

# EVALUATION OF WASTEWATER TREATMENT SYSTEMS FOR THE URANIUM MILL TAILINGS REMEDIAL ACTION PROJECT LAKEVIEW, OREGON SITE

H.R. Meyer, K. Conroy, F. Petelka  
Chem-Nuclear Systems, Inc.\*  
2309 Renard Place SE  
Albuquerque NM 87119

D. Leske, R. Richey  
U.S. Department of Energy  
UMTRA Project Office  
First National Bank Building  
Albuquerque NM 87108

## ABSTRACT

During remedial action at the Lakeview, Oregon, Uranium Mill Tailings Remedial Action Project site, unexpectedly large volumes of contaminated water required quick identification and design of a treatment facility capable of meeting Oregon release limits. A laboratory program was prepared and executed to determine the efficiency and cost-effectiveness of several alternative treatment approaches, and an optimum system was selected, designed and deployed.

## INTRODUCTION

The Lakeview, Oregon uranium mill tailings site is one of 24 identified for remedial action under the Uranium Mill Tailings Remedial Action Project (UMTRAP). The USDOE manages the Project, and contracted with MK-Ferguson Corporation (MK-F) in 1983 to perform design and construction management of remedial actions at the UMTRA Project sites and associated, contaminated vicinity properties. Chem-Nuclear Systems, Incorporated (CNSI) provides all health physics protection and radiological measurements support during remedial action.

UMTRAP deals with large volumes of very low level radioactive tailings material. When tailings are exposed to runoff, slightly contaminated water may be generated. During the Lakeview project design, initial estimates showed relatively small runoff potential; lined evaporation ponds were therefore constructed. When these ponds filled more rapidly than anticipated in the fall of 1986, Chem-Nuclear Systems, and its associate Resource Technologies Group (RTG), were requested by MK-Ferguson and the USDOE to quickly evaluate treatment options, to identify a cost-effective system that would meet the restrictive Oregon release standards. Due to the unusual combination of tailings, heavy metals, calcium and other constituents in the runoff, site-specific studies were required. Two usable systems were identified through a bench scale testing program. This paper discusses design of the evaluation program, bench testing results, and data evaluation

methods used by CNSI and RTG to identify the final qualifying system.

## PROBLEM DESCRIPTION

The potential for contaminated runoff occurred at the tailings relocation site, where water that had come into contact with contaminated material was collected in retention ponds. The combined capacity of these ponds was more than 4 million gallons. It became evident in the fall of 1986 that the capacity of the basins would be exceeded by snowmelt, rainfall, and truck decontamination washwater. Samples were taken for analysis at that time, and again in early 1987. Snowmelt water, after prolonged contact with tailings prior to runoff, was sampled somewhat later, and found to have significantly lower pH and higher dissolved calcium than anticipated, complicating the treatment study. Samples of water showed a variety of suspended and dissolved contaminants. Since suspended material could be removed by settling or simple filtration, the focus of our effort was on dissolved contaminants. Because the State of Oregon had regulatory authority for discharges from the Lakeview site, the applicable Oregon water quality standards were chosen as the target for the study. The dissolved species of concern were determined to be arsenic, radium and manganese.

To allow complete evaluation of alternatives, CNSI and RTG conducted a comprehensive laboratory treatability

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study. Based on literature searches for the best available technology, the study focused on the following tests:

- Precipitation of contaminants at various pH levels with various coagulants and specific precipitants.
- Separation of contaminants by mixed bed ion-exchange.
- Separation of contaminants by precipitation, followed by adsorption of the remaining contaminants by ion-selective resins and activated alumina.

#### INITIAL EVALUATION OF ALTERNATIVES

The results of analysis of water samples taken in October 1986 and February 1987, are presented in Table I. Table II presents related Oregon and Federal water quality standards. As noted, the study described here focused on removal of soluble materials. A literature search, combined with past experience, led to evaluation of the following treatment techniques:

- Arsenic - Removal of arsenic by coprecipitation or adsorption with iron has been reported in numerous references (1,2). Both ferric and ferrous iron have been used for such removal, in conjunction with lime and over a pH range of 6 to 8.5. Above pH 9, the effectiveness of arsenic removal with iron is somewhat diminished, but the technique is generally effective to remove arsenic to 0.01 mg/l (the applicable Oregon standard) even at high pH. Arsenic can also be effectively removed by ion-exchange, and by adsorption on alumina (3). Removal by these techniques is dependent upon the valence state of the arsenic.
- Manganese - Manganese can be removed from wastewater by oxidation of manganous ion to manganese (IV), followed by precipitation, or by treatment of the manganous ion with lime at high pH to precipitate the manganese as  $Mn(OH)_2$  (1). Manganese can also be removed by selective or conventional ion-exchange.
- Radium 226 - Radium is commonly removed from mining wastewater by coprecipitation with  $BaSO_4$  (4). With excess sulfate in the wastewater, residual barium levels are normally less than 0.5 mg/l.
- Other minor contaminants in the wastewater can normally be removed by either coprecipitation, conventional or selective ion-exchange.

Using these technologies, three basic flow schemes were designed for bench-scale testing of the Lakeview water samples:

- System #1 - precipitation of contaminants at various pH levels with various coagulants and specific precipitants. The resulting sludge is

removed by conventional clarification or membrane filtration. This system, utilizing the membrane option (MEMTEK Corporation), was used at the UMRAP sites in Canonsburg, PA, and Salt Lake City, UT.

- System #2 - separation of contaminants by filtration and mixed-bed ion-exchange. A pre-filter is used to remove fine suspended solids that do not settle out in the ponds. Mixed-bed ion-exchange is then used to remove dissolved contaminants.
- System #3 - a combination of systems 1 and 2, with minimization of pH adjustment, the use of selective ion-exchange for manganese removal, and the use of activated alumina for removal of trace levels of arsenic. A pre-filter is used for removal of suspended solids.

#### THE TREATABILITY STUDY

A diagram of the laboratory treatability study designed to determine the efficiencies and cost-effectiveness of the above alternative systems is presented in Fig. 1. The following objectives were set for the study:

- Obtain data on contaminant removal efficiency, required for an NPDES discharge permit application.
- Provide process data on chemical consumption and resin throughputs to be used for economic analysis.
- Provide data on optimum pretreatment chemical dosages, pH ranges, etc.
- Provide scale-up data for full size treatment systems.

Two sets of water samples were taken to support the treatability study. The first set was taken on February 9, 1987, and consisted of fifteen one-gallon samples. Two liters were removed from each sample for analysis. The remaining water was composited, and will be referred to as Composite #1 in this paper. A sample of Composite #1 was submitted to the laboratory for initial analysis; results are presented in Table III. The parameters chosen for analysis were based on data from the previous samples taken at Lakeview (see Table I). Only constituents present at significant levels were included. Composite #1 was used in the precipitation tests and the mixed-bed ion-exchange studies. A second set of ten one-gallon samples was taken on February 17, 1987. One sample was from the pond inlet, identified as being representative of the runoff. The other nine samples were composited along with the pond inlet sample. This set was identified as Composite #2. Analytical results for the pond inlet and Composite #2 samples are presented in Tables IV and V. Composite #2 was used in the chelate ion-exchange resin test, and the test for mixed bed ion-exchange.

TABLE I

Retention Pond Analysis

Species	October, 1986 Samples			February, 1987 Samples		
	Dissolved	Suspended	Total	Dissolved	Suspended	Total
Arsenic	0.527	1.77	2.1	0.275	0.026	0.301
Barium	-	-	-	< 0.1	< 0.1	< 0.1
Boron	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cadmium	< 0.0001	0.0004	0.0004	0.0012	0.0007	0.0019
Chromium	< 0.01	< 0.05	< 0.01	< 0.01	< 0.01	< 0.01
Copper	-	-	-	< 0.01	< 0.01	< 0.01
Cyanide	-	-	-	< 0.001	< 0.001	< 0.001
Fluoride	0.3	-	0.3	0.37	-	0.37
Iron	< 0.03	30.43	30.43	< 0.01	0.20	0.20
Lead	-	-	-	0.0037	0.066	0.0697
Manganese	0.09	0.48	0.37	0.94	0.017	0.957
Phenols	-	-	-	< 0.01	-	< 0.01
Sulfate	78.7	-	78.7	193	-	193
Zinc	< 0.005	0.124	0.124	0.025	0.01	0.035
Radium-226	6.07	107	108.07	6.63	0.90	7.53
Uranium	0.0095	0.084	0.0715	0.00153	0.0021	0.00363
pH	6.33	-	-	5.95	-	5.95
TDS	226	-	224	327	-	322

All units are mg/l, except Radium-226, which is pCi/l, and pH, which is standard units.

TABLE II

Oregon and Federal Water Quality Standards

SPECIES	OREGON	FEDERAL
ARSENIC	0.01	0.05
BARIUM	1.0	1.0
BORON	0.5	-
CADMIUM	0.003	0.01
CHROMIUM	0.02	0.05
COPPER	0.005	-
CYANIDE	0.005	-
FLUORIDE	1.0	1.0-2.0
IRON	0.1	-
LEAD	0.05	0.05
MANGANESE	0.05	-
MERCURY	-	0.02
NITRATE (AS N)	-	10
PHENOLES (TOT)	0.001	-
SELENIUM	-	0.01
SILVER	-	0.05
URANIUM	-	-
ZINC	0.01	-
RADIUM (1)	-	5
GROSS ALPHA	-	15 (3)

mg/l, except Radium in pCi/l

Four precipitation studies were conducted, using Composite #1:

Test#	pH	Barium	Iron	Ca(OH) <sub>2</sub>	Sample Size
1	7	12 mg/l	12 mg/l	As req.	2 l
2	9	"	"	"	"
3	10	"	"	"	"
4	11	"	"	"	"

Barium chloride was used in all tests, ferric chloride was used in the pH 7 test, and ferrous sulfate in the other tests. After precipitation was complete, 2 ppm of moderately anionic flocculant was added, followed by 3 hours of settling. The clear liquid, analogous to the overflow from a gravity settling device, was then analyzed. The remaining (nondecanted) liquid was filtered through 0.45 micron, and the filtrate, representative of the permeate from membrane filtration, analyzed. Data presented in Table VI indicate that manganese does not effectively precipitate below pH 10, and zinc does not precipitate at pH 7. All other contaminants appear to be effectively removed at both pH 7 and 11 on the filtered samples. These results are generally consistent with the theoretical solubilities for metal hydroxides.

Alumina Adsorption of Arsenic

To determine the effectiveness of arsenic removal by alumina adsorption, filtrate from the precipitation test at pH 11, containing 0.006 mg/l As, was passed through a 1 cm column containing a 15 cm bed of activated alumina. Effluent from the column contained 0.002 mg/l As. The removal of arsenic by alumina adsorption was not further

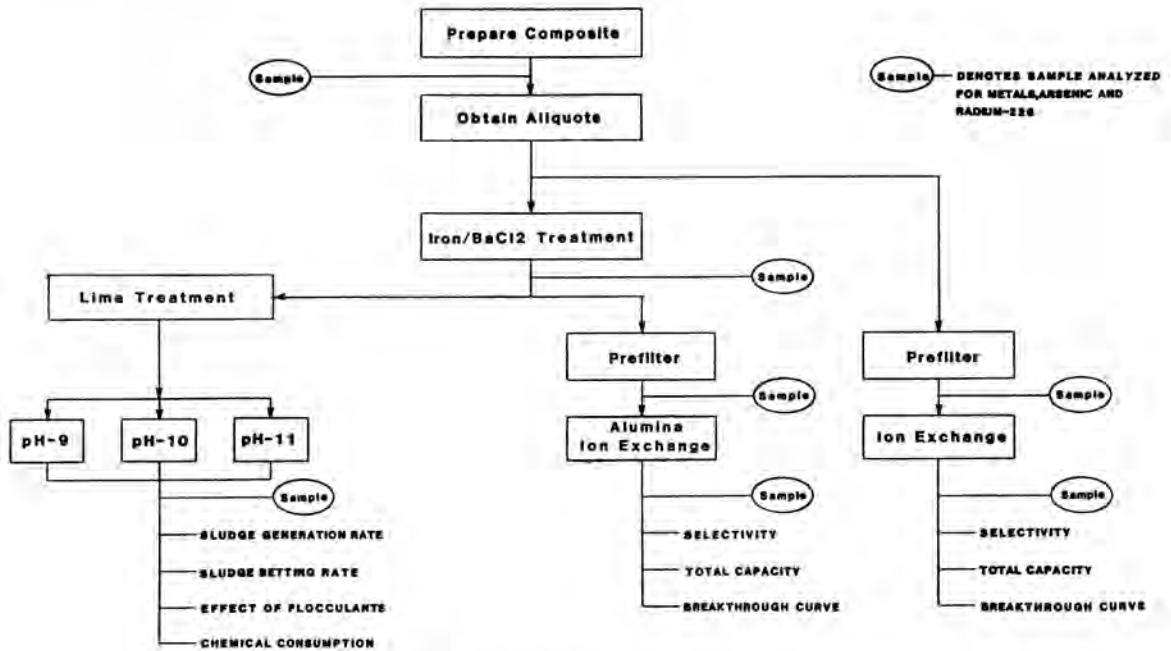


Fig. 1. Labaoratory Program Outline.

TABLE III

Composite #1, 2/9/97

Sample Date: February 9, 1987

<u>Parameter</u>	<u>Dissolved</u>	<u>Suspended</u>
Arsenic	0.160	0.020
Barium	< 0.1	< 0.1
Fluoride	0.3	N/A
Iron	< 0.03	0.088
Lead	< 0.01	< 0.01
Manganese	0.751	< 0.01
Zinc	0.026	0.028
Uranium	0.0013	0.0038
Radium-226	6.8	1.0

All units are mg/l except Ra-226 which is pCi/l

TABLE IV

## Pond Inlet Analysis

Sample Date: February 17, 1987

<u>Parameter</u>	<u>Dissolved</u>	<u>Suspended</u>
Mn	25.4	0.13
Ra-226	9.9 +/- 1.6	1.7 +/- 0.8
As	0.061	0.596
Fe	2.43	38.2
Ba	< 0.1	< 0.1
TDS	2980	N/A
SO <sub>4</sub>	2040	N/A
Na	86.5	N/A
pH	3.22	N/A
Zn	1.71	0.016
Cd	0.017	< 0.001
Cr	< 0.05	< 0.05
Cu	< 0.03	< 0.01
F	1.8	N/A
Pb	0.024	0.004

All units are mg/l, except Ra-226, which is pCi/l, and pH, which is standard units.

TABLE V

## Composite #2, 2/9/97

Sample Date: February 17, 1987

<u>Parameter</u>	<u>Dissolved</u>	<u>Suspended</u>
Mn	1.89	0.02
Ra-226	3.6 +/- 0.6	0.5 +/- 0.3
As	0.008	0.055
Fe	0.19	1.86
Ba	< 0.1	< 0.1
TDS	332	N/A
SO <sub>4</sub>	222	N/A
Na	18.7	N/A
pH	4.18	N/A
Zn	0.10	0.01
Pb	0.001	0.006
F	0.38	N/A

All units are mg/l, except Ra-226, which is pCi/l, and pH, which is standard units.

TABLE VI

Precipitation Studies Pond Composite of Samples #12 To #26 Collected On 2/9/87 Lakeview Site, Oregon

	Ambient pH (7.0)		pH 9.0		pH 10.0		pH 11.0	
	Filtered	Decant	Filtered	Decant	Filtered	Decant	Filtered	Decant
Arsenic	0.003	0.022	0.008	0.020	0.011	0.024	0.006	0.013
Barium	0.3	1.4					0.3	7.0
Fluoride	0.4	0.3					0.4	0.3
Iron	0.04	1.80					0.08	0.46
Lead	0.004	0.014					< 0.001	0.002
Manganese	0.597	0.617	0.210	0.302	0.019	0.110	0.010	0.061
							0up	0.054
Zinc	0.031	0.040					0.012	0.057
Uranium	< 0.0003	0.0026					0.0003	0.0011
Radium-226	0.2	1.0	0.0	0.3	0.0	0.9	0.4	1.0

All units are mg/l, except Ra-226, which is pCi/l.

Above results are "total" element concentration.

Procedures used for "total" element analysis are:

- A) Ten ml of HNO<sub>3</sub> were added to 100 ml of sample, and sample was evaporated to moist salts. Sample was then made up to volume for analysis.
- B) Ra-226 samples were filtered through 0.45 micron filter. The filter was then digested with HNO<sub>3</sub> HF and recombined with the filtrate prior to analysis.

tested, due to the effectiveness of arsenic removal by iron coprecipitation and adsorption.

**Ion-Exchange Study**

Mixed-bed ion-exchange resin was tested to determine effectiveness of removal of key impurities. The resin employed was a strong acid/strong base, mixed-bed type, with a capacity of 12 kg of CaCO<sub>3</sub> per cubic foot of resin for both anions and cations. Composite #2 was used to perform this test. Due to sample volume limitations, a small column with 28 ml of wet settled resin was used. The column was 1 cm in diameter, and 51 cm in length. Pond solution was fed at 15 ml/min, upflow. Samples were collected and analyzed at each 10 bed volumes (BV), and specific conductance was used to determine breakthrough. Figure 2 demonstrates breakthrough at 110 BV, and saturation at 130 BV. Sample analyses from this test showed arsenic breakthrough at 110 BV, but no manganese breakthrough at 130 BV.

**Ion-Selective Resin Tests**

Test 1 - In this test, the feed was pre-treated by addition of Fe and Ba at a pH of 7, primarily to remove arsenic and Ra226. An ion-selective resin was employed. Table VII indicates that manganese begins breakthrough at 200 BV, much earlier than expected. Evaluation of the problem indicated that calcium or magnesium could seriously interfere with manganese loading. A hardness analysis of the feed samples showed:

Composite #1: 156 mg/l as CaCO<sub>3</sub>

Composite #2: 197 ml/l as CaCO<sub>3</sub>

Composite #2, Treated: 268 mg/l as CaCO<sub>3</sub>

At these hardness levels, it would be expected that Ca/Mg would tend to displace Mn on the resin. Since the resin has a favorable selectivity for uranium, nickel, lead and zinc, Ca/Mg would not be expected to displace these elements.

**Test 2**

The objective of Test #2 was to determine if the ion-selective resin could be used to treat the pond water directly. A sample of Composite #2 was filtered through a 10-30 micron paper, then fed to the column (same dimensions and flow rates as in Test #1, above). Samples were collected at 30 BV increments and analyzed. Table VIII presents these results, and shows Mn breakthrough at 270-300 BV, with radium breakthrough at the same point. A fraction of the arsenic was not sorbed; concentration remained at 0.02-0.03 mg/l throughout the test. Since the analytical method employed would indicate both suspended and dissolved arsenic, it was suspected that suspended arsenic was passing through the exchanger.

Test results from this series showed that ion-selective resin can be effectively used to remove metals from the Lakeview wastewater, if treated to remove arsenic and radium. Cost-efficiency of the resin is seriously compromised if high levels of calcium and magnesium are present. Due to the limited amount of test solution available,

TABLE VII

Ion-Selective Resin Test  
Composite #2, 2/17/87

Pre-Treated (See Note 1)

Bed Volumes	Mn	Ba	Cr	Pb	Cd	U	As	Ra-226
Feed	1.64	<0.1	0.3	0.41	0.002	0.046	0.0013	0.001 0.5 ± 0.5
30-60	<0.01	<0.1	0.4	<0.01	<0.001	<0.005	0.0005	
60-90								
90-120	0.003	<0.1	0.3	<0.01	<0.001	<0.005	0.0003	
120-150	0.01							
150-180	0.02							
180-210	0.030	<0.1	0.4	<0.01	<0.001	<0.005	0.0009	
210-240	0.06							
250-270	0.08							
270-300	0.071	<0.1	0.1	<0.1	<0.001	<0.005	<0.001	
300-330	0.11							
330-360	0.11							
360-390	0.168							
390-420								
420-450								
450-480	---	<0.1	0.1	<0.01	<0.001	<0.005	0.0010	

All units are mg/l except for Ra-226 which is pCi/l.

NOTE 1: Sample pre treated by the addition of Fe, Ba and U at pH of approximately 7.0. After settling, the decant was filtered through a 10 to 30 micron paper and fed to a 1 cm column about 45 cm in length containing 10 ml of USR. Feed solution was fed to the column at 12.5 ml/min (3.9 gpm/ft<sup>2</sup>).

TABLE VIII

Ion-Selective Resin Test  
Composite #2, 2/17/87

No Pre-treatment

	Mn		As		Ra-226	
	Diss.	Susp.	Diss.	Susp.	Diss.	Susp.
Feed	1.73	0.02	0.008	0.115	4.3 ± 1.1	0.7 ± 0.5
<u>Bed Volumes</u>						
90-120	0.001		0.030		0.9 ± 1.4	
180-210	0.020		0.024		0.5 ± 1.4	
270-300	0.100		0.024		3.9 ± 2.2	
360-390	0.225		0.024		3.4 ± 2.1	
450-480	0.315		0.023		5.1 ± 2.4	

NOTES:

- 1) All results in mg/l except Ra-226 which is pCi/l.
- 2) The feed to the column was filtered through a 10-30 micron paper prior to contacting the resin.
- 3) The elevated arsenic levels are most likely due to the suspended arsenic moving through the bed.
- 4) All analyses on the BV samples are "total."

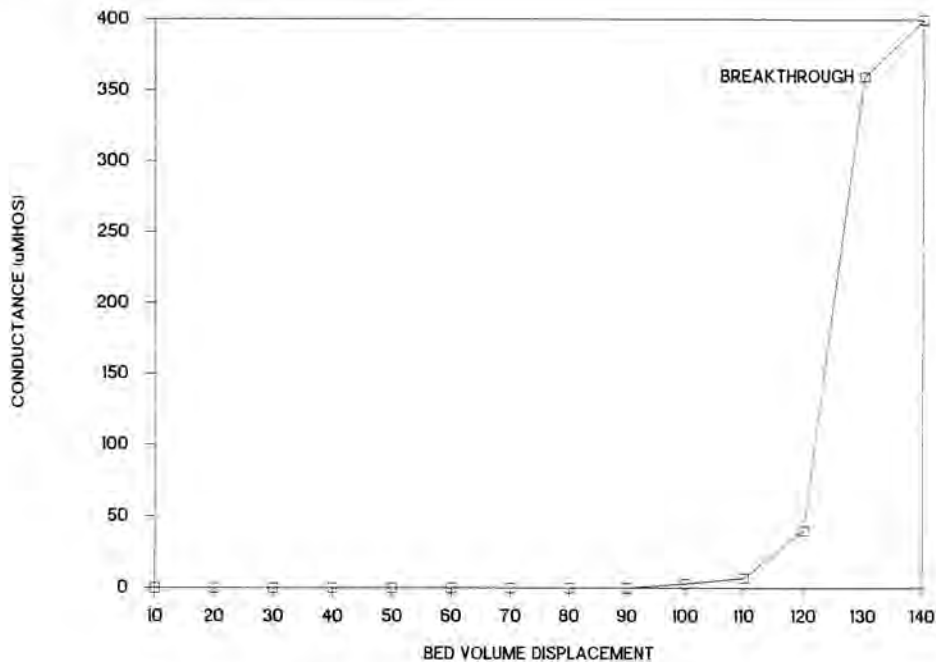


Fig. 2. Mixed Bed Resin Breakthrough.

it was not possible to conduct a saturation test on the ion-selective resin. In a multistage system, the first IX (ion-exchange) bed will be taken to saturation, and subsequent IX beds will be used for polishing. Saturated beds are taken out of service, and either eluted or resin replaced. In order to obtain an estimate of saturation, an isoplot was prepared from equilibrium tests. Known quantities of ion-selective resin were equilibrated with the test solution for a 24 hour period, then analyzed. Standard procedures were employed to extrapolate media saturation data, to be used during later cost estimates.

#### EVALUATION OF ALTERNATIVES

The objective of the above treatability studies was to estimate capital and operating costs for systems capable of producing effluent meeting the Oregon water quality standards. The study indicated the following:

- Chemical precipitation using barium, iron and lime at a pH of 10 to 11, followed by filtration, meets the standards.
- Chemical treatment with barium, iron and lime at a pH of 6 to 7, followed by treatment with a ion-selective resin, meets the standards.
- Treatment with mixed bed ion-exchange meets the standards, but would be economically unacceptable.

Based on these results, two potential treatment systems were considered:

#### System 1: Precipitation and Membrane Filtration

Figure 3 presents a flow sheet for a precipitation and membrane filtration system similar to the system used at the UMTRAP site in Canonsburg PA. Wastewater entering the system is mixed with ferrous sulfate ( $\text{FeSO}_4$ ), a reductant and precipitant. Concentration of  $\text{FeSO}_4$  is determined by feed contaminant levels. Precipitation then occurs in a 2000 gallon reaction tank, with lime [ $\text{Ca}(\text{OH})_2$ ] added as necessary to raise pH to 6. The  $\text{FeSO}_4$  aids in removal of arsenic through coprecipitation.  $\text{BaCl}_2$  is added to remove radium from solution as a coprecipitated barium or radium sulfate.  $\text{BaCl}_2$  concentration is preset based on radium concentration in feed. Uranium in solution is also made insoluble during this reaction. The reaction tank slurry flows into a flocculation tank, with a quick-mix chamber followed by a slow-mix compartment. Underflow from this tank, with 3-4% solids by weight, is stored or recycled to the retention ponds; overflow moves to the lime precipitation tank, where additional lime is added to raise the pH to 11. The remaining metal contaminants form insoluble metal hydroxides and precipitate at this pH. The tank is sized for a 15 minute reaction time; slurry from the tank overflows into the concentration tank, to feed the microfiltration system.

The microfiltration system consists of three MEMTEK membrane modules, each containing 640 square feet of membrane. At 40 PSI, these filters provide a flux rate of 150 gal/ft<sup>2</sup>/day, and represent an absolute particle barrier. Permeate from the membranes is neutralized to pH 8 and discharged. A bleed stream is taken off the circulating stream



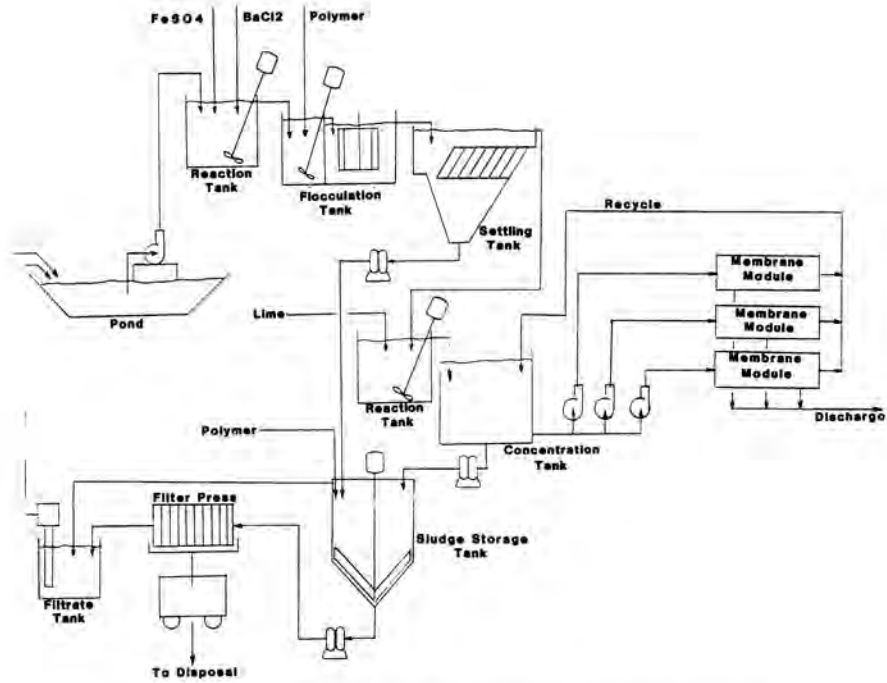


Fig. 3. Precipitation and Membrane Filtration System.

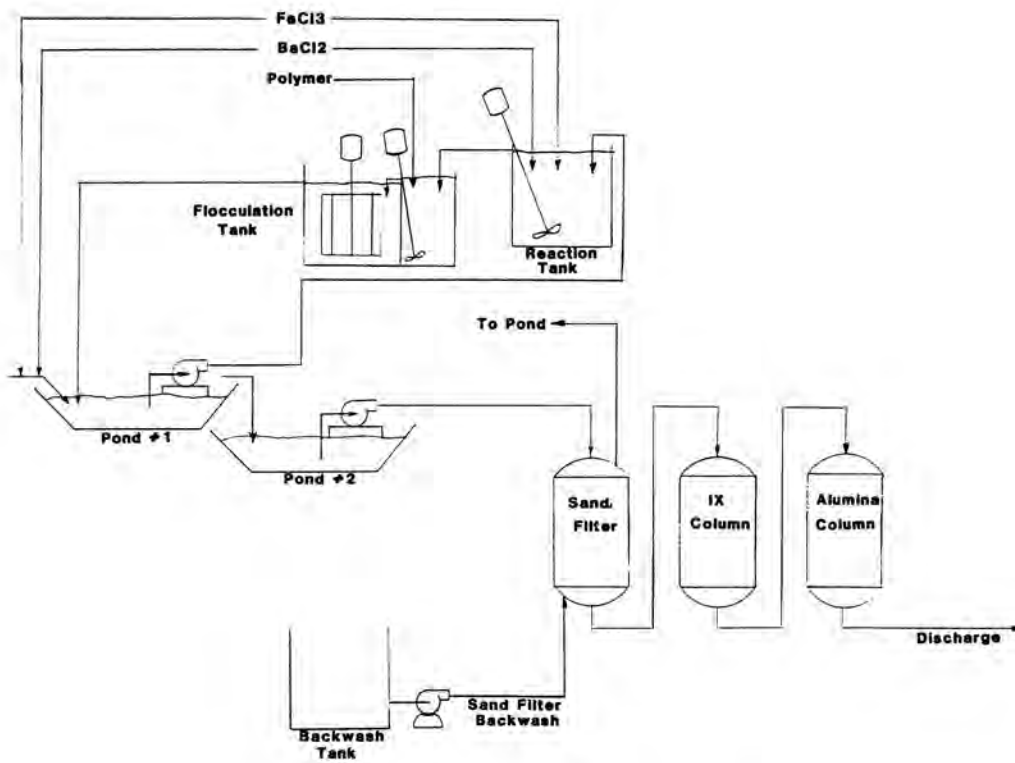


Fig. 4. Precipitation and Selective Ion-Exchange System.

to remove solids from the system, and pumped to storage or back to the retention basins.

#### **Relative Cost**

The MEMTEK membrane system described above enjoyed a significant cost advantage, in that it had been purchased by DOE for use at a previous UMTRA Project site. Therefore, a large capital investment to utilize the system at Lakeview would be unnecessary.

#### **System 2: Precipitation and Selective Ion-Exchange**

The flow sheet for a precipitation and selective ion-exchange system is shown in Fig. 4. The front end of this system is identical to the first precipitation step from the membrane filtration system described above. Wastewater is pumped from the retention ponds into both the precipitation and polishing systems. The precipitation system consists of a 2000 gallon reaction tank and a flocculation tank. Ferric chloride is added to the first tank as a precipitant for arsenic. At ambient pH, quantitative precipitation of iron as ferric hydroxide takes place, with arsenic removed by coprecipitation and adsorption with the iron. Barium chloride is added to the tank to remove the radium as a coprecipitated barium or radium sulfate. Uranium will also be converted to insoluble species, removed by settling and filtration.

Slurry flows to the reaction tank, where a polymer flocculant is mixed, than allowed time to settle out. Unlike the membrane system, the flocculation tank overflows back into the first pond. This pond then acts as a sedimentation basin for the arsenic, ferric hydroxide, and barium or radium sulfate precipitates. Overflow from this pond goes to the second pond, where additional clarification takes place. Clarified water is pumped to the parallel sand filter polishing system. These filters can handle 200 gallons per minute (gpm) each (system full flow), to allow for backflush without shutdown of the system. Backflush is temporarily stored, then returned to pond 1. Filtered water is treated in ion-exchange media (three, four foot diameter by six foot high units, each containing 50 cubic feet of ion-selective cation exchange resin). This resin exhibits tremendous selectivity for divalents such as zinc and manganese. A three unit train of ion-exchange units would be necessary in Lakeview. Based on an expressed Oregon desire to create no resin regeneration waste streams, a once-through cycle would be anticipated.

The laboratory tests indicated that the system described would produce effluent meeting the Oregon standards. To ensure that the very restrictive arsenic limit would be reached, however, provision was made for incorporating an activated alumina column at the end of the system.

#### **Relative Cost**

A portion of this system, the precipitation unit, would be taken from the existing Canonsburg plant to reduce costs. This precipitation and I/X system, in contrast to the MEMTEK membrane filtration plant discussed previously, would have relatively low capital costs, but higher operating costs (non-regenerated resin) per gallon treated. For the specific situation in Lakeview, OR, the membrane filtration plant was determined to be roughly 20-25% more cost-effective, largely due to availability of components previously purchased on the UMTRA Project.

### **CONCLUSIONS AND RECOMMENDATIONS**

Based on the results of the Lakeview treatability study:

1. Mixed-bed ion-exchange would be a viable choice chemically, but not economically, for the Lakeview contaminants and effluent volume.
2. A precipitation and membrane treatment system (Canonsburg system) meets all requirements.
3. The precipitation and selective ion-exchange system would be a viable choice chemically; operating costs vary with contaminant types and levels. For lower calcium loadings, operating costs could drop by 25 to 75%.
4. Pretreatment with soda ash could be used to remove calcium as  $\text{CaCO}_3$ . Further testing to establish the effectiveness of this option would be necessary.
5. Both systems could handle sudden changes in feed chemistry, by modifying levels of feed chemicals. For the membrane system, such adjustments are not of great cost impact. For the selective ion-exchange system, this adjustment is only effective for removal of arsenic and radium.
6. Calcium levels were anomalously high in the Lakeview tailings runoff water during long-term contact with early snowmelt.
7. If a new treatment system were to be built from scratch, the selective ion-exchange system would appear to be more economically attractive, particularly given the incorporation of calcium pretreatment.
8. Given the availability and cost-effectiveness of the membrane system, its selection at Lakeview appeared to be appropriate.

In summary, the study determined that no single technology is both technically and economically viable for resolving all wastewater problems encountered on the UMTRA Project; however, a combination of the technologies described has been found satisfactory to meet all requirements.

**REFERENCES**

1. Patterson, J.W., Industrial Wastewater Treatment Technology, Second Edition, 1985.
2. Shen, Y.S., Study of Arsenic Removal from Drinking Water, Journal AWWA, August, 1973.
3. EPA/600/S2-85/094, Pilot Study for Removal of Arsenic from Drinking Water at the Fallon, Nevada, Naval Air Station, September, 1985.
4. Merritt, R.C., The Extractive Metallurgy of Uranium, 1971.