



Uranium Removal by Ion Exchange

Measures to reduce uranium in the drinking water supply

By Frank DeSilva

Uranium is a naturally occurring weakly radioactive element. High levels of uranium in water may increase the risk of cancer and kidney damage. Most of the uranium that is ingested by food or drink by the human body is excreted, but some amounts are absorbed into the bloodstream and kidneys. The health effects from ingesting uranium are caused primarily by chemical damage, not by the radioactivity. Uranium decreases the kidneys' ability to filter toxins from the bloodstream. These effects are reversible if the uranium contamination is eliminated.

Uranium is a radionuclide, more likely to occur in ground water than surface water, and is often found together with radium. Mitigation of problem waters may require treatment for the removal of both uranium and radium.

The U.S. Environmental Protection Agency (EPA) sets standards in the Safe Drinking Water Limits. These are calculated levels of contaminants in water based on an assumption that a person consumes 2 liters of water per day for 70 years. EPA has set a Maximum Contaminant Level (MCL) for uranium of 30 µg/L. The MCL was set primarily because of the heavy metal toxicity of uranium, not its radioactivity.

The EPA estimates that more than 500 community water systems nationwide have uranium levels in the water greater than 30 µg/L. These systems will need to take measures to reduce the uranium in the drinking water supply. Remedial actions include developing alternate water sources, purchasing water from other providers, or treatment of the water supply.

Uranium typically exists in water as the uranyl ion, UO_2^{2+} , formed in the presence of oxygen. At pH above six, uranium exists in potable water primarily as the uranyl carbonate complex. This form of uranium has a tremendous affinity for strong base anion resins.

The relative order of affinity of strong base anion resins for some common ions in drinking water show uranium at the top of the list:

Uranium/Perchlorate >> Sulfate/Chromium > Selenium/Arsenate > Nitrate > Chloride > Bicarbonate > Fluoride.

Resin Selection

Cation resin in the hydrogen form has been found to remove uranium, probably by converting the uranium complex to the uranium cation. Removal rates are in the 90–95% range, but the pH of the effluent will be low (about 2.5 to 3.5) and the resin used in this method is not selective, removing all cations.

Cation resin in the sodium form, operating as a softener, has limited use in uranium removal and is very pH dependent. At pH 8.2, there is no uranium removal, and at pH 5.6 there is about 70% removal. As the resin exhausts to the calcium form, removal is even less effective, with no removal at pH 8.2 or 7, some removal beginning to occur at pH 5.6, and 60% removal at pH 4.

Obviously, cation resin is not a viable ion exchange removal method because of the pH requirements and especially when the technique is compared to strong base anion resins. Anion resin in the chloride form can easily reduce uranium levels by over 90%. It can be used in a regenerable process or once-through. A mixed bed of cation and anion resins can be considered for some applications that are used to remove both radium and uranium.

For uranium alone, Type 1 or Type 2 anion strong base anion resins can be used. Many prefer to use the Type 2 resins because of the much lower potential for the formation of odor when treating drinking water with anion resin.

Low levels of uranium in the water in the order of a few ppm can be removed effectively with a Type 1 porous anion resin operated in the chloride form. The uranium is present as an anionic complex U_3O_8 or the tetravalent carbonate anionic complex $UO_2(CO_3)_3$. The anion resin should be regenerated with 15 lb. per cu. ft. of

sodium chloride, and the capacity will be about 18 kilograins per cu. ft. The uranium is held more strongly than the sulfate and the specific capacity of the resin for just uranium is approximately 5 kilograins per cu. ft. During service, the sulfate in the water will not displace the uranium.

Estimating Capacity

The uranium carbonate complex has a relative affinity for strongly basic anion exchange resin that is over 100 times greater than any common ions, including the divalent ions like carbonates and sulfates. At the pH levels associated with potable water applications, (6–9), the carbonate ion is negligible as it exists primarily as the bicarbonate species which is monovalent. Therefore, the sulfate ion is the only potential competitor. The throughput capacity of a strong base anion resin for uranium removal can conservatively be estimated as being 100 times the throughput to sulfate breakthrough. In order to maintain this capacity over many cycles, it is necessary to use sufficient salt at sufficiently high concentrations to regenerate the resin back to the chloride form.

At pH above six, uranium exists in potable water primarily as a carbonate complex which is an anion and has a tremendous affinity for strongly basic anion exchange resins. The process has been tested and found to be very effective at pH of 6 to 8.2. Higher pH could result in uranium precipitation which make the problem one of physical removal. Lower pH changes the nature of uranium to non-ionic and/or cationic which would prevent the exchange reactions from operating effectively. Tests have shown effective removal (over 95%) of uranium at pH as low as 5.6. But after the pH was reduced to 4.3, the removal rate dropped to 50% and the run lengths (throughput capacities) were reduced by over 90%.

Therefore, it is advisable to control the inlet water pH above six at all times. It has also been shown that sudden changes in



pH of the influent water to values below 5.6 can result in dumping of previously removed uranium. In situations where the pH cannot be maintained above 5.6, other treatment methods should be considered.

Regeneration

In order to regenerate the uranyl carbonate it is important that the concentration of the regenerant at the resin bed be sufficiently high to reverse or reduce the relative affinities to acceptable levels and to use enough regenerant and contact time. Sodium chloride is the most common regenerant.

Concentration above 10% NaCl, at regenerant levels of 14 to 15 lbs. per cu. ft. is sufficient to insure better than 90% uranium removal through the operating cycle. This dosage will elute at least 50% of the collected uranium from the resin. Leakage will remain low through the service cycles even without complete regeneration because of the very high selectivity during the service cycle. Leakages are essentially nil for regeneration levels of 15 lbs. of sodium chloride per cu. ft. at concentrations of 10% or higher with minimum contact time of at least 10 minutes during regeneration.

Effectiveness of varying concentrations of salt:

Regenerant Level - Approximately 22 lbs. per cu. ft. of Type 1 Gel Anion Resin.

NaCl Concentrations	Uranium Removed
4%	47%
5.5%	54%
11%	75%
16%	86%
20%	91%

Other Regenerants

The chloride ion is the most effective ion for regeneration of uranium of those commonly found in potable water. Neutral salts, (sodium chloride by far the most common) are usually preferred because of environmental and materials of construction considerations. Regeneration with pure hydrochloric acid, though not recommended because of the nature of hydrochloric acid and the added expense for corrosion resistant equipment, shows an even better efficiency than sodium chloride. This is mentioned to point out that lower pH is acceptable in terms of regeneration efficiency.

Higher pH solutions, through the addition or use of alkalis such as sodium hydroxide, sodium bicarbonate or sodium carbonate, will result in severely decreased uranium regeneration. At high pH, uranium tends to form $\text{Na}_2\text{U}_2\text{O}_7$ a non-ionized precipitate.

Safety and Handling

Regenerant waste from the uranium removal system is a concentrated form of the uranium and must be disposed of properly. For the homeowner, the spent

solution is usually discharged the same way softener brine is discharged, the net amount of uranium reaching the disposal point is the same whether or not a uranium removal unit is in place. Still, it is necessary to check the regulations for a given locale.

Disposal of uranium-laden resin must take into account the amount of radioactivity present in the media.

The U.S. Department of Transportation regulates the transportation and handling of low level radioactive waste. Uranium is less toxic and so has higher allowable levels than radium. The reported level for uranium is 2,000 picoCuries per gram of media.

Anticipated throughputs can be calculated by your ion exchange resin supplier. Once-through applications can reach the-

oretical throughput volumes much greater than 100,000 bed volumes (BV), while service cycles on regenerable service can be around 40,000 to 50,000 BV. Although it is tempting to run the resin as long as possible on the once-through applications, consideration must be given to the total amount of uranium collected and the subsequent disposal issues.

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Estimated Costs

The EPA estimates that the annual costs of compliance for individual community water systems to be as follows:

- Smallest systems \$9,000
- Systems serving 3,300 to 10,000 people \$150,000
- Large systems \$500,000

EPA List of Drinking Water Contaminants & MCLs is available at www.epa.gov/safewater/mcl.html#mcls. *wqp*

About the Author

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