Tech Brief

A NATIONAL DRINKING WATER CLEARINGHOUSE FACT SHEET

Radionuclides

Summary

Radionuclide contamination of drinking water is a significant, emerging issue. Until now, manmade radioactivity in drinking water has not been a major problem. Natural sources have been the primary cause of contamination. However, the potential for contamination exists throughout the country as releases from medical facilities or nuclear power plants may wind up in drinking water. Because of their potential health effects and widespread occurrence, natural radionuclides—including radon, radium, and uranium—cause much concern.

Where do radionuclides occur, and what are the public health risks?
Radionuclides occur naturally as trace elements in rocks and soils as a consequence of the "radioactive decay" of uranium-238 (U-238) and thorium-232 (Th-232). This decay happens because radioactive atoms have too much energy. When radioactive atoms release or transfer their extra energy, it is called decay. The energy they release is called ionizing radiation, which may be alpha particles, beta particles, or gamma rays. This energy is transmitted through space or another medium in waves (e.g., x-rays or gamma rays) or particles (e.g., electrons or neutrons) and is capable of either directly or indirectly removing electrons from atoms, thereby creating ions, which are electrically charged atoms.

Radon-222, radium-226, radium-228, uranium-238, and uranium-234 are ions of the U-238 and Th-232 decay series. They are the most common radionuclides found in groundwater. Other naturally occurring radionuclides tend to be environmentally immobile or have short half-lives, meaning they are far less likely to be found in significant amounts in groundwater.

When ionizing radiation strikes a living organism's cells, it may injure the organism's cells. If radiation affects a significant number of cells, the organism may eventually develop cancer. Or at extremely high doses, it may even die.

Radon: Radon is a naturally occurring radioactive gas that emits ionizing radiation. National and international scientific organizations have concluded that radon causes lung cancer in humans. Ingesting drinking water that contains radon also presents a risk of internal organ cancers, primarily stomach cancer. The U.S. Environmental Protection Agency (EPA) and the U.S. Surgeon General recommend testing indoor air for radon in all homes and apartments located below the third floor. If you smoke and your home has high indoor radon levels, your risk of lung cancer is especially high.

Tap water only emits approximately 1 to 2 percent of the radon found in indoor air. However, breathing radon from this source increases the risk of lung cancer over the course of a lifetime.

Radium: Radium-226 and radium-228 are natural groundwater contaminants that usually occur at trace levels. At high exposure levels, radium-226 and radium-228 can cause bone cancer in humans and are believed to cause stomach, lung, and other cancers as well.

Uranium: Uranium is a naturally occurring radioactive contaminant that is found in both groundwater and surface water. At high exposure levels, uranium is believed to cause bone cancer and other cancers in humans. EPA also believes that uranium can be toxic to the kidneys.

Gross Alpha: Alpha emitters naturally occur as radioactive contaminants, but several come from manmade sources. They may occur in either groundwater or surface water. At high exposure levels, alpha emitters are believed to cause cancer in humans.

Beta and photon emitters: Beta and photon emitters are primarily manmade 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.

TABLE 1: What regulations govern radionuclides?

Radionuclide National Primary Drinking Water Regulations						
			EPA Standards			
Contaminants	**Drinking Water Health Effects**	**Proposed Maximum Contaminant Level Goal MCLG**	**Proposed Maximum Contaminant Level (MCL)**	**Current MCL**	**Sources**	**Best Available Technology(BAT)[2]**
Radium-226	Cancer	Zero	20 pCi/L	5 pCi/L combined with radium-228	Naturally occurring	Ion Exchange (IE); Lime Softening (LS); Reverse Osmosis (R0)
Radium-228	Cancer	Zero	20 pCi/L	5 pCi/L combined with radium-226	Naturally occurring	IE; LS; RO
Radon-222	Cancer	Zero	300 pCi/L	-	Naturally occurring	Aeration
Uranium	Kidney toxicity, Cancer	Zero	20 ug/L [3]	-	Naturally occurring	Coagulation/Filtration; Anion exchange; LS; RO[4]
Adjusted gross alpha emitters	Cancer	Zero	15 pCi/L	15 pCi/L	Naturally occurring and manmade	RO
Gross beta and photon emitters	Cancer	Zero	4 mrem ede/yr	4 mrem ede/yr any organ or whole body	Naturally occurring	IE; RO

1 *PicoCuries per liter* (pCi/L) is an activity measurement of radioactive decay (1 pCi/L = 2.2 disintegrations per minute); *micrograms per liter* (µg/L) is a mass measurement; *mrem* is measurement of effective radiation dose to organs.
2 Except as noted, BAT for the purpose of issuing variances is the same as BAT for compliance.
3 20 µg/L is based on kidney toxicity. 20 µg/L is the equivalent of 30 pCi/L.
4 *Coagulation/Filtration* and *Lime Softening* are not BAT for small systems (those with fewer than 500 connections) for the purpose of granting variances.

Note: EPA recognizes that most radionuclides emit more than one type of radiation as they decay. The lists of compounds labeled "alpha" or "beta" emitters identify the predominant decay mode.

Note: In this document the unit mrem ede/yr refers to the dose ingested over 50 years at the rate of 2 liters of drinking water per day.
Source: U.S. Environmental Protection Agency, 1991

What are the treatment technologies for radionuclides?

Whether or not a particular treatment technology effectively removes radionuclides from drinking water depends on the contaminant's chemical and physical characteristics as well as the water system's characteristics (e.g., source water quality and water system size). Other considerations include cost, service life, and co-treatment compatibility.

Evaluation of Technologies

The following treatment technologies were evaluated for their ability to remove radionuclides from water:

- ion exchange (IE);
- point-of-use (POU) IE;
- point-of-entry (POE) IE;
- reverse osmosis (RO);
- POU RO; POE RO;
- lime softening (LS);
- greensand filtration;
- co-precipitation with barium sulfate;
- selective sorbents;
- electrodialysis/electrodialysis reversal (ED/EDR); and
- preformed hydrous manganese oxides (HMOs).

Ion Exchange: Small systems may readily use IE treatment, which removes approximately 90 percent of radionuclides. The effluent must be regularly monitored and the resin must be frequently regenerated to ensure that breakthrough does not occur. Ion exchange units may be controlled automatically, requiring less of the operator's time. However, it is necessary to employ a skilled operator to determine when regeneration is needed and to trouble-shoot. Also, disposal of concentrated radionuclides can be expensive.

Ion exchange treatment generates wastes that include rinse and backwash water, and the resin. The rinse and backwash liquid waste includes brine, radium, and any other contaminants that the process removes.

Cation Exchange: A cation is a positively charged ion. Cation exchange resins exchange like-charged ions equally with protons—sodium ions (Na+), or in sodium-restriction cases, potassium ions (K+)—to remove undesirable cations from water. Cation exchange is often used to remove calcium and magnesium cations, and to treat hard water.

The amount of waste (rinse and backwash) that cation exchange typically generates ranges between 2 and 10 percent of the treated water.

Lime Softening: Lime softening can be used to remove radium from drinking water with 80 to 95 percent efficiency. Also, adding lime or lime-soda ash to water increases the pH of the water and induces calcium carbonate and magnesium hydroxide precipitation. Lime softening also is used to treat hard water.

Lime softening generates wastes that include lime sludge, filter backwash liquid and sludge, and sludge supernatant.

Reverse Osmosis (RO): Reverse osmosis effectively removes many inorganic contaminants, including heavy metals and radionuclides, such as radium and uranium. RO can remove 87 to 98 percent of radium from drinking water. Similar elimination can be achieved for alpha particle activity and total beta and photon emitter activity.

When using an RO system to remove radionuclides, performance depends on a number of factors, including pH, turbidity, iron/manganese content of the raw water, and membrane type. The pretreatment design depends on the quality and quantity of the source water. Existing treatment plants may already provide much of the required pretreatment—for example, coagulation/filtration of highly turbid surface water or iron removal for well waters. RO can be cost effective for small systems.

Technologies for Radionuclide Removal Not Proposed as BAT in 1991

Greensand Filtration for Radium Removal

Greensand filtration technology consists of a conventional filter box with manganese greensand replacing the traditional filtration medium. Studies indicate that greensand filtration removes up to 56 percent of radium.

This process generates wastes that include sludge and supernatant from the filter backwash, and eventually the greensand media must be disposed of.

TABLE 2: Technologies for Radionuclides

Unit technology	Limitations (see footnotes)	Operator skill level required[1]	Raw water quality range and considerations[1]
1. Ion Exchange (IO)	(a)	Intermediate	All groundwater
2. Point of Use (POU) IO	(b)	Basic	All groundwater
3. Reverse Osmosis (RO)	(c)	Advanced	Surface water usually requires prefiltration
4. POU RO	(b)	Basic	Surface water usually requires prefiltration
5. Lime Softening	(d)	Advanced	All water
6. Green Sand Filtration	(e)	Basic	
7. Co-precipitation with Barium Sulfate	(f)	Intermediate to Advanced	Groundwater with suitable water quality
8. Electrodialysis/Electrodialysis Reversal		Basic to Intermediate	All groundwater
9. Pre-formed Hydrous Manganese Oxide Filtration	(g)	Intermediate	All groundwater

1 National Research Council (NRC). "Safe Water from Every Tap: Improving Water Service to Small Communities." National Academy Press. Washington, DC. 1997.

Limitations Footnotes

a. The regeneration solution contains high concentrations of the contaminant ions. Disposal options should be carefully considered before choosing this technology.

b. When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by the water utility to ensure proper performance.

c. Reject water disposal options should be carefully considered before choosing this technology.

d. The combination of variable source water quality and the complexity of the chemistry involved in lime softening may make this technology too complex for small surface water systems.

e. Removal efficiencies can vary depending on water quality.

f. This technology may be very limited in application to small systems. Since the process requires static mixing, detention basins, and filtration; it is most applicable to systems with sufficiently high sulfate levels that already have a suitable filtration treatment train in place.

g. This technology is most applicable to small systems that already have filtration in place.

Source: Environmental Protection Agency, 1998

Preformed Hydrous Manganese Oxide (HMO) Filtration
Costs for HMO treatment can be quite low, if filtration is already in place.

HMO filtration is similar to oxidation/filtration in its complexity and the operator skill it requires. Proper dosages must be determined, and if water quality varies, the dosage must be recalibrated. Once the proper dose is determined, dosing is relatively easy. HMO filtration requires simple equipment and is fairly inexpensive. Filters must be backwashed, which may require intermediate operator skill. Radium containing wastes include HMO sludge, filter backwash, and sludge supernatant.

Co-precipitation of Radium with Barium Sulfate
Adding a soluble barium salt—such as barium chloride—to radium and sulfate contaminated water causes co-precipitation of a highly insoluble radium-containing barium sulfate sludge. This process has primarily been used for wastewater treatment. Mine wastewater treatment data indicates that this process removes up to 95 percent of radium.

This process generates wastes that include the barium sulfate precipitate sludge, filter backwash, and sludge supernatant.

Other Technologies
Some other technologies also are available that may remove radionuclides from drinking water. However, these technologies have not been fully tested for drinking water treatment or have only been used in industrial or experimental situations. Examples of processes that remove radium include selective sorbents (e.g., acrylic fibers or resins impregnated with manganese dioxide) and non-sodium cation exchangers (e.g., hydrogen ions and calcium ions).

Where can I find more information?

(1) American Water Works Association & American Society of Civil Engineers. 1998. *Water Treatment Plant Design; 3rd ed.* The McGraw-Hill Companies, Inc.

(2) U. S. Environmental Protection Agency. September 1998. *Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996.* EPA 815-R-98-002.

(3) U. S. Environmental Protection Agency. August 1998. *Federal Register/Notices.* Vol. 63, No. 151.

(4) U. S. Environmental Protection Agency. October 1999. Office of Groundwater and Drinking Water. *Proposed Radon in Drinking Water Rule: Technical Fact Sheet* EPA 815-F-99-006. *www.epa.gov/safewater/radon/fact.html*

(5) U. S. Environmental Protection Agency. June 1991. Office of Ground Water and Drinking Water. *Radionuclides in Drinking Water - Fact Sheet* EPA 570/9-91-700.

(6) U. S. Environmental Protection Agency. July 1991. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule" *Federal Register,* Vol. 56, No. 138.

(7) U. S. Environmental Protection Agency. March 1997. *Federal Register,* Vol. 62, No. 43.

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