HIGH INDOOR RADON CONCENTRATIONS AT SOME SWEDISH WATERWORKS

Åkerblom, G.[1], Hagberg, N.[1], Mjönes, L.[1] and Heiberg, A.[2]
[1]Swedish Radiation Protection Authority
SE-171 16 Stockholm, Sweden
[2]Norwegian Radiation Protection Authority
P.O. Box 55, N-2345 Österås, Norway

1 ABSTRACT

High indoor radon concentrations are not uncommon in buildings used for water treatment. When raw water is processed in an open system, radon escapes from the water to the indoor air of the buildings. It is not unusual for the staff of the waterworks to have their offices in the building where the water is processed. If large volumes of water are processed and the evaporated radon reaches 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 have 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 range from 85 Bq/l to 300 Bq/l. Measured average indoor radon concentrations exceeding 17,000 Bq/m^3 have been found in Ludvika with peaks of almost 37,000 Bq/m^3. In Kolbäck, radon concentrations of up to 56,000 Bq/m^3 have been measured. It is quite possible that employees at waterworks can receive doses exceeding 20 mSv per year (calculated according to the ICRP dose conversion convention). Measurements of radon and gamma radiation from the waterworks are reported and methods for reducing the indoor radon concentrations are discussed.

2 INTRODUCTION

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

In Sweden, about 50 per cent of the drinking water originates from surface water, 25 per cent from groundwater and 25 per cent from artificially infiltrated groundwater (often lake water that is infiltrated into 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. The 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 per cent of the plants serve less than 1,000 consumers (1).

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 range from 10 to 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 water from a drilled well in Sweden is 89,000 Bq/l (2).

The local health officer of Ludvika municipality in central Sweden reported to the Swedish Radiation Protection Authority, SSI, that he had found high indoor radon levels at the waterworks in Ludvika and Fredriksberg. In May 2000, representatives from SSI visited these waterworks and the waterworks in Kolbäck to investigate the situation, study the remedial measures taken so far and make supplementary 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 for other municipal workplaces, such as offices, to be 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 (2). The dissolved radium is often precipitated together with iron- and manganese-hydroxide and it can also be deposited as scales on the inside of tubes and pumps. Radon progeny will also be deposited in filters containing activated charcoal and sand. Elevated gamma radiation from filters and pumps can therefore sometimes be a problem. 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, at Ludvika, Fredriksberg and Kolbäck, are all situated in central Sweden.

3 INSPECTIONS AND MEASUREMENTS

The Ludvika waterworks

This 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 it is infiltrated into the esker, Fig.1. 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 into the esker, Fig. 2. Through 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 3. From the mixing basin, the water is pumped into a 3,000 m^3 reservoir situated below 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 has been between 200 and 800 hours.

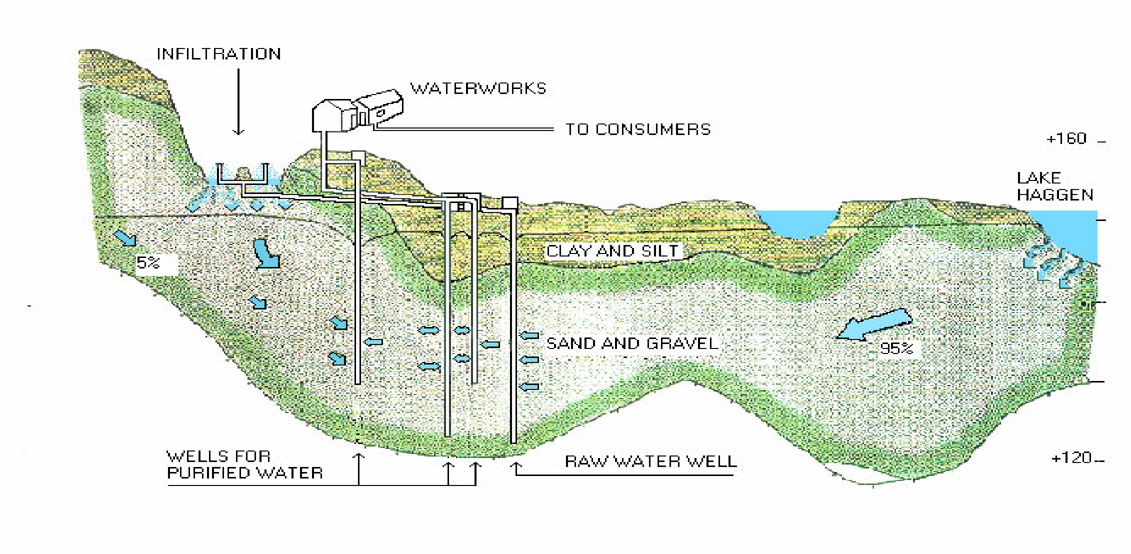

Fig.1: The Ludvika waterworks

Fig.2: Re-infiltration basin at the Ludvika waterworks

Fig.3: Inspection opening to the mixing chamber

On average, 6,000 m^3 of water passes the waterworks per day. The measured radon concentration in the raw water is 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, see 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 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 spreads 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 great variations in the radon concentrations in the building, one example is shown in Fig. 4.

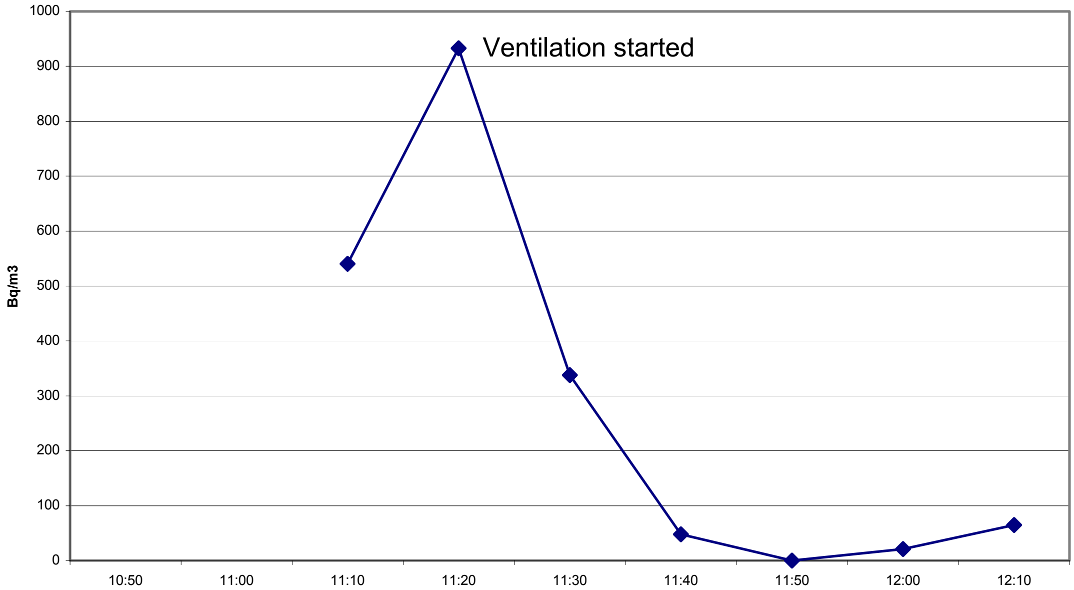

Fig.4: Radon measurements close to the mixing chamber at the Ludvika waterworks

To reduce the indoor radon levels, a supply/exhaust ventilation system has been installed with a local extraction point (430 litres of air per second) just above the water surface in the mixing basin, see Fig 3. As can be seen from Table 1, the remedial measures have been quite successful. The indoor radon levels are now 40–100 Bq/m^3.

The Fredriksberg waterworks

This waterworks supplies the village of Fredriksberg and the neighbouring area with drinking water. It is situated on the shore of a small lake. The raw water rises into cased wells from an esker on a small island in the lake and it is pumped into the waterworks. The raw water is not aired or further filtered before it reaches the waterworks. In the plant, potassium permanganate and soda are added, after which the water is aired and flocculated in open basins. The flocculation is removed by an open contact filter. As a result, the open water surfaces are exposed in the main hall of the waterworks with consequent release of radon into the indoor air. After that, the water is treated in closed sand filters and it is stored in a reservoir situated below 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, corresponding to about 1,000 hours per year.

600–700 m^3 of water is treated per day. The measured radon concentration of the raw water was 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 measured radon concentration further out in the distribution network was 35 Bq/l .

The average radon concentration in the main waterworks hall was 11,200 Bq/m^3, as measured by the municipal authorities, before any remedial measures had been taken. 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 open contact filter has been arranged. With the new ventilation system working, the radon levels in the main hall and the laboratory are just below 400 Bq/m^3. In very cold weather the temperature in the building becomes too low and the ventilation system has to be temporarily shut off.

During 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. 5. The doors to the plant had been closed for several days prior to our visit and the ventilation system had been shut off.

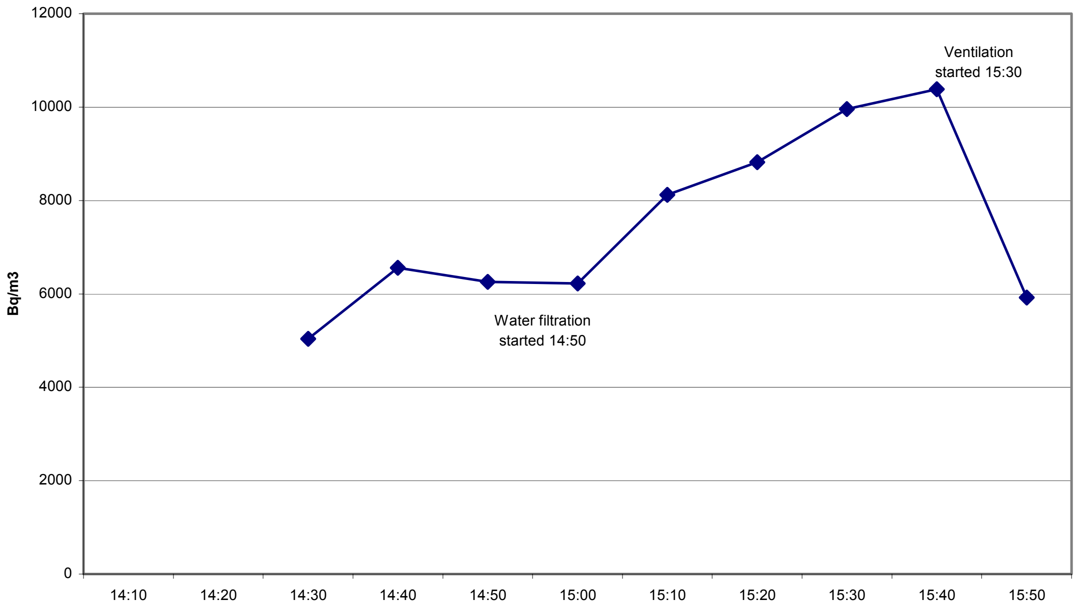

Fig.5: Radon measurements in the main hall at the Fredriksberg waterworks

Gamma radiation measurements were performed around the water treatment equipment. Elevated gamma radiation levels were found close to some of the pumps, 0.2–0.4 μSv/h, and close to a cooling radiator of a dehumidifier 0.8 μSv/h was found. The gamma radiation was caused by radon progeny deposited on the cooling fins of the pumps and in the radiator.

The Kolbäck waterworks

This waterworks supplies drinking water to the village of Kolbäck and the surrounding area. The waterworks is situated at the edge of a very long esker, Strömsholmsåsen, running through Kolbäck. The raw water is brought up in 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 the year 2000, see Fig 6. Before that, the water was distributed from an old waterworks situated close to the new one. When the old plant was in use 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.

Fig.6: The Kolbäck waterworks

Fig.7: Equipment for intense aeration of the water at the Kolbäck waterworks

Equipment for intense aeration, supplying 5,500 m^3 air per hour, was installed in the new waterworks building, Fig. 7. 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 there are a small control room and an office. Normally, the door between the water treatment hall and the rest of the building is closed.

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 measured radon concentration was found to be 90 Bq/l. The radon concentration of the distributed water is about 50 Bq/l.

When the new plant was put in operation, the radon concentration in the air in the main hall was monitored. Since the concentration was found to be high, some preliminary action was taken, including installing an additional fan to increase the ventilation rate and some sealing work to prevent the passage of radon from the reservoir. Measurements performed by the municipal authorities showed radon concentrations exceeding 40,000 Bq/m^3 in the main hall prior to the installation of the additional fan. Fig 8 shows the effect of the preliminary measures reducing the concentration from 40,000 to less than 10,000 Bq/m^3 during the period 27 April to 3 May 2000. In connection with our visit to the plant the ventilation was shut off in order to monitor the highest values. During the period 5–9 May 2000, the mean value of the concentration was around 30,000 Bq/m^3 . The short time variations reflect the effect of pumping the water in and out from the reservoir below the building. During our visit, supplementary measurements were taken confirming the values obtained by the municipality and advice was given on how further to reduce the radon level.

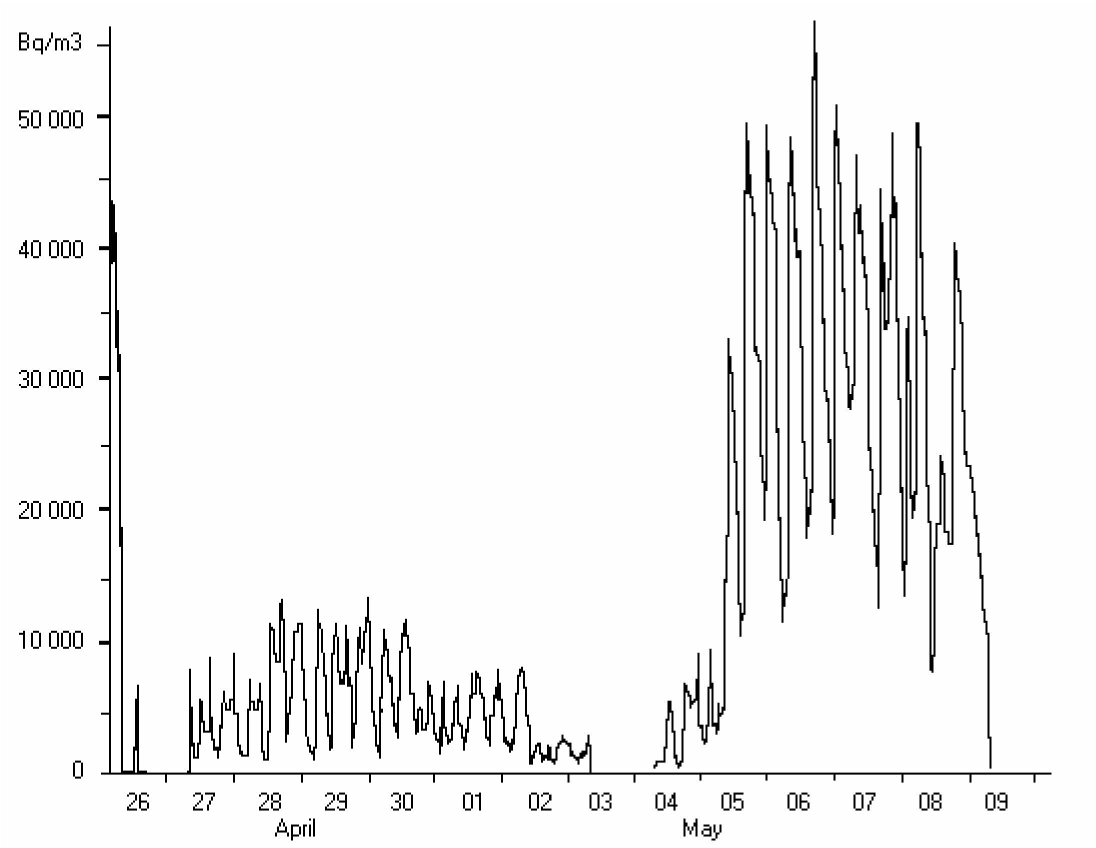

Fig.8: Radon gas measurements in the main hall at the Kolbäck waterworks

Gamma radiation measurements were performed near the water treatment equipment and filters but no elevated levels were found.

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

4 DISCUSSION

The experience from the three waterworks investigated shows that there is a substantial risk for high indoor radon concentrations when large volumes of groundwater or artificially infiltrated surface water are treated indoors in open systems. The radon concentration in the raw water 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 an enclosed 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 introducing a ventilation system with a suction point immediately 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 aerating device was entirely contained. Most of the radon that entered the building 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 buildings. Our recommendation is that indoor radon levels should be measured in all premises where large volumes of groundwater or artificially infiltrated surface water are treated. Measurements should also be made 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 at all workplaces where large volumes of groundwater are used or treated indoors. Possible examples of other workplaces where similar problems could occur are breweries, indoor swimming-baths, food processing industries and laundries.

An estimation of the dose (according to the ICRP dose conversion convention), shows that it is quite possible that employees at waterworks could receive doses exceeding 20 mSv per year.

5 REFERENCES

1. Hult, A. The drinking water in Sweden. (In Swedish, with a summary in English). VA FORSK Rapport 1998 – 15. The Swedish Food Administration, 1998.

2. Nordic 2000. Naturally Occurring Radioactivity in the Nordic Countries – Recommendations. The Radiation Protection Authorities in Denmark, Finland, Iceland, Norway and Sweden. ISBN 91-89230-00-0, 2000. Available as a pdf-file from www.ssi.se.