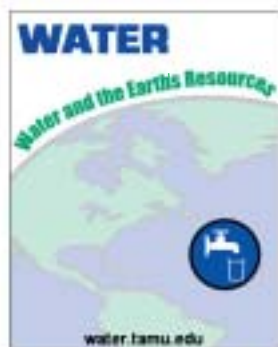


Drinking Water Problems: Radionuclides



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Radionuclides are types of atoms that are radioactive. The most common radionuclides in drinking water are radium, radon and uranium.

Most of the radionuclides in drinking water occur naturally at very low levels and are not considered a public health concern. However, radionuclides can also be discharged into drinking water from human activity, such as from active nuclear power plants or other facilities that make or use radioactive substances.

People who are exposed to relatively high levels of radionuclides in drinking water for long periods may develop serious health problems, such as cancer, anemia, osteoporosis, cataracts, bone growths, kidney disease, liver disease and impaired immune systems.

What are the Sources of Radionuclides in Water?

Radiation comes from outer space, from the ground and even from within our own bodies. Radiation is all around us and has been present since the birth of this planet.

Most of the radionuclides present in drinking water are from natural sources. Naturally occurring radionuclides are created in the upper atmosphere and are found in the Earth's crust. They are found in certain types of rocks that contain trace amounts of the radioactive isotopes (forms) of uranium, thorium and/or actinium. As these rocks weather, the resulting clays and other materials may transmit radionuclides into drinking water. Higher levels of radionuclides tend to be found more

often in groundwater, such as from wells, than in surface water, such as lakes and streams.

Many human-made devices and processes result in radioactivity. The list includes, but is not limited to, color television, medical instruments (x-rays and chemotherapy), coal/lignite power plants, industrial processes and cigarette smoking. Radionuclides in water are more likely to be from naturally occurring sources than manmade sources.

Over time, radionuclides decay. As they decay, they produce daughter products that are shorter lived, and "more radioactive." Of particular concern are naturally occurring uranium and radium, which can accumulate to harmful levels in drinking water.

As radionuclides decay, they emit radioactive particles such as alpha particles, beta particles and gamma rays. Each type of particle produces different effects on humans.

Alpha particles are the least penetrating type of radioactive particles; they can be stopped by a sheet of paper or the skin. However, they are still harmful if inhaled or ingested, because then they come into contact with internal organs. Even though they are the least penetrating, alpha particles cause more damage per unit volume than do beta particles or gamma rays.

Beta particles and **gamma rays** deposit their energy over longer distances. Beta particles can be stopped by a piece of wood or a thin sheet of metal such as aluminum foil. Gamma rays, like x-rays, can pass through the human body and are best shielded by dense materials such as lead or thick concrete.

Most of the naturally occurring radionuclides (such as some forms of uranium and radium) emit alpha particles, but some (such as radium-228) emit beta particles.

One of the naturally occurring radionuclides that emit beta particles is tritium. Tritium forms in the upper atmosphere and can be deposited onto surface waters via rain or snow. It can also seep into and accumulate in groundwater. Although natural tritium tends not to occur at levels of concern, contamination from human activities can result in relatively high levels of this radionuclide.

Although most water systems have no detectable radionuclide activities, some areas of the United States have significantly higher levels than the national averages. For example, some areas of the Midwest have elevated radium-226 levels and some Western states have elevated uranium levels compared to the rest of the United States.

Who Regulates Drinking Water Safety?

In 1974, the United States Congress passed the Safe Drinking Water Act. This law requires the U.S. Environmental Protection Agency (EPA) to determine the safe levels of contaminants in U.S. drinking water. The EPA conducts research of drinking water to determine the level of a contaminant that is safe for a person to consume over a lifetime and that a water system can reasonably be required to remove from it, given present technology and resources. This safe level is called the maximum contaminant level (MCL).

Maximum contaminant levels in drinking water have been established for a variety of radionuclides. For radium, the MCL has been set at 5 pCi/L (picocuries per liter, a unit of measure for levels of radiation). The MCL for gross alpha radiation is 15 pCi/L, and the maximum limit for gross beta radiation is 50 pCi/L.

In addition to causing cancer, exposure to uranium in drinking water may cause toxic effects to the kidney. Based on human kidney toxicity data, the MCL for uranium is 4 millirems per year. The EPA says that a treatment system would be considered vulnerable if it contained 50 pCi/L of uranium.

Although the MCL applies only to public drinking water sources, it can give those who use private wells an idea of what an appropriate level of a contaminant should be for private wells.

There is no current MCL for radon. However, the EPA is proposing two options for states wanting to regulate concentrations of radon in drinking water:

- The first option would require community water suppliers to provide water with radon

levels no higher than 4,000 pCi/L. Because about 1/10,000th of radon in water transfers to air, this would contribute about 0.4 pCi/L of radon to the air in a home. This level will be permitted if the state also takes action to reduce radon levels in indoor air by developing EPA-approved, enhanced state radon indoor air programs (called Multimedia Mitigation Programs). This is important, because most of the radon you breathe comes from the soil under the house. This option gives states the flexibility to focus on the greatest problems, encouraging the public to fix indoor air problems and to build homes that keep radon from entering.

- A second option is provided for states that choose not to develop enhanced indoor air programs. Community water systems in those states would be required to reduce radon levels in drinking water to 300 pCi/L. This amount of radon in water contributes about 0.03 pCi/L of radon to the air in your home.

Even if a state does not develop an enhanced indoor air program, water systems may choose to develop their own local indoor radon programs. This option would require them to meet a radon standard for drinking water of 4,000 pCi/L. This option would enable the reduction of overall risks from exposure to radon from both air and water.

Where have Wells with High Levels of Radioactivity been Found in Texas?

To monitor the quality of our water, the Texas Water Development Board (TWDB) collects groundwater samples in the state through its Groundwater Quality Sampling Program. From 1988 to 2004, the board collected 5,471 samples from 4,941 wells to test for gross alpha radiation (Fig. 1). Of the total number of samples, 29 percent contained no detectable amounts of alpha radiation.

The studies found 3,864 samples in Texas containing detectable amounts of gross alpha radiation. Of those, about 11 percent contained gross alpha radiation above the primary MCL of 15 pCi/L.

High levels of gross alpha radioactivity (over the MCL) were found in 22 of the 31 major and minor aquifers in Texas. One stock well in the Queen City aquifer in Frio County contained gross alpha detected at 302 pCi/L; the two aquifers with the most wells with gross alpha over the MCL were the Dockum and the Hickory aquifers, with 129 and 86 wells, respectively. The wells with the high-

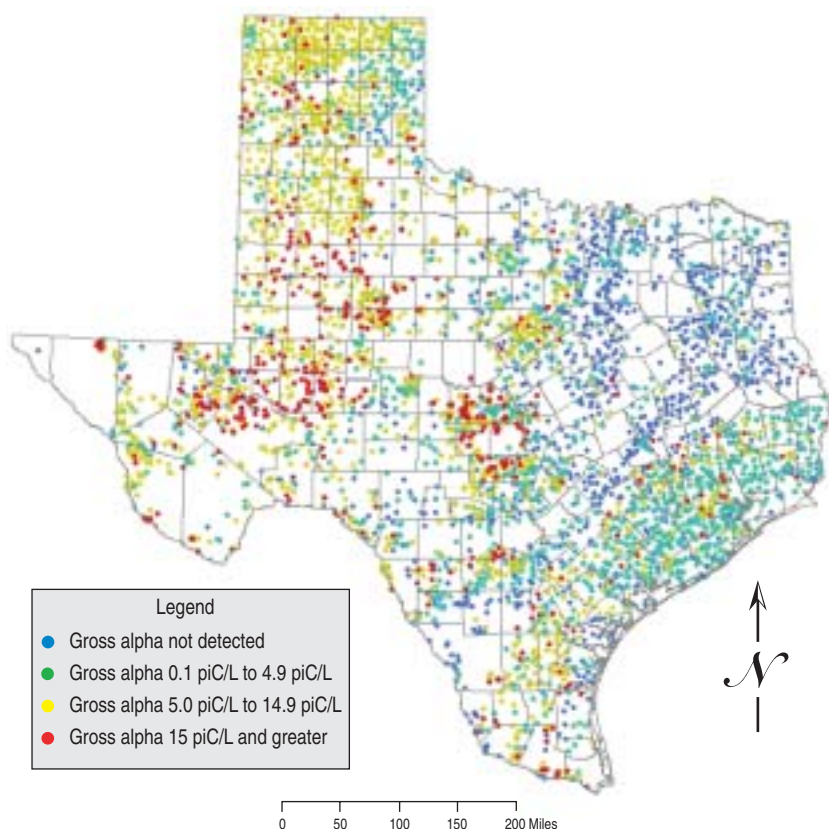


Figure 1. Gross alpha particle concentrations in Texas groundwater, 1988-2004.

est gross alpha values were found in the Carrizo and Gulf Coast aquifers, which contained 1,120 and 835 pCi/L, respectively.

Other aquifers that contained significant numbers of wells with excessive alpha were the Edwards-Trinity Plateau (74 wells), the Gulf Coast (64 wells), and the Ogallala (53 wells). Of the 610 water wells with concentrations above the maximum limit, about 28 percent supplied water to households, 24 percent to livestock, 19 percent to public supply facilities, 17 percent to irrigation wells, 6 percent to industrial facilities and 3 percent to other uses. Five percent of those wells were unused.

The TWDB also collected 5,327 samples from 4,698 Texas wells and analyzed them for gross beta activity. The maximum limit for gross beta activity is 50 pCi/L.

Of the samples analyzed, 34 percent were below detection (Fig. 2). In the samples where detectable levels of gross beta activity were found, the median (midpoint) value was 8.1 pCi/L. Of the 87 samples with

detectable gross beta levels, or 1.6 percent, were over the EPA's maximum limit.

Wells in 15 of the designated major and minor aquifers in Texas were found to have high levels of gross beta activity. The number of wells with high gross beta levels ranged from one well each in the Queen City, Yegua, Trinity and West Texas Bolson aquifers, to 15 and 21 wells in the Dockum and Hickory aquifers, respectively.

Of the 87 water wells with concentrations over the maximum limit, about 29 percent supplied water to stock wells, 17 percent to households, 17 percent to irrigation wells, 16 percent to public supply facilities, and 14 percent to industrial facilities. Seven percent were unused.

The TWDB has also analyzed for radon and radium-226 and radium-228, although not throughout the state. The Texas Commission on Environmental Quality (TCEQ) has collected more of these data from its public supply wells. Using the data collected up until 1999, the commission has identified several public water supply sites where there are projected radon violations (Fig. 3).

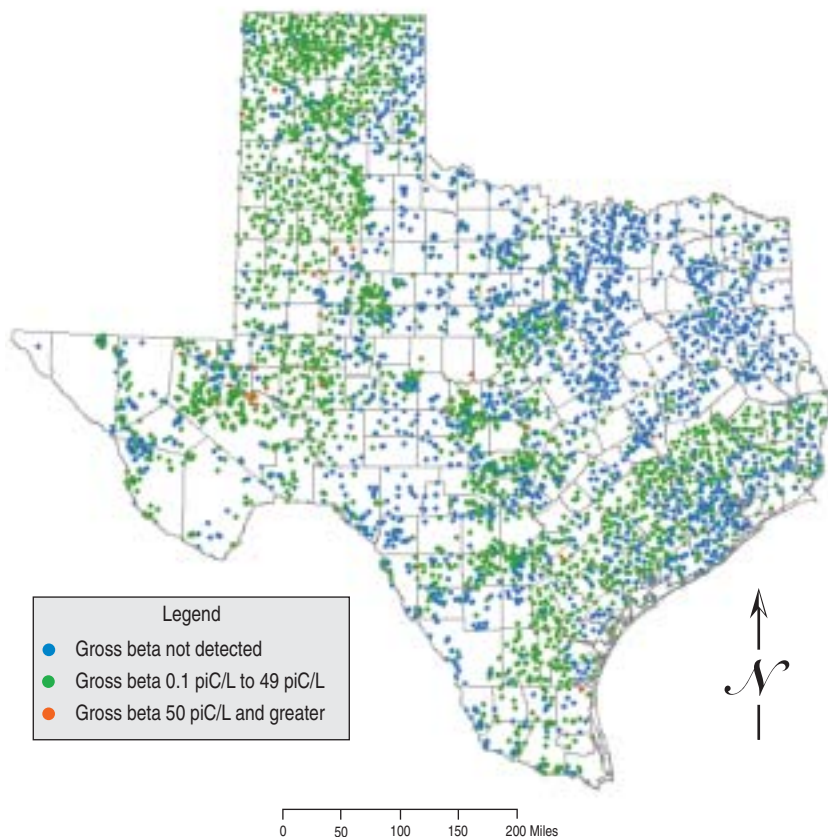


Figure 2. Gross beta particle concentrations in Texas groundwater, 1988-2004.

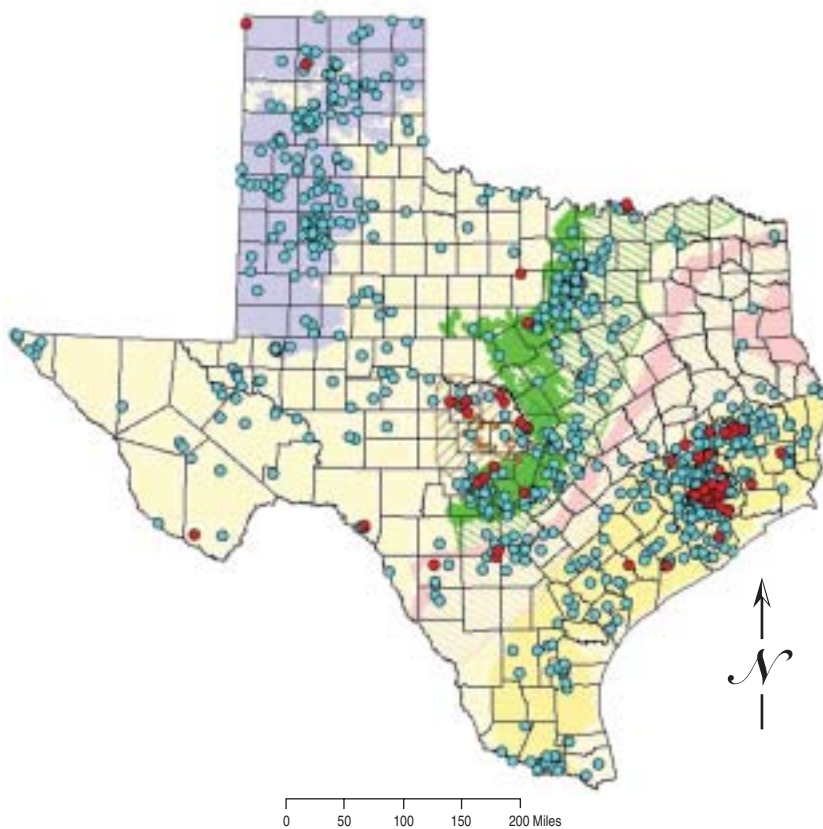


Figure 3. Public water well sites with the potential for high levels of radon.

Although the sites indicated in red do indicate geographic areas where consumers might be more concerned about radon, consumers also need to take into account the amount of radon they are exposed to in the air in their homes as well as in their well water.

How do Radionuclides affect Health?

People ingest radionuclides by either drinking contaminated water or eating food that has been washed with contaminated water. Once ingested, the radioactive particles ionize (destabilize) nearby atoms in the body as they travel through a cell or other material. This ionization process can damage chromosomes or other parts of the cell and can lead to the death or unnatural reproduction (cancer) of the cell.

Uranium: For uranium, the concern is not only that its radioactive decay can cause cancer, but also that exposure to the uranium itself can damage the kidneys. When people are exposed to high levels of uranium in drinking water, changes occur in their kidney functions that can indicate potential kidney failure in the future.

Radium: In the 1920s, the numbers on some watch dials were hand-painted by workers using paint that contained radium. These workers later suffered noncancerous health problems such as benign bone growths, osteoporosis, severe growth retardation, tooth breakage, kidney disease, liver disease, tissue and bone necrosis (death), cataracts, anemia and immunological suppression. Many of these health problems caused death of the dial painters.

These workers also had higher rates of two rare types of cancer: bone sarcomas and carcinomas of head sinuses and mastoids. Patients medically treated with radium-224 also showed an increase in bone sarcomas but not head carcinomas.

However, the levels of exposure that people experience from naturally occurring radium are much lower than those of the watch painters or the people medically treated with radium-224. Therefore, the noncancerous health effects have not been of concern in setting a limit for radium in drinking water.

Radon: Radon is a naturally occurring, odorless and invisible radioactive gas that emits radiation. Inhaling radon increases a person's chance of developing lung cancer. This risk is associated primarily with inhaling radon and its decay products when they are released from water. Levels of radon are generally higher in groundwater than in surface water.

Although not of major concern, ingesting drinking water that contains radon also presents a risk of cancer of the internal organs, primarily the stomach.

Gross alpha emitters (uranium and radium-226): Uranium and radium-226 emit alpha particles. These and other alpha emitters occur naturally as radioactive contaminants, but several also come from man-made sources. They may occur in either groundwater or surface water.

At high exposure levels, alpha emitters may cause cancer.

Beta and photon emitters (radium-228 and tritium): Beta and photon emitters are primarily man-made radioactive contaminants associated with operating nuclear power plants, facilities that use radioactive material for research or manufacturing, or facilities that dispose of radioactive material. Some beta emitters occur naturally. Beta and photon emitters primarily occur in surface water.

At high exposure levels, beta and photon emitters are believed to cause cancer in humans.

Treatment Units for Radionuclides

Whether or not a particular treatment technology can effectively remove a specific radionuclide from drinking water depends on the contaminant's chemical and physical characteristics.

Some treatment options can successfully remove a particular group of radionuclides, yet allow other radionuclides to pass through untreated (Table 1). The effectiveness of most drinking water treatment systems depends on the water quality of the source as well as the size of the water system.

Table 1. Technologies used for the treatment of radionuclides.

Contaminant	Treatment Technology
Radium (-226 and -228)	Ion exchange (IE)-cation, reverse osmosis (RO), distillation (D)
Radon-222	Aeration, granular activated carbon (GAC)
Uranium	IE-anion, RO, D
Adjusted gross alpha emitters	RO, D
Gross beta and photon emitters	IE-mixed bed, RO, D

Reverse Osmosis

One treatment available for a wide range of radionuclides is reverse osmosis (RO). RO can remove 87 to 98 percent of radium from water. It can also reduce the levels of uranium, alpha particle, beta and photon emitter activity.

RO operates by subjecting pressurized water to a special semipermeable membrane (Fig. 4). The membrane allows the water to flow through it but prevents the radionuclides from passing through.

The effectiveness of the process depends on the pH, total suspended solids (TSS, which are materials in water that can be trapped by a filter), pressure and iron and manganese content of the water and the type of membrane used in the system. The water may need to be pretreated to prevent the membrane from degrading. The TSS need to be removed to prevent fouling and to extend the life of the membrane. Some water sources also contain dissolved solids; removing them will prevent scaling in the unit.

The disadvantage of an RO unit is its relatively poor water recovery. Most units are designed to achieve 20 to 30 percent recovery, which means if 100 gallons are treated, only 20 to 30 gallons are usable, and the rest of the water is sent to the wastewater treatment system. Homeowners using on-site waste-

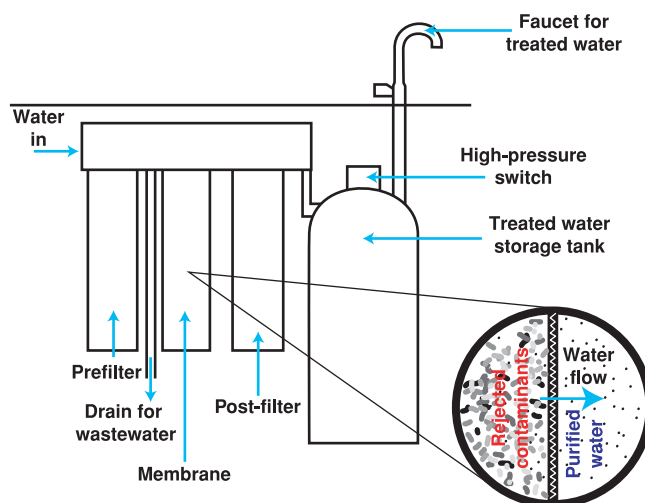


Figure 4. Reverse osmosis treatment unit (adapted from Kneen et al., 1995 and US EPA, 2003).

water treatment should consider the effect that the additional loading may have on their septic systems.

Because of the RO system's inefficiency, it is typically used to treat only drinking and cooking water. The size of the system should be based on the number of gallons that will be used for these purposes each day.

Typical treatment units produce from 5 to 15 gallons of usable water per day. If large amounts of water are needed, a better option may be another method of treatment, such as ion exchange.

Costs

RO devices usually cost from \$300 to \$1,000. If no significant plumbing modifications are needed, installing the device should take 30 to 60 minutes. The RO membrane will need to be replaced according to the manufacturer's recommended schedule. New membranes cost about \$150.

Depending on the system and based on a 10-year life of the system, the cost of water production ranges from 5 to 10 cents a gallon. This estimate does not take into account the cost of the wasted water or the cost, if any, of treating the wastewater.

Ion Exchange

Ion exchange (IE) is a residential water treatment option that can remove about 90 percent of radionuclides from drinking water.

In the IE process, contaminated water is sent through a resin that contains charged particles. As the water flows through the resin, the contaminant is exchanged with the charged particles in the resin (Fig. 5). The contaminant stays in the resin, and

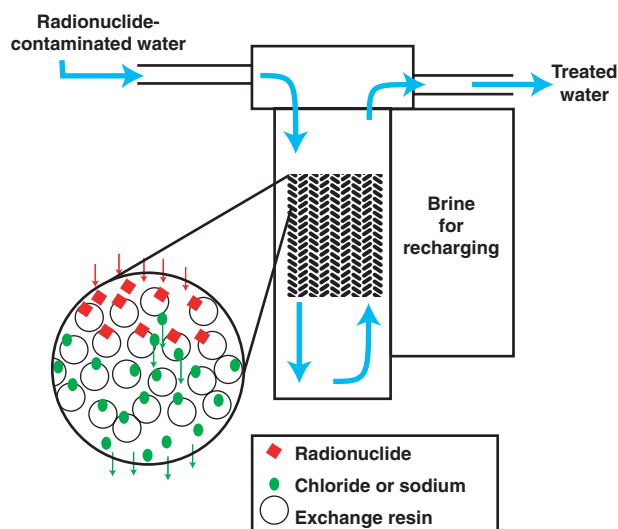


Figure 5. Ion exchange process (adapted from Robillard et al., 2001b).

charged particles from the resin flow out with the treated water.

IE systems can contain different types of resin, depending on the charge of the contaminant intended for removal. Ion exchange units may have cation (positively charged), anion (negatively charged) or mixed bed (a combination of positive and negative ions) resins. Cation exchange is often referred to as water softening.

For example: In a cation exchange unit, radium in the water will replace what is usually sodium or potassium cations on the resin. The radium stays in the unit attached to the resin, and the cations it replaced flow out with the treated water.

Anion exchange units have a similar process, in which uranium replaces chloride or hydroxide anions on the resin. If the water contains both uranium (negative) and radium (positive), a mixed bed ion exchange media can be used.

Anion exchange systems have been found to effectively remove 85 to 95 percent of alpha emitters, depending on the quality of the source water and the kind of alpha emitters in it.

A mixed bed system can also effectively remove gross beta and photon emitters from drinking water. However, keep in mind that other ions present in the water, such as nitrate or sulfate, may compete with the radionuclides for exchange sites on the resin.

When all of the original ions on the resin have all been replaced with contaminants, the resin must be replaced or regenerated to prevent the radionuclide from passing through the resin untreated. An IE unit is regenerated by flushing the resin with a strong

solution, usually a sodium chloride or potassium chloride solution. This displaces the positively or negatively charged radionuclides with sodium (positive) or chloride (negative) ions.

The waste from the regeneration process, which may be radioactive, must be disposed of in accordance with local and federal regulations.

The effectiveness of an IE system may be compromised by excessive amounts of TSS. If the source water is high in solids, a pretreatment filter should be installed.

Costs

Ion exchange units cost from \$400 to \$1,500 each. Operation and maintenance costs have been estimated to be 2 cents per gallon of treated water.

Distillation

A process that can remove all common types of radionuclides, except radon, from drinking water is distillation.

In the distillation process, water is heated to boiling in an enclosed container (Fig. 6). As the water evaporates, the impurities in the water are left behind in the container. The steam passes over coils that deliver the cooler untreated water to the unit, causing the steam to cool and condense back into a liquid.

Some of the dissolved gases and compounds in the water volatilize (evaporate) near the temperature at which water boils. These will be carried with the

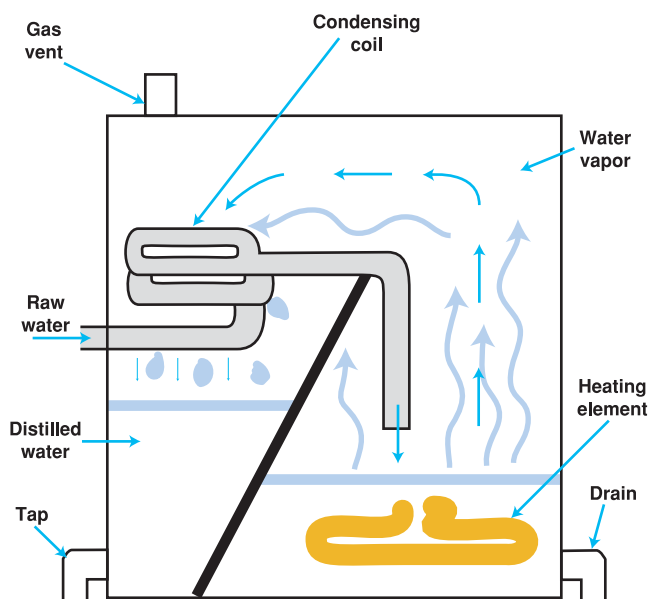


Figure 6. Distillation process (adapted from Kocher, et. al., 2003).

steam and therefore end up in the treated water. These contaminants can be removed by passing the distilled water through a post-filter.

Most distillation units can treat 5 to 11 gallons of water a day.

Costs

Distillation units can be purchased for \$300 to \$1,200. The operating costs for distillation systems may be higher than for other treatment methods because of the amount of electricity required to operate the distiller. Use this formula to estimate the cost of the energy:

$$\text{Cost/gallon} = 0.024 \times \frac{\text{Wattage of unit}}{\text{Production (gallons/day)}} \times \text{Cost of electricity (\$/k Wh)}$$

Aeration

One technology available for removing radon is aeration. By exposing the water to enough air, up to 99.9 percent of the radon can be removed before the water reaches your tap.

Aeration units have not been tested or certified by the National Sanitation Foundation or the Water Quality Association. However, radon can be removed by three main types of home aeration units: spray aeration, packed column, and a unit that uses a shallow tray.

For all types of aeration units, the water may need to be pretreated if it is high in total suspended solids. Also, after the water is treated for radon, the contaminated air may need to be treated with a granular activated carbon (GAC) system to lower the concentration of radon being discharged through the outside vent.

Spray Aeration

In a spray aeration system, contaminated water is sprayed through a nozzle into a holding tank (Fig. 7). When the water is sprayed, the radon in it evaporates. Then an air blower carries the volatilized gas to a vent outside the house.

With the initial spray, 50 percent of the radon is removed. As the water is sprayed multiple times, even more radon is removed.

To work properly, a spray aeration system needs to include a holding tank of at least 100 gallons.

Packed Column Aeration

In a packed column aeration system, radon is removed from contaminated water as it is sprayed into the top of a column filled with packing material (Fig. 8). The thin layer of water is exposed to air being blown from

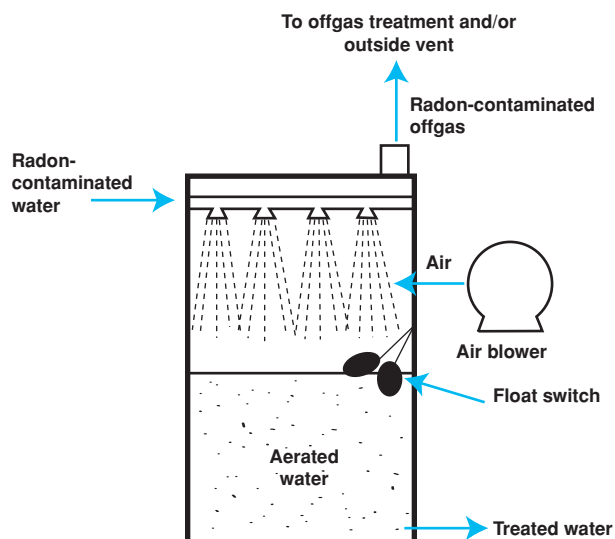


Figure 7. Spray aeration system (adapted from Robillard, 2001a).

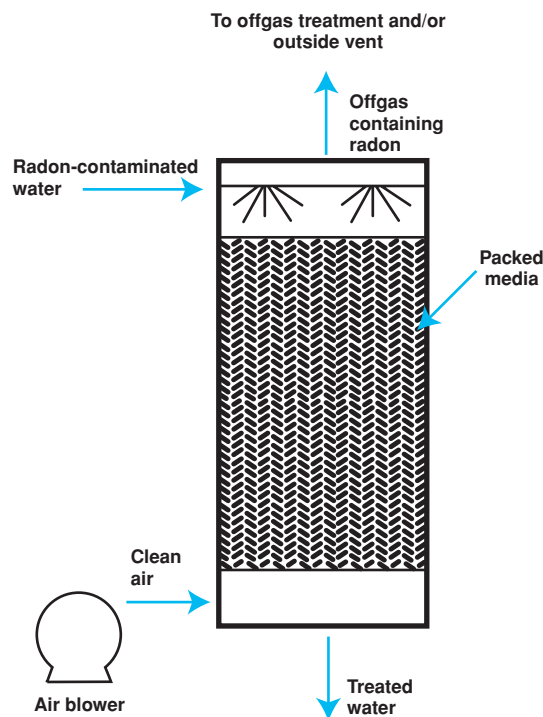


Figure 8. Packed column aeration system (adapted from Robillard 2001a).

the bottom of the column. The air then carries the radon gas out of the column to an outdoor vent.

Depending on the height of the column, a packed column aeration system can remove 90 to 95 percent of the radon in the water.

This treatment option is not practical for water having radon concentrations higher than 20,000 pCi/L.

Another drawback to this type of system is that over time, biological growth on the packing material or hardness in the water may cause scaling of the equipment.

Shallow Tray Aeration

Shallow tray aeration systems can remove more than 99.9 percent of the radon in water. In this type of system, contaminated water is sprayed onto a tray with tiny holes in it (Fig. 9). As the water flows across the tray, air is blown up through the holes.

The water collects on the bottom of the tank and is then pumped to a water pressure tank. As with the other aeration systems, the radon-contaminated air escapes through an outside vent.

This type of unit is traditionally smaller than other types and uses low-pressure air blowers. Unlike the packed column, the tray is not subject to fouling.

A drawback to this type of system is that it uses more air per minute than the other systems; its air flow rate is so high that it can even depressurize the area where it is stored.

Costs

The cost of home aeration units starts at about \$3,000. There will be additional installation and maintenance costs, such as energy requirements for blowers and filter replacement if GAC air filters are used.

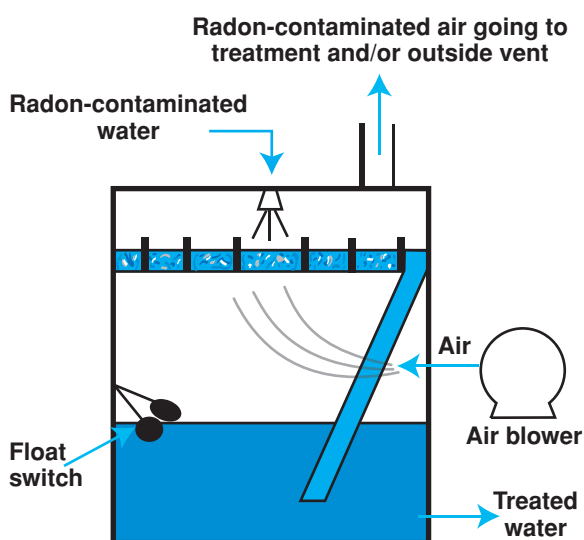


Figure 9. Shallow tray aeration system (adapted from Twitchell, 2000).

Granular Activated Carbon

Another way to remove radon gas from water is to use granular activated carbon. GAC systems remove radon from water through adsorption—that is, when water is passed through the carbon material in the unit, radon collects on the surface of the material and is removed from the water.

The effectiveness of the adsorption process depends on factors such as the pH and temperature of the water; the chemical composition and concentration of the contaminants; and the system's water flow rate and exposure time to the carbon. As the temperature and pH levels drop, the rate of adsorption usually increases.

Granular activated carbon lasts longer when the water has low concentrations of contaminants and when flow rates through the unit are low. The type of carbon used in the system should be determined by the system manufacturer's recommendations.

If the source water contains bacteria or high levels of total suspended solids, the water may need to be prefiltered. Bacteria and suspended solids can disrupt a GAC system. If microorganisms collect and grow on the filter, the water treated by the filter may end up with a higher bacteria concentration than what was in the source water. Also, if TSS are not removed, the solids may clog the pore spaces, making the system ineffective.

A range of GAC systems is available for home use, including:

- Point-of-entry (POE) devices, which treat all the water entering a home. They include pour-through filters and faucet-mounted units.
- Point-of-use (POU) devices, which are used to treat water for drinking and cooking.

When a GAC system is used to remove radon, the filter eventually becomes radioactive as it picks up the radon gas. For this reason, the treatment unit must be placed outside of the home or in an isolated area. This makes GAC point-of-use systems impractical for radon treatment.

The disposal of spent filters may pose a problem. All waste needs to be disposed of in accordance with local and state laws. The contractor providing the media replacement may offer disposal of the spent GAC.

Costs

Point-of-entry GAC systems usually cost from \$300 to \$3,000. Depending on the unit's size and the

manufacturer's recommendations, the GAC can treat about 100,000 gallons of water before needing replacement. Replacing the media costs \$80 to \$100 per cubic foot. The media will need to be replaced rather than backwashed because backwashing with hot water can release the captured radon.

Selecting a Treatment Unit

No single technology can treat all water contaminants. Before selecting a treatment option, you should have your water source tested by a qualified third-party laboratory to determine the water quality. For a list of labs certified by the Texas Commission on Environmental Quality (TCEQ) to test drinking water, see <http://www.tnrc.state.tx.us/permitting/waterperm/pdw/chemlabs.pdf>.

Once you have established what is in the water, research the different products on the market and find one suitable for treating that contaminant. If more than one contaminant is to be treated, check the systems' co-treatment compatibility. For example, an ion exchange unit can remove multiple types of radionuclides, but to do so, an appropriate resin must be chosen.

When comparing treatment units, consider the initial cost, operation and maintenance costs and requirements, the contaminant removal efficiency, warranties, the system's life expectancy and the reputation of the manufacturer. Before making a final decision, consider the wastewater or solid waste that the system will generate and whether or not you will be able to dispose of the waste.

It is important to note that home treatment systems are not regulated by federal or state laws. There are, however, national organizations that offer certification of products. The Water Quality Association (WQA) offers a validation program and advertising guidelines. Products that receive a Gold Seal Product Validation from the WQA are certified in their mechanical performance, but not in their ability to remove harmful contaminants.

The National Sanitation Foundation (NSF) provides certification of a product's ability to remove contaminants that affect health. For a list of drinking water treatment units with NSF certification, see <http://www.nsf.org/Certified/DWTU/>.

If you have questions about whether a particular product is certified, contact the NSF by calling 877-8-NSF-HELP (877-867-3435), e-mailing to info@nsf.org, or writing NSF International, NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113-0140.

If a product has an EPA registration number, this merely indicates that the unit is registered with the EPA; it does not imply EPA approval or certification.

Keeping the System Working

No matter what treatment technology is being used, the system must be maintained to keep operating properly. The first step to proper operation and maintenance is proper installation. Qualified installers:

- Carry liability insurance for property damage during installation
- Are accessible for service calls
- Accept responsibility for minor adjustments after installation
- Give a valid estimate of the cost of installation

After the system is installed, the unit must be maintained properly. RO membranes must be replaced as needed. The resin in ion exchange units must be replaced or recharged. Distillation units must be periodically cleaned to remove scaling and solid buildup. Any filters used in the system should be replaced according to the manufacturer's recommendations. All wastes should be disposed of properly.

Every system should be operated according to the manufacturer's specifications. If you treat more water than the system is designed for in a certain period, the treatment may be less effective and quality of the treated may be diminished.

To make sure your system is working properly, have the treated water tested regularly by a certified lab.

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