there it is spread to the other parts of the waterworks building. The reservoir is covered with a concrete roof . In the reservoir, radon is released from the water surface to the air contained between the water surface and the roof. When the water surface in the reservoir is raised as water is pumped in, the radon-rich air is forced via the mixing basin up into the building. This is the reason for the strong variations in the radon concentrations in the building, one example is shown in Fig.x.

Figur från Ludvika kommun, mätning vid blandningskammare.

To reduce the indoor radon levels a supply/exhaust ventilation system has been installed with a local extraction point (434 litre air per second) just above the water surface in the mixing basin, se Fig x. As can be seen from Table 1 the remedial action has been quite successful. The indoor radon levels are now 40 – 100 Bq/m^3.

<u>Fredriksberg waterworks</u>

The waterworks supplies the village of Fredriksberg and the neighbouring area with drinking water. It is situated on the shore of a small lake and the raw water is brought up by cased wells from an esker on a small island in the lake and pumped into the waterworks. The raw water has not been aired or further infiltrated before it reaches the waterworks. In the plant potassium permanganate and soda are added after which the water is aired and flocked ??? in open basins. The flocculation is removed by an open Carex filter. This implies that open water surfaces are exposed in the main hall of the waterworks and consequently release of radon into the indoor air. After that the water is treated in closed sand filters and is then stored in a reservoir situated under the waterworks building until it is pumped out into the distribution system. Apart from the main water treatment hall the building also contains a small laboratory and an office. The door between the main hall and the other parts of the building is normally closed.

Two people work regularly at the waterworks. They normally spend about five hours per day there, which corresponds to about 1 000 hours per year.

600 – 700 m^3 of water is treated per day. The radon concentration of the raw water has been measured to be 110 Bq/l. Samples have also been taken after the sand filters and from the outgoing water. The results were 40 Bq/l and 15 Bq/l, respectively. The radon concentration further out on distribution network has been measured to be 35 Bq/l ....

The average radon concentration in the main waterworks hall was measured by the municipal authorities, before any remedial measures had been taken, to 11 200 Bq/m^3. In the laboratory the average radon level was 7 000 Bq/m^3. In order to reduce the indoor radon levels the ventilation system has been improved and a local extraction point just above the water surface of the Carex filter has been installed. With the new ventilation system working the radon levels in the main hall and the laboratory are just below 400 Bq/m^3. At very cold weather the temperature in the building gets too low, so the ventilation system has to be shut off temporarily.

At our visit we made measurements in the main hall and the laboratory using continuous radon gas monitors. The result from the measurements in the main hall is shown in Fig. X. The doors to the plant had been closed for several days before our visit and the ventilation system had been shut off.

Gamma radiation measurements were performed on the water treatment equipment. Elevated gamma radiation levels were found at some of the pumps, 0.2 – 0,4 μSv/h and at a cooling radiator of a dehumidifier, 0.8 μSv/h. The gamma radiation was caused by radon progeny deposited on the cooling fins of the pumps and in the radiator.

Kolbäck waterworks

The waterworks supplies drinking water to the village of Kolbäck and the surrounding area. The waterworks is situated on the edge of a very long esker, Strömsholmsåsen, running through Kolbäck. The raw water is brought up by cased wells directly from the esker into the waterworks for treatment and subsequent distribution to the customers. The treatment plant was built recently, it was finished in 2000, see Fig x ???. Before that the water was distributed from an old waterworks situated close to the new one. From the old plant the water was pumped through a closed system directly out into the pipeline network without airing or any other treatment. The radon concentration of the water was 200 – 300 Bq/l. Since Sweden has an action level of 100 Bq/l for radon in public drinking water, the municipal authority that owns the waterworks had to take remedial action to reduce the radon level in the distributed water. That was one of the reasons for building the new plant. An INCA airing equipment, supplying 5 500 m^3 air per hour, was installed in the new waterworks building, Fig. X. After airing the water is stored in a 150 m^3 reservoir situated under the building. In direct connection to the main hall of the waterworks is a small control room and an office. Normally the door between the water treatment hall and the rest of the building is closed.

Five employees are working at the plant. Normally one person is performing maintenance and surveillance about half an hour per day, five days a week. The total working time per year is estimated to about 1 000 hours.

The average throughput is about 1 500 m^3 water per day. The radon concentration of the raw water is 200 – 300 Bq/l. After passing the airing equipment the radon concentration has been measured to be 90 Bq/l. The radon concentration of the distributed water is about 50 Bq/l.

Discussion

The experiences from the three investigated waterworks show that there is a substantial risk for high indoor radon concentrations when large volumes of groundwater are treated indoors in open systems. The radon concentration in the raw does not necessarily have to be high for the indoor radon levels to exceed 400 Bq/m^3, the action level for radon at workplaces in Sweden. New knowledge, at least for Sweden, is that radon can be forced into the premises by changes in the water level in a reservoir. This can also give rise to substantial diurnal variations in the indoor radon concentration. These examples show how important it is to decrease the release of radon from open water surfaces to the indoor air. In the Ludvika waterworks the problem was successfully solved by applying a ventilation system with a suction point right above the open water surface at the rather small shaft connecting the reservoir with the building. In the Fredriksberg waterworks the open surfaces of the filters are more difficult to limit or cover. In the Kolbäck waterworks the indoor air radon levels were very high, even though the INCA aerating device was entirely contained. Most of the radon that entered the premises was released from the already treated water in the reservoir in the same way as in Ludvika.

It is obvious that even well designed water treatment systems may have weaknesses that can cause high radon levels in the waterworks premises. Our recommendation is that indoor radon levels should be measured in all premises where large volumes of groundwater are treated. Measurements should also be performed in neighbouring premises. Installed mitigation systems should be checked regularly and the measurements should be repeated every second year or so. There is a risk for high indoor radon concentrations in all workplaces where large volumes of groundwater are used or treated indoors. Possible examples of such workplaces are breweries, indoor swimming-baths, food processing industries and laundries.

References

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