United States
Environmental Protection
Agency

Water Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-88/039 Sept. 1988

EPA

Project Summary

Radium Removal for a Small Community Water Supply System

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In 1984, a radium removal treatment plant was constructed for the small community of Redhill Forest, located in the central mountains of Colorado. The treatment plant consists of a process for removing iron and manganese ahead of an ion exchange process for the removal of radium. The raw water comes from deep wells and has naturally occurring radium and iron concentrations of about 30 to 40 pCi/L and 7 to 10 mg/L, respectively. Before the raw water enters the main treatment plant, the raw water is aerated to remove radon gas and carbon dioxide.

The unique features of the Redhill Forest Treatment Plant are related to the ways in which the radium removed from the raw water is further treated and eventually disposed of as treatment plant waste. A separate system removes only radium from the backwash/regeneration water of the ion exchange process, and the radium is permanently complexed on a Radium Selective Complexer* (RSC) resin made by Dow Chemical. The RSC resin containing radium is replaced with virgin resin as needed and the resin waste transported to a permanent final disposal site in Beatty, NV.

The aeration system reduces the radon gas by about 85% based upon the data obtained. Typically, the radon gas is reduced from 23,000 pCi/L to about 3,400 in the raw water after passing through the aerator.

The water quality data on the operation of the ion exchange system indicates that the radium in the inflow to the ion exchange tanks is reduced from about 22 to 35 pCi/L to 0.0 to 4 pCi/L in the outflow from the treatment system.

The RSC system has been very effective in the removal of radium from the ion exchange system wastewater by removing an average of over 99% of the radium in the inflow to the RSC system. The average inflow radium concentration was about 1,180 pCi/L with the average effluent at about 9.0 pCi/L.

This report presents a detailed description of the Redhill Forest treatment system and the results of in-depth monitoring of the processes and other factors relating to the overall operation of the radium removal system. Included are descriptions of modifications made in the plant operation to improve the overall system operation and of the procedures for final disposal of the RSC resin containing radium.

This Project Summary was developed by EPA's Water Engineering Research 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).

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

A 21-month project was initiated to monitor and evaluate the full-scale operation of the treatment plant processes designed and constructed to remove iron, manganes, and radium and to determine appropriate methods for disposal of plant wastewater and complexed radium waste.

In October 1985, the U.S. Environmental Protection Agency in cooperation with the Redhill Forest Property Owners Association undertook a study of the Redhill Forest water treatment system.

The following summarizes the processes that make up the treatment plant and identify the areas where in-depth monitoring was performed:

1. Aeration for radon and carbon dioxide gas removal.
2. Chemical clarification, including settling and filtration for iron and manganese removal.
3. Ion exchange for radium and hardness removal.
4. Chlorination and water stabilization.
5. Removal of radium from ion exchange regeneration water by RSC resin.
6. Infiltration/evaporation (I/E) disposal pond for plant wastewaters.

The problem of radium in groundwater, which serves as the raw water supply for the development, is common for many communities in the United States. If the development of new water sources that do not have a radium problem is not possible or economically feasible, then a treatment process for radium removal needs to be considered. This report concerns itself with one treatment alternative and not with locating new raw water sources that are free of radium.

The treatment of well water for the removal of radium is not practiced to any great extent in the water treatment field. However, the ion exchange process using standard water softening type resins for radium removal is well documented. The Redhill Forest water treatment system incorporates a new process for concentrating the radium removed by the ion exchange process to simplify the final radium disposal problem. The regeneration water from the ion exchange process passes through a bed of RSC resin to remove the high levels of radium before the wastewater is discharged to the I/E pond for final disposal. There are no known water treatment systems like the Redhill system. The RSC resin has been used on a trial basis at several locations primarily in Texas and one site in Wyoming. In all these cases, raw water from the wells was passed directly through the RSC bed with radium levels up to about 100 Ci/L.

Experimental Procedures

Raw water from two wells is pumped through a countercurrent flow aeration tower located at the booster pump house. The purpose of the aeration process is to remove dissolved gases, specifically radon and carbon dioxide, from the raw water. The water is pumped to the treatment plant at a rate of about 90 to 100 gpm for further water treatment to remove iron, manganese, radium, and hardness prior to chlorination and discharge to the water distribution system.

As the raw water enters the treatment plant, alum, potassium permanganate, and a polyelectrolyte are added to remove iron and manganese by chemical precipitation. The treatment unit is a prefabricated self-contained unit that includes a mixing and flocculation chamber, tube settlers, and multi-media filtration. The effluent from the iron and manganese removal process is further treated to remove radium and hardness in a ion exchange system that uses a cation resin. The effluent from the ion exchange system is chlorinated and zinc hexame taphosphate added to control corrosion and sequester any residual iron before being pumped to the treated water storage tank. The radium removed from the water supply in the ion exchange process is removed from the regeneration brine by passing the brine through a separate treatment process in which the radium is permanently complexed on the RSC material. The wastewater from this process along with the backwash wastewater from the iron removal process is pumped to the final disposal I/E pond. Figure 1 is a schematic diagram of the processes presented above.

Ultimate Disposal of Wastewater and Radium Removal from Water Supply

The original concept and design approved by the Colorado State Health Department for ultimate disposal of waste generated at the treatment plant are as follows:

Plant Wastewater

All wastewater from the plant operation is discharged into an I/E pond. The main purpose of the pond is to allow for rapid infiltration of plant wastewater into a geologic formation, which dips steeply to the east and is located beneath the geologic formation in the area of the raw water supply wells. The deep wells obtain the raw water from this formation to supply the development.

Radium Waste

Most of the radium removed from the raw water entering the treatment plant is eventually complexed on the RSC resin. As needed, RSC resin is replaced and transported to an approved hazardous/radiological waste disposal facility for final disposal.

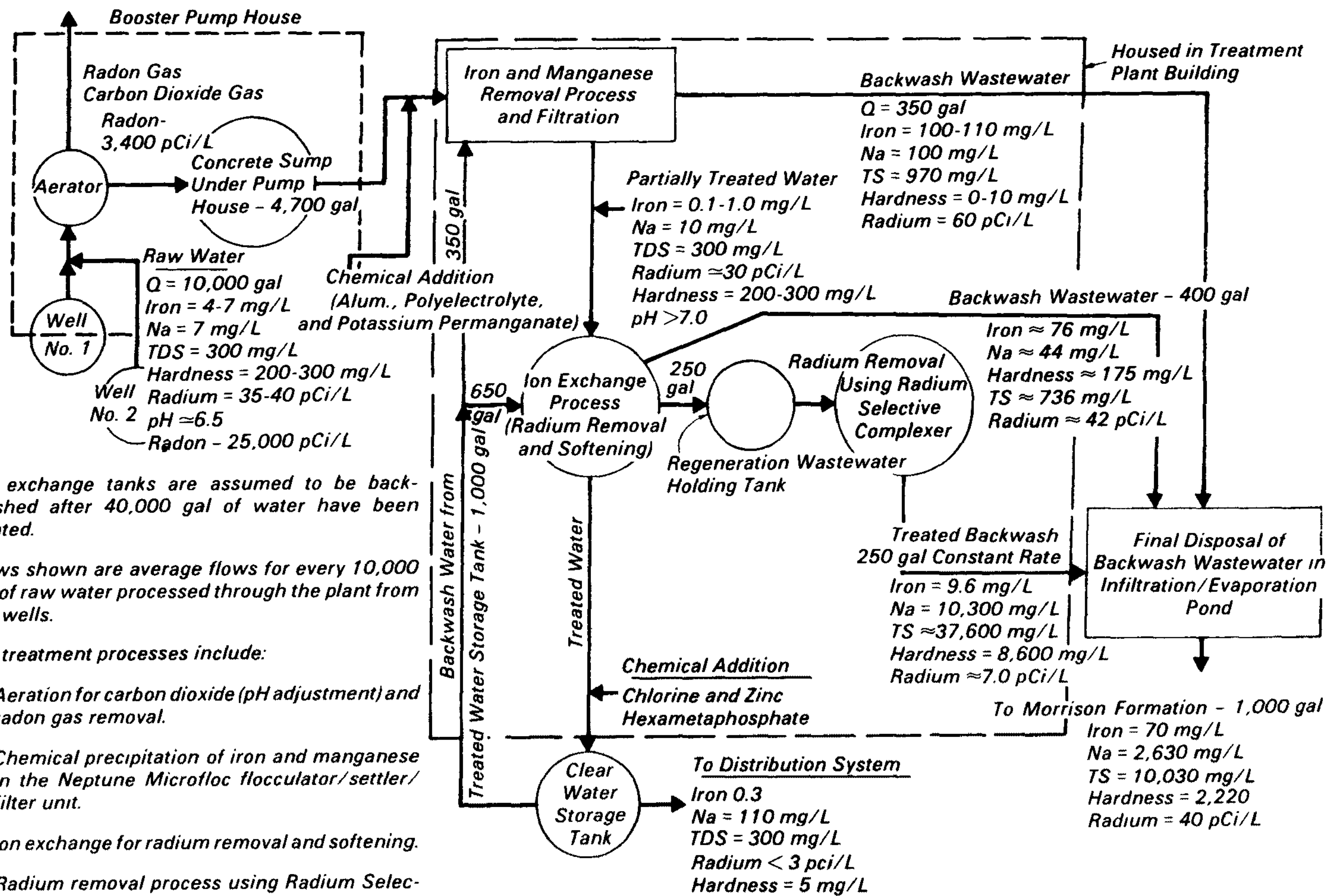
Sampling and Analyses

The project generally consisted of in-depth monitoring of the operation of the full-scale Redhill Forest water treatment plant over a 21-month period from October 1985 through June 1987. All water quality parameter concentrations were determined according to *Standard Methods for the Examination of Water and Wastewater (15th Edition)*.

Most of the water quality analysis work was performed by Hazen Research Laboratory, a commercial lab in Golden, CO. Some analysis work was performed by the EPA Laboratory in Cincinnati, OH, and some radon gas analyses were performed by Lowry Engineering in Maine.

In-depth monitoring included water quality sample collection and laboratory analyses, field measurements, flow measurement, and detailed plant operation and was performed to evaluate the following components of the treatment plant operation:

1. Aeration system for radon removal. Water samples were collected and analyzed for radon concentration in the raw water before and after aeration.
2. Treatment system for iron and manganese removal. Samples were collected and analyzed on the raw water inflow to the process and the effluent from the system to assess the efficiency of operation. The water samples were typically analyzed for iron, manganese, gross alpha, gross beta, and radium 226. The process wastewater from backwash operations was also analyzed on several occasions to determine the composition of the wastewater discharged to the I/E pond for final disposal. Parameters of primary interest for the wastewater included total iron, manganese, solids, and radium 226.
3. Ion exchange process for radium and hardness removal. Water samples were collected for the inflow and outflow to the unit process. The samples typically were analyzed for iron, manganese, sodium, hardness, gross alpha, gross beta, and radium 226. Water samples were collected from the backwash, regeneration, and quick rinse water on several occasions.
4. Radium Selective Complexer process for radium removal. This process was monitored frequently to determine the efficiency of radium removal from the ion exchange process wastewater and the buildup of radium in the complexer resin. Environmental radiation monitoring of the area outside the RSC tank surface was done to determine the exposure and to relate the exposure to radium buildup on the complexer resin.



Notes

1. *Ion exchange tanks are assumed to be backwashed after 40,000 gal of water have been treated.*
2. *Flows shown are average flows for every 10,000 gal of raw water processed through the plant from the wells.*
3. *The treatment processes include:*
   a. *Aeration for carbon dioxide (pH adjustment) and radon gas removal.*
   b. *Chemical precipitation of iron and manganese in the Neptune Microfloc flocculator/settler/filter unit.*
   c. *Ion exchange for radium removal and softening.*
   d. *Radium removal process using Radium Selective Complexer (RSC). Removes radium from the ion exchange backwash wastewater and concentrates radium on complexer resin.*
4. *The normal treatment plant flowrate is about 100 gpm The water from the ion exchange process for radium removal and softening is discharged into the wastewater holding tank from which the wastewater is pumped through the RSC at a constant rate for radium removal*

Figure 1. *Flow diagram of water treatment plant processes.*

5. I/E pond monitoring of the sand and soils was done to determine the extent of radium buildup due to the disposal of plant wastewater containing small amounts of radium.

General plant monitoring of plant flow rates, volumes of water processed, wastewater volumes, etc., was performed for use along with water quality data in determining plant process efficiencies, plant operation and maintenance costs, etc.

Some radon gas measurements were conducted on site using a RDA-200 Radon/Radon Daughter Detector unit manufactured by EDA Instruments, Inc. Also, some samples were collected and sent to Lowry Engineering for additional radon gas analysis.

Results and Conclusions

Figure 1 shows the flow volumes for each part of the total system operation for an assumed raw water flow volume of 10,000 gal into the plant. Also presented are the average water quality data for each component that makes up the treatment plant.

The aeration system has been proven to effectively remove radon and carbon dioxide gases from the raw water supplied by the deep wells. Carbon dioxide gas has been typically reduced from about 125 to 25 mg/L in the aeration system. The reduction of radon gas has been about 85% from about 23,000 pCi/L in the raw water to about 3,400 pCi/L in the effluent from the aeration system. Additional measurements have indicated that the radon gas concentration in the treated water from the main treatment plant is about 600 pCi/L. The iron removed about 13% of the radium from the inflow to this process. When the iron removal system was backwashed, the radium removed was wasted in the I/E final disposal pond. Based upon the results of the monitoring of the backwash water, the average concentration of radium in the wastewater was about 60 pCi/L.

The ion exchange system removes radium, hardness, and residual iron and manganese through the use of a standard cation exchange resin. The process has been very effective in removing radium, hardness, and residual iron, and in polishing the effluent from the iron removal process as long as the ion exchange capacity is not exceeded. The monitoring results generally indicate radium 226 levels of less than 3 pCi/L and iron levels of less than the recommended maximum level of 0.3 mg/L. Frequent monitoring of the system operation has indicated that the radium breakthrough occurs between 40,000 and 45,000 gal (i.e., 178 to 200 resin bed volumes). The quality of the influent to and effluent from the ion exchange process has generally been as given in Table 1.

The RSC system is designed and operated to remove radium from the ion exchange process wastewater and to permanently concentrate the radium on the complexer resin. On July 10, 1986, new RSC resin was placed in the complexer tank and a detailed program of monitoring the flow rate and the water quality of the inflow and outflow was initiated. Table 2 presents a summary of some of the results of the monitoring from July 10, 1986, up through June 1987. It should be noted that the flow rate through the column has been about 22 gpm, which is equivalent to the surface loading rate of about 10 gpm/ft^2. The RSC resin bed depth is 2 ft.

It can be seen in Table 2 that the RSC resin is highly radium selective with generally over 99% removal of radium from the influent wastewater. Average data for the water quality parameters included in Table 2 are shown on the bottom of the Table. The average inflow and outflow water quality data indicate that iron, sodium, hardness, and total solids are virtually unchanged in passing through the resin whereas over 99% of the radium in the influent is removed and concentrated on the RSC resin. Also shown on the bottom of Table 2 is the total quantity of radium removed and concentrated on the resin from July 10, 1986, to June 10, 1987. Based upon the operation of the plant during this time, the rate of radium buildup on the RSC resin is about 347 μCi/yr (347 X 10^6 pCi/yr).

Further, it has been determined that the rate of radium removed from the raw water and permanently complexed on the RSC resin is about 9.6 μCi (9.6 X 10^6 pCi) per 100,000 gal of water treated at the plant. After some period of operation, the RSC resin containing radium will be removed from the RSC tank and replaced with new resin and the old resin will be disposed of at a Nevada waste disposal site. It is anticipated that the RSC resin will be replaced when the radium on the complexer reaches about 3,080 μCi (3,080 X 10^6 pCi). The 4 ft^3 of RSC resin will then be placed in a 55-gal drum, 3.35 ft^3 of concrete will be added, and the entire drum will be transported to Nevada for final disposal. This method of handling the radium waste will ensure that the total radium content of the container to be buried will not exceed 10 nCi/g (i.e., 10,000 pCi/g).

Finally, plant operating costs have been determined and estimated in Table 3.

The full report was submitted in fulfillment of Cooperative Agreement No. CR-812691-01-0 by the Redhill Forest Property Owners Association under the sponsorship of the U.S. Environmental Protection Agency.

Table 1. *Summary of Quality of Water to and from Ion Exchange Process*

Parameter	Influent	Effluent
Flow rate, gpm	90 to 100	90 to 100
Iron, mg/L	0.15 to 2.7	0.03 to 0.5
Manganese, mg/L	0.4 to 1.3	0.01 to 0 15
Sodium, mg/L	7.4 to 12.5	40 to 150
Hardness, mg/L as $CaCO_3$	212 to 350	5 to 70
Radium 226, pCi/L	22 to 35	0 to 4

Table 2. *Summary of Water Quality Data for Regeneration Wastewater from Ion Exchange Regeneration Through RSC Resin* (Effluent Discharged to I/E Pond)*

Date	Accumulated Volume Treated gal	Bed Volumes	Sample	Parameters: Iron mg/L	Manganese mg/L	Sodium mg/L	Hardness mg/L	Total Solids mg/L	Total Radium 226 pCi/L	% Radium Removal
7/10/86	0	0								
			Inflow	2.48	23.8	11,600	476	34,900	860 ± 30	
			Outflow	0.98	16.7	13,300	245	34,600	16 ± 11	98.1
7/30/86	2,400	77								
			Inflow	2.03	31.8	11,000	9,850	41,700	1280 ± 40	
			Outflow	1.56	32.2	11,000	10,200	41,800	1.6 ± 3.2	99.9
8/31/86	9,460	305								
			Inflow	9.0	33.1	12,600	11,500	54,200	1400 ± 40	
			Outflow	8.5	33.1	12,700	11,600	55,200	9.4 ± 3.5	99.3
9/29/86	14,600	471								
			Inflow	7.21	30.5	11,400	8,350	37,600	920 ± 30	
			Outflow	7.15	31.5	11,500	8,420	37,600	4.1 ± 2.4	99.6
10/30/86	22,600	729								
			Inflow	2.79	33.1	8,170	9,380	35,000	860 ± 50	
			Outflow	2.07	33.5	8,640	10,100	35,300	5.3 ± 2.8	99.4
11/26/86	27,700	894								
			Inflow	7.17	28.2	13,400	9,620	45,400	1040 ± 30	
			Outflow	6.30	26.9	13,300	9,520	45,500	8.1 ± 3.3	99.1
1/14/87	39,550	1,276								
			Inflow	31.4	19.2	9,350	7,260	31,300	1070 ± 60	
			Outflow	27.8	18.1	9,000	7,740	30,400	8.4 ± 2.3	99.2
2/21/87	49,700	1,603								
			Inflow	61.3	30.5	12,300	10,900	49,800	1780 ± 80	
			Outflow	62.2	32.4	12,100	11,400	50,400	7.2 ± 7	99.6
3/18/87	57,700	1,861								
			Inflow	93.4	31.2	13,500	11,600	53,200	2000 ± 80	
			Outflow	92.0	31.9	12,400	12,600	53,300	18 ± 9	99.1
6/10/87	71,700	2,313								
			Inflow	8.08	17.4	8,070	5,580	28,100	650 ± 20	
			Outflow	3.76	15.8	8,460	4,940	28,300	9.2 ± 2.4	98.6
Averages			Inflow	19.8	29.9	10,850	8,890	40,590	1181	
			Outflow	18.5	27.7	10,760	9,030	40,550	9.0	99.2

Note: From 7/10/86 to 6/10/87 (i.e., 355 days), 71,700 gal of plant wastewater was treated in RSC tank. The following is the amount of radium removed and deposited in the resin.

Radium removed = 71,700 gal (3.785 L/gal) (1181-9.0 pCi/L)
= 318.1 X 10^6 pCi
= 318.1 μCi about 0.949 μCi/day
Estimate for year = 347 μCi

*Resin bed volume = 4.15 ft^3 (31.0 gal)

Table 3. *Summary Treatment Plant Operating Costs*

	Item	Cost/1,000 gal of Water Treated
1.	Plant Chemicals, Alum, Permangante, Chlorine, etc.	$0.137
	Salt	$0.475
2.	Energy Costs	$0.206
3.	RSC Resin Disposal (includes disposal and new resin)	$0.088
	Total	$0.906*

*Operator cost not included.

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***Richard P. Lauch** is the EPA Project Officer (see below).*
The complete report, entitled "Radium Removal for a Small Community Water Supply System," (Order No. PB 88-235 551/AS; Cost: $14.95, subject to change) will be available only from:
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