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Project Summary

Uranium Removal from Drinking Water Using a Small Full-Scale System

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Sometime during 1989, the U.S. Environmental Protection Agency (USEPA) will propose new drinking water regulations for radionuclides. The Agency has indicated that the new proposed regulations will contain a maximum contaminant level (MCL) for uranium, and that the MCL will probably fall somewhere between 10 and 60 picocuries per liter (pCi/L). Of the approximately 60,000 community water systems in the United States, between 100 and 200 will probably require treatment to reduce uranium levels to a concentration within this proposed range.

The study summarized here presents the background and history of water quality, the basis for design, and 9 months of actual operating data for a small, full-scale, strong-base ion exchange system that is used to reduce levels of uranium to less than the probable MCL range. The system was efficient in removing over 99 percent of the uranium present in the raw water. The presence of radon and radium, ion exchange regeneration results, regenerant wastewater disposal, and gamma radiation profiling of the system are discussed, together with capital costs and operation and maintenance (O&M) costs.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (See Project Report ordering information at back).

Introduction

Uranium is a naturally occurring radionuclide that can be found in both groundwater and surface water. The USEPA, Office of Drinking Water, is proposing to establish an MCL for uranium as required by the 1986 Amendments to the Safe Drinking Water Act. Until now, there has not been an MCL for uranium.

Groundwaters generally contain higher concentrations of uranium than do surface waters. The highest average uranium concentrations in public groundwater supplies are found in the Rocky Mountain area. Studies have concluded that 300,000 people in the contiguous 48 states are served by groundwater drinking water supplies with uranium concentration exceeding 10 pCi/L uranium. As many as 2,000 of the 60,000 community drinking water supplies in the United States will exceed this 10 pCi/L, with between 25 and 650 community drinking water supplies exceeding 20 pCi/L concentration. Most of these supplies are groundwater sources serving small populations in rural areas. In May Valley, Colorado, an average of 64 pCi/L uranium was found in the public groundwater system, and concentrations greater than 100 µg/L have been reported.

To provide the supporting treatment technology information for the removal of uranium from water, the USEPA Drinking Water Research Division has conducted several laboratory and pilot-plant studies on the application of ion exchange treatment. In one field survey, several

small ion exchange systems were used to remove uranium from 12 different water sources in Colorado and New Mexico. The data from this survey and the other USEPA inhouse laboratory studies have shown that anion exchange resins have a large capacity for uranium and that the technology is a viable method for uranium removal.

One participant in the field survey, the Jefferson County School District (District), operates numerous educational and maintenance facilities in the foothills west of Denver, Colorado. Many of these facilities are served by groundwater, and analyses of water samples from several of their wells have indicated gross alpha levels in the 30 to 150 pCi/L range. These gross alpha levels come almost entirely from uranium-234 (U_{234}) and uranium-238 (U_{238}).

The four full-scale ion exchange systems the District has installed to remove uranium from groundwater sources are considered to be among the first full-scale facilities used primarily for the removal of uranium from drinking water. The report summarized here concerns the 9-month study of the full-scale system at the Coal Creek Elementary School – a study to determine the operating characteristics, removal efficiencies, regeneration efficiency, and costs.

The mining industry has used ion exchange in the uranium recovery process since the 1950's. The result of studies to determine the feasibility of removing uranium from drinking water by ion exchange, along with historical information regarding ion exchange use in uranium processing, decisively indicate that ion exchange is suitable for uranium removal from drinking water. The Coal Creek Elementary School system study results agree with this accepted thesis and provide information on the practical aspects of implementing ion exchange for uranium treatment. One of the most difficult questions concerning the treatment scheme is, however, disposal of the uranium-laden brine generated during regeneration of the ion exchange media. Possible options for disposal of the concentrated waste uranium brine and the disposal method implemented at the Coal Creek Elementary School facility are also discussed in the report.

System Design

Over the previous 10 years, analyses of samples from several wells operated by the District and other private wells in the foothills west of Denver, Colorado, have indicated levels of gross alpha particle activity ranging from 30 to 150 pCi/L range. More recently, taking into account the ratio of U_{234} to U_{238} being greater than the normally assumed 1:1, essentially all of the gross alpha activity in the wells operated by the District was found to be attributed by the uranium isotopes. Data from two wells are presented in Table 1.

Although none of the wells in the study serve a community water system, the District decided in 1981 to participate in a 2-year investigation conducted by USEPA to remove uranium from one of the wells (raw water uranium = 28 µg/L) by the selective ion exchange process.

Based on the results of the USEPA field investigation at one of the District wells, the findings of other researchers, and the results from a 3-week pilot-scale column study, the District constructed a full-scale ion exchange treatment facility for removal of uranium in May 1986. Nine months later, a second system was installed at another well site within the District, then, in the summer of 1987, systems were constructed at two additional locations. Since well yields of 19 to 38 L/min (5 to 10 gpm) are similar at all four locations, the four treatment systems are essentially equal in capacity. Design criteria for the Coal Creek well system are summarized in Table 2.

The treatment system consists of two, spiral-wound cartridge prefilters in parallel, a two-tank commercial water softener system arranged in series, a brine tank to batch regenerant, and facilities to store and transfer spent regenerant. The water softener tank diameter and resin volume were based on typical loading rates and media depths for ion exchange systems. The second ion exchange tank was provided for redundancy. Also, because the time for laboratory analysis of uranium is 2 weeks, the second tank provides an added measure of safety with respect to uranium breakthrough.

When uranium is present in a groundwater supply, the radon and radium that may be present are of greater concern, from a health effects perspective, than is the uranium. Before the design of the treatment system was made final, the extent of radon and radium present was determined. Only small levels of radon gas and insignificant amounts of radium were detected in the District's well water. At all of the District locations, however, vented, treated-water storage tanks provide sufficient detention time and water-air interface to release the relatively insoluble radon gas before the treated water reaches the point-of-use. At the Coal Creek location, testing indicated radon gas was being removed in storage tank. Thus, radon remc processes were not originally provi with uranium removal facilities. As pa another contract, however, a gran activated carbon (GAC) column v added to the uranium removal treatm scheme in August 1987, downstream the ion exchange columns.

Results

Uranium and Gross Alpha Removal Efficiency

Uranium and gross alpha removal d for the Coal Creek system are su marized in Tables 3 and 4, respective Review of the uranium concentrati results indicates that greater than percent of the uranium present in the r water was removed by the resin except two cases when the uranium in t effluent of column No. 1 was slight elevated immediately after regeneration

Although gross alpha analysis is n as accurate an analysis for alpha-emittir radionuclides as is determining activi concentration of individual contributors, is an inexpensive screening technique determine relative occurrence of alph emitting species. For the first 5 months the Coal Creek treatment evaluatio gross alpha analysis was used t compare uranium concentration data. A indicated in Table 4, more than 8 percent of gross alpha was removed i column No. 1.

Regeneration Efficiency

During the study period, the systen was regenerated twice. A typica regeneration sequence includes one be volume of backwash water, approximatel five bed volumes of saturated NaC regenerated solution, and approximatel five bed volumes of slow rinse. Thus, th total volume of wastewater generatec during a regeneration for the Coal Creel system is between 200 and 300 gallons Characteristics of the mixed regeneratior wastewater are shown in Table 5 Comparison of the mass of uranium loaded on the first column over the loading cycle before regeneration with the mass of uranium in the regeneration wastewater indicates that 97 and 66 percent of the uranium loaded was removed during the first and second regenerations, respectively. Other research has shown that 100 percent regeneration does not occur with a NaC regenerant solution.

U_{234}/U_{238} Ratio

A concern about compliance with future uranium drinking water standards expressed in units of activity (i.e., pCi/L) occurs when samples are analyzed for uranium by the fluoroscopic method and U_{234} and U_{238} exist in a ratio other than in equilibrium (1:1). The concentration of uranium obtained from the fluoroscope analysis (µg/L) is typically converted to pCi/L by using the conversion factor of 0.677 pCi/µg, assuming U_{234} and U_{238} occur in a ratio of 1:1. For example, in West Jefferson County, Colorado, it is difficult to account for all of the gross alpha activity present if this conversion factor is used since no radium is present in the sample.

Because of this concern, several samples from the Coal Creek system were analyzed using alpha spectroscopy to determine the activity of each of the uranium species. The average U_{234}/U_{238} ratio ranged from approximately 2:3 to 3:7. When U_{234}/U_{238} activity ratio and uranium concentration in µg/L are known, converting the mass results to activity involves multiplying the concentration (in µg/L) times the ratio and then times the conversion factor of 0.677 pCi/µg.

Brine Disposal

Regeneration wastewater collected in the holding tank at the Coal Creek location is eventually hauled by truck to a 13,000-gallons-per-day (gpd) secondary domestic wastewater treatment facility operated by the District at another location. The regeneration wastewater is introduced to an equalization basin at the headworks of the facility. Limited data indicate that uranium is present in the wastewater treatment plant effluent and may concentrate in the sludge of the wastewater treatment plant.

Gamma Radiation Profile

A health consideration for operators of these ion exchange facilities is that of potential elevated exposure to gamma radiation. A gamma radiation profile was developed for various locations in and around the building that contains the Coal Creek uranium removal system and for individual unit treatment processes within the building. The levels for September 2, 1987, ranged from a background reading of 18 micro Roentgens per hour (µR/hr) to a maximum of 44 µR/hr at the 2-ft level on ion exchange column No. 1

A gamma radiation measurement in R/hr can conservatively be assumed to be equivalent to the radiation dose equivalent in rems per hour (rem/hr). With the use of conversion and based on the results from the September 2, 1987, profile, the exposure of an operator at the Coal Creek uranium removal system could be estimated to be 44 µR/hr (26 µR/hr above natural background) for 40 hours per week, 50 weeks per year, and yet only have received a dose of 52 mrem/yr This dose level is minor, even when compared to the recommended maximum dose equivalent of 100 mrem/year for the general public. Further, in a small facility such as the Coal Creek system, an operator is only in the building for short exposure times performing routine inspection, sampling, or regeneration duties.

The objective of a second gamma survey was to measure the gamma fields produced by the uranium-loaded resin in column No. 1 before regeneration. Unfortunately, between the initial gamma survey (September 2, 1987) and the second survey (November 18, 1987), an unshielded GAC column was installed to remove the radon. The gamma radiation from the radon decay products that accumulated in the carbon system was sufficiently strong to produce levels higher than the uranium-loaded resins at all points throughout the building where the Coal Creek system is housed.

Costs

Capital costs, including equipment, labor, and engineering, for the Coal Creek uranium removal system were approximately $8,900 in 1986. Although these costs do not include the well, well pump, pump controls, or the building where the treatment facilities are housed, they are indicative of costs that may be incurred for a system of similar capacity.

O&M costs for the uranium removal system only (including labor for operation, regeneration, and sample collection; sample analyses; pre-filter replacement; resin replacement; regenerant salt; and electrical requirements) are estimated to be $4.30 per 1,000 gallons of water treated. Regenerant wastewater disposal costs (including transportation by tanker truck to the wastewater treatment plant for disposal and analysis of plant effluent and sludge for uranium) are estimated to be $2.40 per 1,000 gallons of water treated. Thus, total O&M costs are approximately $6.70 per 1,000 gallons. Because of the costs associated with regenerant disposal and sophisticated analyses, O&M costs for similar uranium removal systems will be significantly higher than costs for conventional treatment.

Conclusions

Laboratory studies and pilot-plant tests have shown that conventional anion exchange resins in the chloride form are capable of removing uranium from as high as 23.8 mg/L in drinking water to 1 µg/L. Based on the initial 6 months of operating history for a full-scale uranium removal system, the following conclusions have been identified:

1. Anion exchange treatment can consistently remove uranium in well water at a reasonable cost for small systems.
2. Following both regenerations, it appears that concentrated brine remained in column No. 1 and was displaced into the finishes water during the subsequent loading cycle. This resulted in elevated levels of uranium in the treated water from the ion exchange columns for a very short period of time following regeneration.
3. Disposal of uranium-laden ion exchange regenerant wastewater is the most complex task involved in a project for removal of uranium from water.
4. Gamma radiation buildup in the individual components of the uranium removal system does not appear to be a health concern. If treatment is provided for radon removal, gamma radiation may be a concern.

Recommendations

1. If uranium is found in a drinking water supply, the water should also be analyzed for radon and radium.
2. Following regeneration of an iron exchange system, the length of the subsequent rinse cycle should be sufficient to remove all concentrated regenerant brine from the system.
3. Federal and/or state regulatory agencies should establish guidelines for both treatment (regeneration frequency) and disposal of wastes generated from systems removing radionuclides from drinking water.
4. Further research is needed about the fate of the uranium-laden ion exchange regenerant wastewater discharged to a wastewater treatment facility.

The full report was submitted in fulfillment of Contract No. 7C7639 by Richard P. Arber Associates, Inc., under the sponsorship of the U.S. Environmental Protection Agency.

Table 1. Radiochemical Water Quality Summary

Parameter	Coal Creek Well	Marshdale Well
Gross alpha activity (pCi/L)	50 - 60	80 - 170
Uranium concentration (mg/L)	0.024	0.047 - 0.09
U_{234}/U_{238} activity ratio	3.6	2.4
Radium 226 activity (pCi/L)	1.9	0 6 - 1 3
Radium 228 activity (pCi/L)	--	1.0 - 1.8

Table 2. Design Criteria

Well Pump Capacity	38 L/min (10 gpm)
Prefilters	2, operated in parallel, spiral wound, 1 micron pore opening
Ion exchange vessels	2, operated in series, 0.4 m dia x 1.3 m high (16-in. x 52-in. high)
Resin	Sybron Ionac A642* (potable water grade), 85 L (3-ft^3) per vessel, 0.60-m (24-in.) depth
Length of loading cycle before regeneration	60,000 BV
Brine tank	0 60-m dia x 1.04-m high (24-in. dia x 41-in. high) 255 kg (560 lb) NaCl storage capacity
Regenerant wastewater tank	1 9 m^3 (500 gal) volume

Table 3. Uranium Concentration Removal Coal Creek Elementary School

Sample Date	Volumes Gallons Treated	Bed Volumes After Regeneration	Uranium Concentration (µg/L) Raw Water	After Column No. 1	After Column No. 2	Across Carbon Column	% Removal Across Column No 1
7-2-87*	66,000	2940	56.6	<0.1	0.6	--	>99
7-2-87	67,200	0	92.2	0.9	9.2	--	>99
9-2-87	116,740	2260	45.2	0.1	0.1	--	>99
10-6-87	165,220	4420	39.7	0 1	0.1	0.1	>99
11-18-87	218,620	6800	47.0	<0 1	0.1	0.0	>99
2-3-88*	284,790	9750	110.0	0.3	0.2	0.0	>99
2-3-88	284,960	0	75.0	320.0	0.4	5.0	0

*The first ion exchange column was regenerated on these dates.

Table 4. Gross Alpha Removal Coal Creek Elementary School

Sample Date	Gallons Treated	Gross Alpha (pCi/L) Raw Water	After Column No. 1	After Column No. 2	% Removal Across Column No 1
4-15-87	DNA*	68.9	10 ± 4	DNA	85
4-15-87	DNA	46.8	3 ± 3	DNA	93
7-2-87†	66,000	34.5	2 ± 1	2 ± 1	94
9-2-87	116,740	475	3 ± 1	3 ± 1	93
2-3-88†	284,785	575	9 ± 2	8 ± 2	

*DNA = Data not available
†The first ion exchange column was regenerated on this date

Table 5. Characterization of Mixed Regeneration Wastewater

Date	Characteristic	Amount
July 2, 1987	Calcium as ($CaCO_3$)	46 3 mg/L
	Uranium	16,502 µg/L
	Gross alpha	6,154 ± 580 pCi/L
	Chloride	18,480 mg/L
	Sulfate	3,100 mg L
	pH	8.75 units
	TDS	39,600 mg/L
	Volume	833 L (220 gal)
February 3, 1988	Uranium	30,500 µg/L
	Gross alpha	41,000 ± 914 pCi/L
	Volume	1079 L (285 gal)

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Thomas J. Sorg *is the EPA Project Officer (see below).*
The complete report, entitled "Uranium Removal From Drinking Water Using a Small Full-Scale System," (Order No. PB 89-169 890/AS; Cost: $13.95, subject to change) will be available only from:
National Technical Information Service
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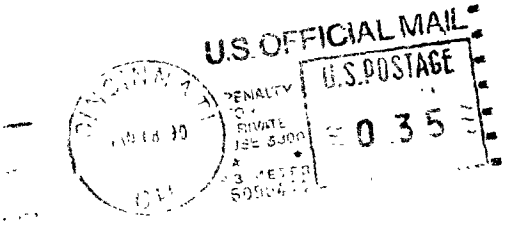

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