4.7 Removal of Radionuclides from Private Well Water with Granular Activated Carbon (GAC): Removal of U, Ra, Pb and Po

The laboratory experiments showed that lead and polonium ions were removed quantitatively by all activated carbon types investigated and that no dependence on pH value, water hardness or DOC content of the water on adsorption was noticeable. The adsorption of radium and uranium was, though, dependent on the coal type. Low water hardness increased the adsorption rates and higher DOC contents decreased the adsorption rates. The laboratory tests were carried out to define a granulated activated carbon for the field experiments, with best adsorption behaviour for natural radionuclides. Two coal types (F-100 and Aqua sorb) showed the best results.

The results of the field tests showed that GAC filtration (when carbon is selected based on the adsorption rate of radon) does not offer a viable technique for removing the long-lived radionuclides of the uranium series along with radon. No clear tendency regarding the removal of uranium, radium, polonium, and lead could be discerned. It is obvious that the chemical forms (speciations) of these radionuclides vary greatly in the waters that were studied. The best reduction was obtained for polonium and the poorest for uranium. The results for the same radionuclide varied between different test locations.

A consumer guide was prepared. The guide is intended to be used by the water utility owner to enable one to define the problem and to evaluate the possible solutions in case the water contains excessive levels of natural radioactivity.

4.8 Removal of Radioactivity by Methods Used for Fe- and Mn-removal from Private Wells

Iron and manganese removal equipment based on various removal principles are not a viable treatment alternative for removing natural radionuclides. For example in aeration and filtration equipment the amount of air applied to oxidise iron is not sufficient to remove radon. The air-to-water ratio is mostly 1:10 while it should be 10:1 in order to remove radon sufficiently.

The removal of the long-lived radionuclides ($^{238,234}U$, ^{226}Ra, ^{210}Pb and ^{210}Po) varied a great deal depending on the type of equipment and the radionuclide composition of the water. Uranium was best removed by ion exchange as long as anion exchange resin had been added in the filter. Radium was removed by cation exchangers and greensand filters regenerated with $KMnO_4$. The reduction of lead and polonium varied within a large range mainly due to their varied speciation in natural waters.

External gamma dose rate measurements on the surface of the equipment and at various distances indicated that this equipment does not significantly increase the dose for residents. The dose rates on the surface of the equipment varied from 0.09 to 1.90 µSv/h at the different test places. The highest values occurred with the highest radon concentration in the raw water.

The range of the removal efficiencies attained by the various types of iron and manganese removal equipment based on different principles are set out in Table XIV.

Table XIV. *The range of reduction percentages for Rn, Ra, U, Pb and Po by various Fe and Mn removal equipment based on different principles.*

Equipment type	**Reduction (%)**				
	^{222}Rn	**^{226}Ra**	**^{238,234}U**	**^{210}Pb**	**^{210}Po**
Aeration-filtration	12–89	3–93	0–92	21–70	33–82
Regenerated by $KMnO_4$	0–44	56–97	6–60	12–59	40–87
Ion exchangers					
- cation resin	–	50–92	5–84	13–93	79–97
- anion and cation resins	–	69–99	50–99	0–73	0–97

The results of the water quality analyses indicated that water quality improved rather than deteriorated during the treatment due to the removal of Fe, Mn and humus compounds (in some test places).

4.9 Removal of U and Po from Private Ground Water Wells Using Anion Exchange Resins and Removal

of Ra and Pb from Private Ground Water Wells Using Cation Exchange Resins

Batch and small column experiments using spiked waters as well as different types of real groundwater were conducted to find ion exchange resins that have a high capacity for the removal of uranium, radium, lead and polonium.

The strong basic anion resin gave the best results for uranium in both the batch experiments for determining the K_D value and the column tests for the evaluation of the decontamination factor.

The highest K_D values for radium were obtained by the inorganic ion exchangers, sodium titanate and manganese dioxide, while the best performance in the column tests was achieved with weak and strong acidic cation resins and the inorganic exchanger zeolite A.

The best results for the removal of polonium and lead from water were obtained by the strong and weak basic anion resins. However, the mechanism of removing these nuclides is only partly an ion exchange process. Polonium and lead are possibly mainly bound to particles in natural waters and adsorb to the surface of the anion resins.

The influence of nuclide activity, competing ions and pH value on the removal of uranium, radium and lead was evaluated by conducting small column tests (mixed bed exchangers containing strong acidic cation and strong basic anion resins) with six different water types. Because of the good correspondence with the measured data it was possible to extrapolate the results for radium to a wider range of water qualities by using simulation programmes.

The greatest reduction of radium removal capacity was observed in conjunction with high total hardness followed by elevated sodium values. No significant influence was observed from pH or radium concentration in feed water.

The removal efficiency for lead was much better at pH 7 than at pH 8, and little influence was observed from hardness. The feed concentration of sodium and lead was of no significant influence.

Flat effluent concentration curves were measured for uranium because of the high flow rate used in the experiments. Contrary to the results reported in the literature, the greatest impact on the effluent concentration was observed in the case of chloride and not in the case of sulphate concentration. For final conclusions experiments using lower flow rates and longer investigation time would be necessary.

For practical applications this means that water quality has an important influence on the capacity of ion exchangers for radionuclide removal. Water quality must be considered when fixing the regeneration intervals; capacities should be given by the manufacturers dependent on the concentrations of competing ions and pH of the feed water.

Although the maximum flow rate which can be used for achieving an acceptable breakthrough curve depends greatly on the properties of the individual resin, a range of 80 to 200 BV/h was determined as reasonable throughout the column tests. Filter geometry had only minor influence on the form of the effluent curve; an insignificant later breakthrough was observed with a more compressed filter form (lower ratio of height to diameter).

Regeneration tests both in the laboratory and in the field showed that uranium can be almost completely (up to 100%) removed from strong basic anion resins by sodium chloride or sea salt solutions. Empty bed contact time (EBCT) had no significant influence on regeneration efficiency. The clear influence of the concentration of regenerant and the total mass of salt applied on the extent of regeneration was observed. The efficiency was reduced to only about 70%, when water rich in organic matter was treated.

When simulating the conditions in a commercially available ion exchanger containing strong acidic cation resin (domestic water softener) the efficiency of radium regeneration was poor, only from 6% to 22%; this was proved in practical experiments with such a system. Slightly higher results were achieved with gel type resins than with macro-porous resins. With $CaCl_2$ as an alternative to NaCl higher efficiencies were reached but the application in the water softener failed because of a blockage in the system. The constant separation factors for radium resulted in an upper limit of activity accumulated on the ion exchanger after repeated operation and regeneration cycles; the accumulation followed a geometrical series.

Higher efficiencies but the same behaviour were observed for lead on the strong acidic cation exchanger.

The mass of salt applied and the concentration of the regenerate exercised practically no influence on the regeneration efficiency of polonium. In addition, the kinetic behaviour of the regeneration process for polonium is totally different from that for uranium, radium and lead. This clearly indicates that polonium is only adsorbed to the resin and no ion exchange in the real sense happens.

Field tests (in Finnish households) and laboratory tests with several different commercially available ion exchange systems were conducted to evaluate their efficiency in removing radionuclides, their impact on other water quality parameters and to determine the quantity and quality of waste produced.

Ion exchangers containing strong basic anion resin in the chloride form removed over 95% of uranium at all test places, independent of water quality. Many thousand bed volumes of natural water can be treated without regeneration—uranium breakthrough does not primarily limit the use of the filter. More likely it is restricted by the clogging of the filter, by national regulations concerning the maximum allowable amount of uranium to be accumulated on the filter or for hygienic reasons.

The anion resin also partly removed radium (from 35% to 60%), possibly because of anionic Ra compounds. Systems containing strong acidic cation resins in the sodium form removed radium in the range of 90% to 95%. Radium reduction nearly always exceeded hardness removal, while total hardness—an easy to measure parameter—might be used as a surrogate for regular qualitative checks of the operation of small cation exchange systems by the owner. The removal of lead and polonium varied a great deal due to their varied speciation in natural waters.

Simultaneously with radionuclides a decrease of turbidity, phosphate, sulphate and nitrate (with anion resins) was observed. The decrease of iron occurred mainly with cation resins but also with anion resins if organically bound iron was present. The more or less total removal of hardness (calcium and magnesium) by cation exchange resins in the sodium form must be judged negatively from the point of view of health and conflicts with many national drinking water regulations, which demand a minimum hardness. Furthermore, the water tends to be corrosive, which makes the addition of corrosion inhibitors necessary to protect metal pipes. To avoid this effect strong acidic cation resins in the calcium form were successfully tested in point-of-use ion exchangers (countertop pour-through filters). For the use of $CaCl_2$ in point-of-entry devices with automatic regeneration changes of the design are necessary.

Hygienic studies showed that the heterotrophic plate count may increase when using ion exchangers, but no negative health effects on the people were observed at the test places.

Dose rate measurements on the surface of the ion exchangers and also at various distances from the filters indicated that no remarkable dose for the residents is caused by the treatment systems, if they are properly located in the house.

Ion exchange systems cause either solid waste, exhausted filter cartridges from point-of-use systems, or liquid waste, the regeneration agent used. Since the activity found in the waste depends on the quality of raw water, the period between two regeneration cycles or the frequency of change of cartridges and the individual type of system, only rough estimations can be given. The exhausted filter cartridges may contain an activity of up to several 100 Bq/g. The regeneration agent used, high in salinity, has a radionuclide concentration from 10 to 30 times the feed value; the quantity is in the range from 3% to 10% of the volume of water treated.

A consumer guide was prepared. The guide is intended to be used by the water utility owner to enable one to define the problem and to evaluate the possible solutions in case the water contains excessive levels of natural radioactivity.

4.10 Removal of U, Ra, Pb and Po with Adsorptive or Membrane Filters

Hydroxyapatite has a good capability for adsorbing uranium and radium as shown in laboratory experiments and also in field experiments with very small flow rates. The high adsorption at slow flow indicate that a strong interaction between the feed water and the surface of the hydroxyapatite is necessary to gain good results. Therefore a new granular form has to be discussed to obtain smaller and perhaps more porous particles to increase the surface and contact time.

The RO and NF systems (laboratory experiments) tested, typical of the great number of commercially available ones, removed on average from 95.6% to 99.8% of the radioactive compounds radium (^{226}Ra), uranium and lead (^{210}Pb) from the feed water. The measured gross alpha reduction showed that the same is true for polonium (^{210}Po). Concerning the removal of radioactivity, no significant differences were observed between the RO units and the NF system.

In several cases no radioactivity was found in the retentate but it was adsorbed onto the treatment systems. High adsorption rates were observed for ^{210}Pb in particular. GAC pre-filters seemed to favour this effect.

A comparison of radioactivity with electrical conductivity (EC) and total hardness (TH) rejection showed that EC and TH always exceed radioactivity in the permeate and therefore might be used as surrogates for checking the proper operation of RO and NF systems regarding radioactivity removal.

Additionally to radioactive isotopes, RO and NF systems also reduce all other dissolved compounds to a high degree (average 95%) and decrease the pH value, resulting in water which favours corrosion and is poor in essential minerals for human health. To reduce these unfavourable effects, filtration over granular calcium-carbonate ($CaCO_3$) was tested as a post-treatment step (re-hardening). About 15% to 35% of the original hardness was reached by this method and the water can be brought again into lime-carbonate equilibrium so that it does not behave corrosively anymore. No significant difference was observed between waters from RO and NF systems.

A microbiological analysis of feed water and permeate showed that the hygienic quality of the water can deteriorate when using such kinds of treatment systems where the treated water is stored in the storage tank for daily supply for drinking and cooking.

The NF pilot plant study enabled one to estimate the suitability of NF membranes for removing uranium from water. It showed that the most important species of uranium in natural water, which represent anion, cation and uncharged compounds, can be removed to about 95% over a wide range of pH and hydrochemical settings. It showed further that the heavy molecular weight of uranium compounds is mainly responsible for the high rejection. Since even the molecular weight of the uranyl cation, which is the lightest uranium compound in water, is above the typical molecular weight cut-off of NF membranes, it can be expected that the rejection of other uranium compounds, not investigated in this study, would also be more than 90%.

The uranium rejection at the NF membranes at various hydrochemical settings was from 95% to 98% in most cases. The rejection of other constituents of water (phosphate, bicarbonate and electrical conductivity) differed from 40% to 97%. The two RO membranes rejected from 98% to 99.5% of uranium and from 93% to 99.5% of other water constituents.

The suitability of two commercially available POE-RO devices for removing ^{238,234}U, ^{226}Ra, ^{210}Po and ^{210}Pb from drinking water was determined in field tests. While the radionuclides were removed by more than 90%, the rejection of other water constituents was mainly above 94%.

The membrane devices used in the field tests were suitable for treating drinking water. The main feature of RO equipment was its ability to remove most water constituents effectively. The best reduction of water constituents achieved was over 94%. The reductions of uranium, radium and polonium were over 90%.

4.11 Speciation of U, Ra, Pb and Po in Water

The literature study indicated that despite a very large number of investigations on the speciation of uranium, our knowledge regarding ground water is still limited. The composition, abundance and properties of many components of ground water systems are poorly known. This applies particularly to natural organic matter and colloidal components. The speciation of radium has been studied moderately but especially the knowledge of the speciation of radioactive lead and polonium in ground water is poor and only a few articles are available.

The principal objective of this study was to find out the division of ground water ^{210}Po and ^{210}Pb into soluble and particle-bound fractions. For this purpose real ground water samples were filtered using filters of varying pore sizes. It was found that these radionuclides exist mainly as particles in ground waters. Only in one water were considerable fractions of them seen to be in soluble form. It was also found that the sizes of the particles carrying the radionuclides vary markedly from water to water.

The secondary objective was to identify the chemical factors affecting the presence of polonium and lead in particles. The chemical composition of the waters prior to and subsequent to the filtrations were determined but only a few indicative results could be obtained suggesting that iron and aluminium containing colloidal particles may be responsible for carrying the radionuclides.

One main conclusion from the results of this study is that correct results can be obtained only by using real ground water samples. Tracers to mimic the behaviour of naturally occurring radionuclides cannot be used.

The initial phase of this study was to study whether these radionuclides are present in groundwaters in ionic forms which could be removed by ion exchange materials. It was observed that polonium and lead are mainly present as particles and thus ion exchange would not be the primary method for these nuclides. However, it is probable that they, though not exchanged into ion exchangers, may be adsorbed on surfaces of the exchanger material and equipment.

In the ground waters studied representing, on the one hand, ground water with good water quality but rich in soluble uranium and, on the other hand, groundwater with relatively high NaCl concentration and high content of humus material, practically all uranium (>95%) was in the highly soluble U(VI) form.

4.12 Disposal of Radioactive Wastes from Water Treatment Methods: Recommendations for the EC

The radioactive wastes arising from the treatment of water involve natural radionuclides, but their production, processing, handling, use, holding, etc. cannot be considered practice (as stated in the Basic Safety Standards) and the exemption levels of the Basic Safety Standards are not applicable. However, wastes from water treatment methods involving natural radionuclides may lead to a significant increase in the exposure of the members of the public (or workers who are handling the waste) to radioactivity.

The following recommendations were made. The Member Countries of the European Union can use the recommendations made in this report as a basis for their own regulations or the European Union may recommend a common approach for all the Member Countries.

- The radon-laden air from the aerator should be directly funnelled into the open air. The aerator itself does not accumulate any radionuclides.
- It is recommended that the annual dose to residents from the external gamma radiation of a GAC filter should not exceed 0.1 mSv. GAC filters emit gamma radiation when they are in service. The higher the radon concentration and the larger the water usage, the more intense the external gamma dose rate around the filter.
- It is also recommended that the dose rate at a distance of 1 m from the GAC filter should not exceed 1 µSv/h. As a rule of thumb, if the radon concentration of water exceeds 2000 Bq/L, special shielding is needed. Instead of constructing special shielding, the location of a GAC filter can be chosen in such a way that the distance from the filter to occupied rooms is long enough to attenuate the gamma radiation.
- The use of GAC filter is not recommended if the radon concentration of water exceeds 5 000 Bq/L.
- It is recommended that used GAC filter material could be discharged into communal dumps after it has been “aged” about four weeks after use. The GAC filters also accumulate ^{210}Pb. Depending on the water consumption and radon concentration in influent, high activities of ^{210}Pb may be found in spent GAC beds. When the GAC filter is no longer used, the amount of radon in the filter decreases rapidly and is close to zero after four weeks. Simultaneously the external dose rate around the filter decreases. Normally the spent carbon contains high amounts of ^{210}Po and ^{210}Pb and low amounts U and ^{226}Ra.
- It is recommended that if Fe- and Mn-removal methods are used and backwashing or regeneration is carried out about once a week, the liquid could be discharged into the sewer and after use the spent matrix could be discharged into municipal dumps. Depending on the Fe- or Mn-removal system, large amounts of radionuclides may be accumulated by the equipment. Backwashing or regeneration at regular intervals, however, enables a safe daily use of these units because radionuclides are rinsed out of the fixed bed and drained into the sewer. The higher the concentration of radionuclides and the higher the daily water usage, the more often backwashing or regeneration should be carried out. The

regeneration interval is in most cases frequent enough to prevent this technique from causing a problem of waste disposal.

- It is recommended that if anion or cation exchange resins are used and regeneration is done about once a week, the regeneration liquid could be discharged into the sewer. It is also recommended that the resins of the exchange units without automatic regeneration could be discharged into municipal dumps. In connection with ion exchangers different operation principles and exchange materials can be utilised. Organic ion exchangers (resins) can usually be regenerated. The properties of many inorganic exchangers (mineral based) cannot be restored by regeneration and therefore they must be discarded after exhaustion.
- It is recommended that the solid wastes produced by membrane techniques (i.e. spent membranes and pre-filters) could be discharged into communal dumps. The other wastes produced by membrane techniques are not accumulated in fixed matrices. The concentrate containing radionuclides, is constantly drained into the sewer as the unit operates. The concentrations of radionuclides in concentrate are, however, low and do not create a waste problem.

5. DISCUSSION

5.1 Survey of Literature on Natural Radioactivity in Drinking Water and Treatment Methods in European Countries

The data on levels of natural radionuclides in ground, drinking and mineral water in 17 European countries and the distribution of uraniferous deposits in Europe enabled the drawing of a European map. This map shows regions which are geologically dominated by basement rocks (especially granite plutons and metamorphic rocks), to be the most important areas with potentially elevated levels of natural radionuclides in ground water. Typical geological settings for such basement rocks are orogen cores and roots of eroded orogens. In Europe, this applies to the following regions:

- the Proterozoic part of the Fenno-Scandinavian (Baltic) Shield which is almost entirely formed of high grade metamorphic rocks and granite plutons,
- the Pre-cambrian of the Ukrainian Shield and the Scottish Grampians and Highlands,
- the Moldanubian zone, which is the inner zone of the Hercynian orogen, corresponding to the area of maximum orogenic, metamorphic and plutonic activity. It includes (1) the Vendée of the Armorican Massif, (2) the French Central Massif, (3) Vosges and the Black Forest, and finally (4) the Bohemian Massif with adjacent areas in south-eastern Germany and northern Austria,
- the Central Iberian zone, which is the south-western foothill of the Herzynian orogen on the Iberian peninsula, and
- to a lesser extent on Corsica and Sardinia, in the Rhodope massif and in the central Alps.

Beside these granite-related regions other small-scale areas surely exist with high contents of natural radionuclides in ground water. For example, areas with small uraniferous accumulations of local importance which typically occur in felsic volcanics or in surrounding sedimentary rocks.

5.2 Intercomparison of Analysis Methods

The intercomparison runs accompanying the analytical work of the project were highly justified by the quality of the data, improving from exercise to exercise.

5.3 Definition and Classification of Different Water Types and Experimental Conditions

With the definition of the experimental conditions and the definition of water types to be selected for the tests an important project basis was laid. Although the partners were not able to cover all the water types for organisational reasons and due to the restricted budget, sufficient and comparable results have been achieved throughout the project.

The ftp-server, communication platform and database of the TENAWA project allowed an efficient and quick information transfer between the research groups independent of the document size. The TENAWA homepage will also be used after the end of the project for the dissemination of the results and reports to the scientific community.

5.4 Removal of Radon by Aeration: Testing of Commercially Available Equipment for Domestic Use

Radon removal systems based on aeration can be designed and installed in different ways. The following aspects should be considered when the installation is designed:

- average water consumption
- maximal momentary consumption
- radon concentration in raw water

- the need for untreated water
- previously installed components
- additional treatment units
- requirements for the room where water treatment is carried out
- maintenance of the system.

One result of this study was the development of a standard sampling protocol. The previously used conventional tests did not provide enough information either about the effective capacity of the aerators or about the real removal efficiency. New manufacturers of aerators have come into the market since this study started. It is important to be able to compare these equipment even-handedly and also to monitor the operation of the ones already installed. The manufacturers can benefit from the newly introduced parameter, the effective flow rate, when designing the aerators. The sampling protocol, including the plot of radon concentration against the volume of water flowed, indicates unfavourable and otherwise undetectable phenomena such as leaking solenoid valves or malfunction of the control unit.

The proposed sampling protocol includes constant measuring of the flow rate applied and frequent sampling of the continuous water flow in order to cover all situations of water consumption. Information on the removal efficiency and whether the installation has been carried out appropriately can be gained from the results. The sampling enables calculating the removal efficiency that is most applicable to assessing exposure through ingestion but it also makes it possible to measure the removal efficiency related to water volume, which is more indicative for assessing exposure through inhalation.

Some effects of the aeration process on certain water quality parameters could be demonstrated. As might be expected, the iron (Fe) and manganese (Mn) concentrations were generally lower in the treated water than in the raw water. Iron precipitates as ferric hydroxide during aeration and manganese may be co-precipitated at the same time. These iron and manganese precipitates can cause fouling of the treatment system if they are not removed. The precipitates can settle down on the bottom of the aeration tank, be removed by a sediment filter installed after the aerator, or be released into the water line.

The water becomes virtually saturated with oxygen during aeration. This improves the taste of the water and reduces the corrosiveness. Carbon dioxide is also removed, which causes a rise in the pH value. Water with a higher pH value is less corrosive for the plumbing. Other water quality parameters change only slightly. No clear trends in their results could be observed.

The results gained from this project indicate that radon removal by aeration did not increase the bacterial densities of the water. However, factors affecting bacterial growth, i.e. microbiological quality, organic carbon and the nutrient concentrations of raw water should always be examined before installing an aeration unit. Heterotrophic plate counts should be included in routine water quality surveillance in order to obtain information on the fluctuation of the microbiological quality of raw water and the need of maintenance, cleaning and disinfection of the water treatment equipment.

The type and model of aerator should be selected according to water consumption and the radon concentration in the raw water. The manufacturer should guarantee a certain water output for each available system. The first factor affecting the water output of the system is the aeration time. Longer aeration times are needed to reduce higher concentrations of radon. The water output of the system diminishes, however, when the aeration time is prolonged. Therefore, the aeration time should be adjusted so that a sufficient reduction is achieved and no unnecessary aeration takes place. However, during this study it was noticed that the radon concentration of the raw water can vary significantly. The aeration time should always be set longer than needed at the time of sampling.

The second factor contributing to the water production capacity is the size and the pre-pressure of the pressure tanks (when installed after the aerator). The effective volume of the pressure tank should be large enough to enable sufficient water feed into the plumbing during aeration.

Instead of installing pressure tanks, another way of guaranteeing sufficient water supply is to direct aerated water into a storage tank. These tanks can be very large and they require a lot of cool space. A practical application is to build a “dummy well” which is filled up with aerated water.

The third factor affecting the water production capacity is the well pump. A pressure tank must always be installed after an ejector pump. An ejector pump is usually not as efficient as a submersible pump but the pressure tank adds its capacity to fill up the aerator. If the well is situated far from the aerator and a submersible pump is used (without a pressure tank), the time that the pump needs to fill up the aerator can be quite long. Most aerators have a spray mouth-piece or an ejector mounted at the inlet of the aerator in order to intensify the radon removal. The spray mouth-piece and the ejector function more efficiently with high water pressure. Consequently, the radon removal efficiency can decrease if the incoming water pressure is low.

When the radon concentration in the raw water is extremely high the short-lived radon daughters can also cause a significant effective dose even though the radon has been expelled from the water. The most significant daughter products are lead (^{214}Pb) and bismuth (^{214}Bi). According to one estimate the dose caused by the radon daughters is 10% of the corresponding radon concentration. The freshly aerated water should, therefore, stand for a while before consumption. The pressure tanks or the storage tank must be large enough to enable the delay that is needed to reduce the activity of the radon progeny. When large tanks are installed the water production capacity of the system improves. Long storing times, however, can cause the growth of bacteria.

The nature of this study was more of a practical testing programme than research. For the consumer it is very important that this kind of relatively new equipment undergoes long-term testing under the surveillance of qualified independent scientists and technicians to find out if they are capable of doing what the manufacturers claim that they can do. And further, that they can perform reliably for a long time without needing too much maintenance. This kind of equipment is often “forgotten” by the residents once it has been installed. Therefore it is important that the residents have written directions as to how the equipment should be used.

From the radiation protection point of view the general conclusion that can be drawn is that aerators are very capable of also reducing very high radon concentrations in drinking water to acceptable levels. This confirms experiences from the United States and Sweden, where this kind of equipment has been in use for a number of years.

Most of the problems that have been encountered have been of a technical nature and can easily be solved. There is, however, one area of problems that needs further investigation. This is the risk of hygienic problems in the long-term use of aerators when the equipment is used in different environments, for instance in areas with warm climates. The quality of the