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TREATMENT STUDIES AT THE PROCESS WASTE TREATMENT PLANT AT OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

Precipitation and ion-exchange methods are being developed to decontaminate Oak Ridge National Laboratory process wastewaters containing small amounts of ^{90}Sr and ^{137}Cs while minimizing waste generation. Many potential processes have been examined in laboratory-scale screening tests. Based on these data, five process flowsheets were developed and are being evaluated under pilot- and full-scale operating conditions. Improvements in the existing treatment system based on this study have resulted in a 66 vol % reduction in waste generation.

1. INTRODUCTION

Improved chemical precipitation and/or ion-exchange (IX) methods are being developed to decontaminate process wastewater at Oak Ridge National Laboratory (ORNL) while concentrating the radioactive materials into a nonhazardous solid waste form that can be safely stored for permanent disposal. Wastewaters that are slightly contaminated with ^{90}Sr and ^{137}Cs have been routinely processed at ORNL at a rate of 6 to 10 L/s for 25 years by chemical precipitation and/or IX methods. Although these processes have sufficiently decontaminated the wastewater for release to the environment, they produced large volumes of concentrated radioactive wastes. These wastes were easily disposed of by the hydrofracture process,[1] which was discontinued in 1984.

Because hydrofracture is no longer authorized, liquid low-level wastes (LLLWs) are being stored until an alternative means of disposal can be implemented. LLLW tanks now have limited storage capacity, and a method for solidifying and disposing of LLLWs is being developed to prevent the shutdown of the LLLW system. Alternative means for disposing of LLLW concentrate will be more costly than disposal through hydrofracture; therefore, efforts to reduce the generation of LLLW have been vigorously implemented at ORNL.

Before March 1986, operation of the Process Waste Treatment Plant (PWTP) generated ~30% by volume and 80% by weight (dissolved solids) of all ORNL LLLWs. Extensive research, development, treatability studies, and analysis of alternatives are being conducted to reduce the LLLWs generated by this plant.

Several potential chemical precipitation techniques and IX materials were considered for possible use in laboratory-scale screening tests. Initial scouting tests resulted in the selection of two caustic/soda-ash softening processes to be tested in conjunction with IX materials in proposed process flowsheets. Experimental, small-scale column tests were conducted to determine distribution and mass transfer coefficients of 16 commercially available zeolites and organic cation-exchange resins plus one experimental material as a function of the Ca, Mg, and Na concentrations in the feed stream. Based on those results, five process flowsheets have been proposed for pilot- and full-scale testing. Two of the more promising flowsheets have been tested to date. This report summarizes the bench-scale tests, describes the proposed flowsheets, and lists the results of pilot- and full-scale tests.

2. BACKGROUND

ORNL treats liquid wastes by one of the three methods shown in Fig. 1. Process wastewater from the 4500 building complex (which has been traditionally nonradiological) and the Melton Valley buildings are sent to a holding pond, monitored for radioactivity, and discharged to White Oak Creek. The remaining process water that has traditionally contained low levels of beta and gamma activity is treated at the PWTP by various methods described below and discharged to White Oak Creek. Known LLLWs are concentrated by evaporation and treated for disposal. From the mid-1960s until late 1984, these wastes were permanently treated at the ORNL Hydrofracture Facility [Fig. 1(a)]. The waste is now being stored in the Melton Valley Storage Tanks until a new disposal process can be installed [Fig. 1(b)]. In 1989, the effluent from the PWTP was treated at the Nonradiological Waste Treatment Plant to remove metals and organics before discharge to White Oak Creek. Because the regeneration of the IX resin at the PWTP produces more LLLW than any other single source, a major effort has been made to develop a decontamination process that would minimize the waste generated by the PWTP.

The process waste system at ORNL is used to collect liquid wastes that (1) are normally not radioactively contaminated (but have the potential to be contaminated), (2) have varying concentrations of residual chemicals, (3) and are slightly contaminated with radioactivity. The process waste system is also used to collect drainage from radioactively contaminated soil from such places as tank farms and spill sites. Approximately 50 vol % of the process waste consists of surface water and groundwater that are slightly contaminated with radioactivity. Groundwater contributes a high concentration of dissolved minerals to the process waste.

The process wastewater (PWW) is collected in an equalization basin for subsequent treatment before discharge to the environment. The PWW contains a number of trace radionuclides, as shown in Table 1, and relatively large amounts of competing ions (representative of city water and local groundwater in Oak Ridge, Tennessee), as shown in Table 2. The major chemical constituents are calcium, sodium, and magnesium bicarbonates, and the major radionuclides are ^{90}Sr and ^{137}Cs. The ^{90}Sr is the more hazardous contaminant because of its potential for introduction into the human and animal food chain. It tends to be the limiting ion in most processing alternatives.

Concentrated spikes of radioactive materials have occasionally entered the feed stream as a result of the decontamination of research facilities and leakage from equipment. Variations in feed composition between 2000 and 8000 Bq/L for ^{90}Sr and 300 and 1000 Bq/L for ^{137}Cs have not been uncommon.

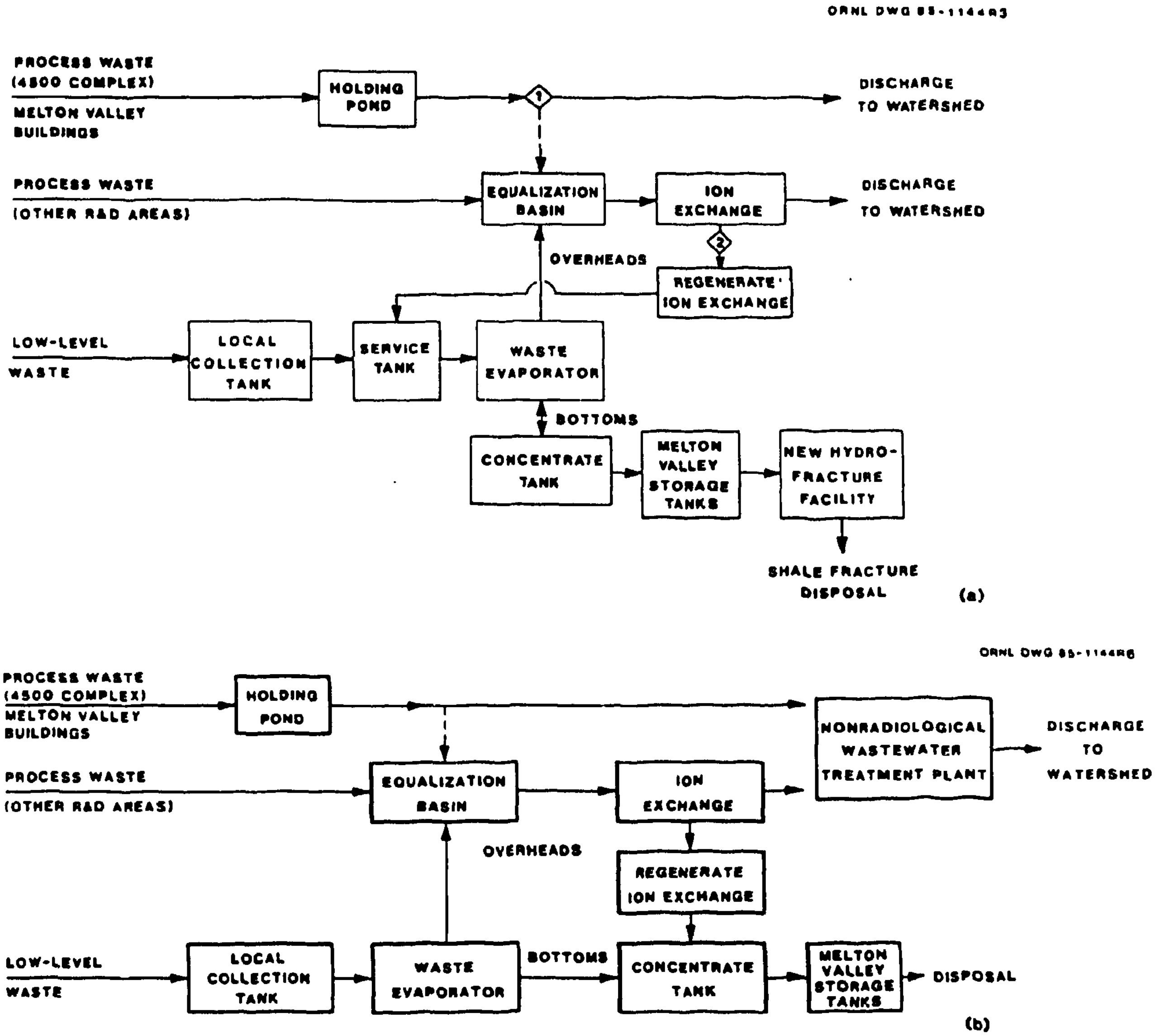

Fig. 1. Radioactive liquid waste treatment systems used at ORNL (a) before 1984 and (b) after 1984.

Table 1. Radiochemical composition of process wastewater

Radionuclide	Concentration (Bq/L)
Gross alpha	5
Gross beta	6000
^{60}Co	25
^{90}Sr	4000
^{95}Zr-Nb	50
^{106}Ru	10
^{137}Cs	400

Table 2. Chemical composition of process wastewater

Cation	Concentration (mg/L)	Anion	Concentration (mg/L)	Parameter	Concentration (mg/L)
Ca	40	HCO_3	93	pH	8.8
Mg	8	SO_4	23	TDS	250
Na	5	Cl	10	TSS	3
K	2	NO_3	11	Total hardness[a]	133
Si	2	CO_3	7		
Sr	0.1	F	1	Alkalinity[a]	125
Al	0.1			COD	6
Fe	0.1			TOC	12
Zn	0.1				

[a]As $CaCO_3$.

Several processing methods have been used to decontaminate process wastewater at the PWTP. Before 1975, slightly contaminated liquid wastes were treated by means of a lime/soda-ash precipitation process that removed only 80 to 85% of the activity.[2] When more stringent regulations made this process inadequate, the "Scavenging-Precipitation Ion-Exchange" (SPIX) process[3-6] was developed. From March 1976 to August 1981, ORNL wastewater was treated by the SPIX process.[7] This process involved chemically softening the water by adjusting the pH to 11.9 with NaOH to precipitate $CaCO_3$ and $Mg(OH)_2$. Ferrous sulfate was added at a concentration of 5 ppm iron to act as a scavenger to help flocculate other insoluble materials. Precipitation was followed by clarification and polishing filtration.. Sludge from the clarifier was stored in a rubber-lined pond. The supernate was fed to IX columns containing Duolite CS-100, a bifunctional phenolic-carboxylate resin in the sodium form, which reduced the concentrations of ^{137}Cs and ^{90}Sr to 30 and 0.5 Bq/L, respectively. The column effluent was neutralized by H_2SO_4 before discharge to White Oak Creek. The resin was regenerated by elution with 0.5 *M* HNO_3 after processing ~2000 bed volumes (bv), and the eluate was concentrated by means of evaporation, neutralized with NaOH, and stored for permanent disposal.

In 1981, the decontamination method was changed to the filtration/ion exchange process (FIX) because storage of the SPIX sludge was troublesome and the capacity of the CS-100 resin deteriorated after ~20 regeneration cycles.[8] In the new process, a strong-acid cation resin manufactured by the Dow Chemical Company, HCR-S, was loaded with Ca^{2+} ions after a throughput of ~400 bv. The column was then regenerated by elution with 2.7 *M* HNO_3. The eluate was treated similarly to that of the SPIX process. Although this process produced a much larger volume of LLLW, it was easily handled until hydrofracture disposal was canceled.

3. BENCH-SCALE TESTING

This study was initiated to develop an alternative decontamination process for the PWTP that would minimize waste generation and produce nonhazardous solid waste forms that can be safely stored with a minimum of surveillance. Improved IX methods considered for potential use were largely based on the previous development of an IX process used at the Three Mile Island Nuclear Power Station to decontaminate high-activity-level water.[9]

For IX sorption of $^{90}Sr^{2+}$ and $^{137}Cs^{+}$ ions from ORNL process water, the major competing ion is Ca^{2+} unless the water is first softened; then the major competing ion is Na^{+}. Based on previous experience, the selection of an inorganic zeolite to remove $^{137}Cs^{+}$ from the process water was not expected to be difficult. However, finding an ion exchanger that would efficiently separate $^{90}Sr^{2+}$ and Ca^{2+} was considered doubtful. Thus, consideration was given to the use of a softening process, followed by the use of an ion exchanger, to separate $^{90}Sr^{2+}$ from Na^{+}.

The flowsheet shown in Fig. 2 was, therefore, used as a guideline for the bench-scale tests. It incorporates all possible steps that might be needed to treat the PWTP efficiently. By evaluating each step of the flowsheet in sequence, alternative flowsheets could be developed for further testing. The proposed flowsheets would not include all of the unit operations shown in Fig. 2 if bench-scale tests indicated that they were unnecessary.

Several potential alternatives are available for use in each step of the generalized flowsheet shown in Fig. 2. Laboratory-scale scoping studies were conducted for each separate step of the proposed process to develop the most promising unit operations upon which flowsheets would be developed. The first phase of these studies consisted of batch simulation of the potential water-softening processes to remove the calcium and magnesium ions from the wastewater, followed by dewatering of the sludge generated in the precipitation step. In the next phase, potential IX and sorption processes were tested in conjunction with the best water-softening processes. Sorption processes were also tested for treatment of fresh, unsoftened feedwater.

3.1 WATER SOFTENING TESTS

Two general methods for water softening are well known in the water-treatment industry: the lime-soda (calcium hydroxide and sodium bicarbonate) process and the caustic-soda (sodium hydroxide and soda ash) process.[10] In each process, calcium removal is achieved by adding alkali to raise the pH to >10, causing the bicarbonate in the water

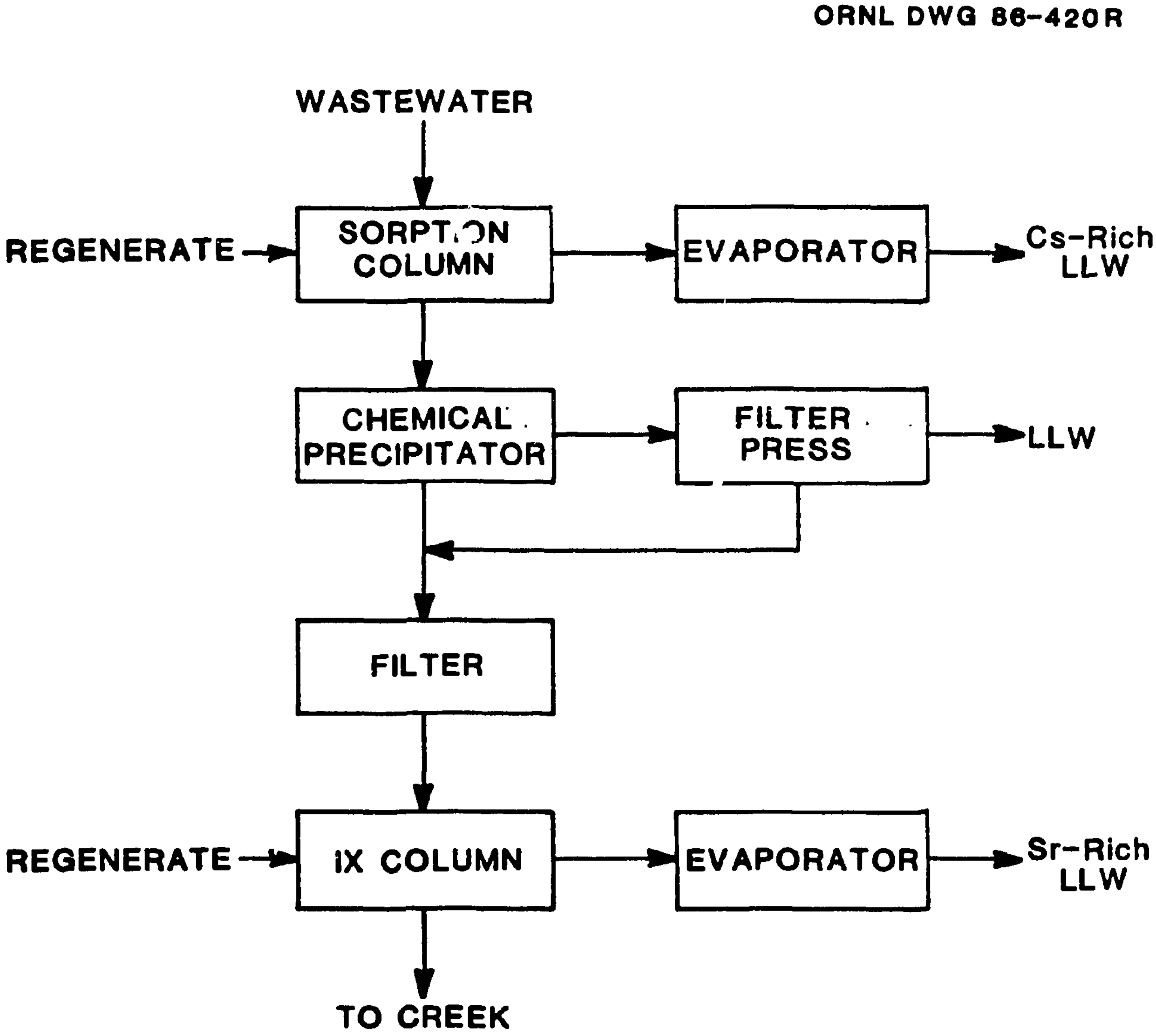

Fig. 2. Proposed flowsheet for wastewater treatment at ORNL.

to be converted to carbonate, which reacts with calcium ions to form $CaCO_3$. If equilibrium is attained, the amount of calcium remaining in solution is determined by the solubility product:

$$K_{sp} = [Ca^{2+}] [CO_3^{2-}]$$

If the total quantity of bicarbonate, that originally present plus that generated during precipitation with NaOH, is less than the quantity required to precipitate the calcium, carbonate must be added in the form of soda ash (sodium bicarbonate) to achieve maximum calcium removal. Increasing the pH to a level of 11 to 11.5 provides sufficient hydroxide ions to precipitate the magnesium as $Mg(OH)_2$. When the total hardness of the process water is <150 ppm (as $CaCO_3$), the degree of supersaturation obtained is usually small at room temperature, causing the precipitation of calcium and magnesium to be slow or incomplete. The degree of softening may be improved by increasing the temperature, adding excess reagents to reduce the solubility, or nucleating the reaction with preformed particles of precipitation in a sludge-blanket or sludge-recirculation reactor.

Lime and soda ash usually cost less than the equivalent quantity of caustic and are, therefore, more commonly used in nonhazardous wastewater treatment. However, the lime-soda process produces a larger quantity of sludge because the calcium present in the lime is also precipitated in the softening process. The additional disposal costs associated with radioactive materials can make the lime-soda process unattractive for these applications.

Small-scale batch tests (called "jar tests") were used in scouting experiments to determine the most promising water-softening processes to be studied in the PWTP flowsheets. These jar tests are used as guidelines of in-plant water-softening processes to determine parameters such as dosage requirements, pH, alkalinity, and floc time, but they cannot be used to determine flocculation rates for "scaling up" to plant operation.[11] Some refinements of the process conditions are needed to obtain optimum operability in a full-scale continuous plant.

The jar tests involved mixing 800 mL of ORNL process wastewater with aqueous solutions of lime, NaOH, or soda ash at 100 rpm for 5 min. The solutions were usually spiked with sludge from a previous test or with $CaCO_3$ prepared by reacting lime and soda ash to nucleate the reaction. At this point, either alum (a polymer) or $FeCl_3$ was added as a coagulant, and the stirring rate was reduced to 30 to 40 rpm. At the end of a 15- or 75-min slow agitation period, the solution-slurry was transferred to Imhoff cones and gravity settled for 30 min to determine settling characteristics and sludge volumes. Initial tests were made using a 15-min stirring period, but the test shown in Fig. 3 indicated that a 75-min agitation period was needed to obtain maximum softening. After the 30-min

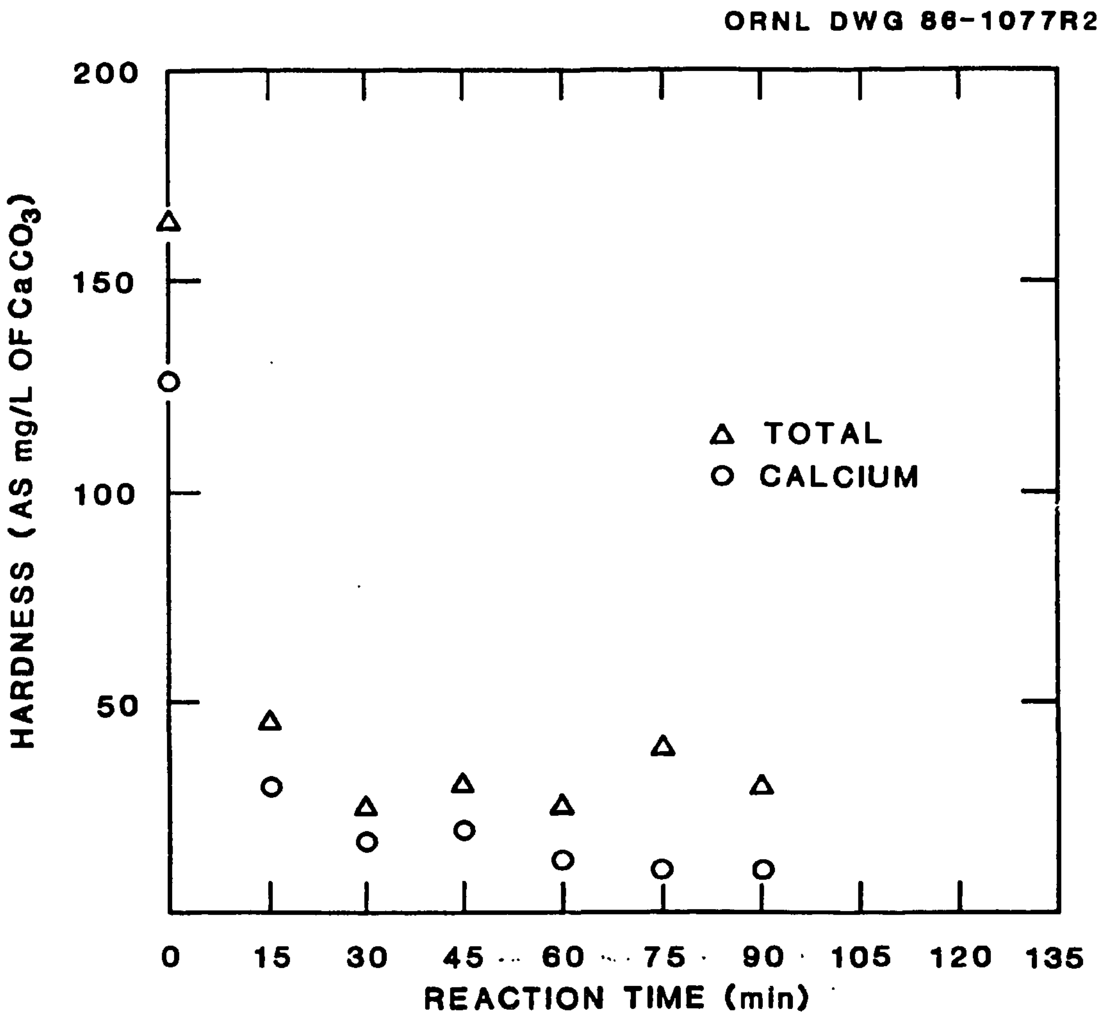

Fig. 3. Effect of reaction time on water softened by the scavenging-precipitation process.

settling period, the supernate solution was decanted and immediately analyzed for calcium and calcium-plus-magnesium concentrations or acidified with nitric acid to a pH of <2 to prevent further precipitation.

Calcium hardness was analyzed by titration at pH 12 with 0.00125 *M* disodium ethylenediaminetetracetate dihydrate, using Eriochrome Blue Black R as the indicator.[12] Total hardness (i.e., calcium plus magnesium) was determined at pH 10 with an Eriochrome black T indicator. These results were routinely checked with inductively coupled plasma analysis when sodium concentrations were also desired. Values for calcium and total hardness will be reported in mg/L of $CaCO_3$ unless otherwise indicated.

Several types of water-softening processes were tested for use at the PWTP. They included adding individual chemicals (lime, caustic, or soda ash) and the traditional lime/soda-ash and caustic/soda-ash processes. Tests with the latter two processes focused on determining the ratio of caustic and soda ash (or lime and soda ash) required to soften the water while minimizing the addition of sodium ions, which also compete with the radionuclides during IX. A modified caustic-soda process, the scavenging-precipitation process, was used in the SPIX decontamination process in conjunction with CS-100 resin; the CS-100 resin contains a phenolic group capable of removing cesium at a pH near 12. In this pH range, only caustic addition is required to achieve calcium precipitation. Ferrous sulfate was added at a concentration of 5 ppm iron to act as a flocculating agent and scavenger to help remove insoluble materials. Although processing at pH 12 would not be required if another resin were used, this treatment method was also tested for the purpose of comparison. Ferric chloride was usually substituted for ferrous sulfate for ease of handling. Ferrous ions rapidly convert to ferric ions at high pHs; therefore, the use of $FeCl_3$ is equivalent to $FeSO_4$.

The results of the water-softening tests are given in Appendix A and are summarized below. Addition of lime, caustic, or soda ash alone produced fine particulates that did not settle well and only reduced the calcium hardness from 115 to 30-70 mg/L. The calcium hardness was lowered to 10-20 mg/L by traditional cold lime-soda and caustic-soda processing over a pH range of 10.5 to 11. Similar results were obtained from the scavenging precipitation process at pHs of 11.5 to 12, but the process did not soften the water at a pH of 10.5. Flocculating agents improved the settling characteristics of the sludge. Adding $FeCl_3$ or alum to the caustic/soda-ash and scavenging-precipitation processes also tended to improve the softening characteristics when a sludge blanket was not present. In all cases, alum produced pinhead-sized granular flocs, whereas ferric chloride produced a less desirable, fluffy, voluminous precipitate. To reduce the calcium hardness to <10 mg/L, each system was seeded with $CaCO_3$ particulates. These particulates are naturally present in sludge-blanket or recycled-sludge type clarifiers.

The most promising recipe was selected for each type of treatment method (lime/soda-ash, caustic/soda-ash, and scavenging-precipitation) based on softening ability and sludge characteristics. An additional caustic/soda-ash process that minimized the sodium concentration while exhibiting acceptable processing characteristics was also selected for further consideration. Six synthetic water-soluble polyelectrolytes, listed in Table 3, were tested as coagulating agents on each of the above processes over a range of 0.3 to 1 mg/L. The results indicated that Betz 1100 enhanced flocculation better than the other polymers. Percol 757 worked almost as well as the Betz and tended to lower the calcium concentration slightly. The other polymers had little effect on softening. Because Betz 1100 is widely used at ORNL in other processes and is readily available, it was chosen for use in filtration and IX tests.

Jar tests indicated that a less gelatinous sludge is produced when $FeCl_3$ is replaced with Betz 1100 as the flocculating agent in the scavenging-precipitation process. The tests also suggested that $FeCl_3$ is not needed to enhance softening when a sludge blanket is present. Because the elimination of iron from the softening process could offer several advantages, the caustic precipitation (scavenging-precipitation with iron eliminated) method was considered as the fourth alternative that was selected for flowsheet evaluation, as shown in Table 4. The hardness values obtained from the full-scale, continuous sludge-blanket reactor (a reactor with a sludge filter zone) can be expected to be lower than those obtained from small-scale batch tests.

The jar tests (completed in December 1985) were scaled up to 204-L (54-gal) batches to produce softened water for IX tests and sludge-dewatering tests in January 1986. The large-scale batch processing did not produce satisfactory softening results, and additional jar tests indicated that a contaminant had entered the PWTP feed, inhibiting precipitation of calcium and magnesium and yielding the data shown in Table 5. A series of tests conducted to determine the type and source of the contaminant gave inconclusive results. Tests using synthetic feeds containing 1 mg/L of detergents, sewage, and phosphates indicated that these components were not the cause of the upset. Methyl blue active surfaces and mass spectroscopic analyses of the basin water detected no unusual substances.

Although the source of the inhibitor was not determined, the jar tests did suggest ways of overcoming the problem. Precipitation is affected to a larger extent during startup when a small sludge blanket is present. Increasing the ferrous sulfate and/or soda ash concentrations at startup should reduce the time required to build up a sufficient blanket to nucleate precipitation. Once a blanket was formed, these chemicals could be reduced or eliminated without affecting the softening process.

The tests also indicated that the effect of the contaminant was less severe for the scavenging precipitation and caustic processes than either of the two caustic/soda-ash processes. Calcium hardnesses of 10 mg/L were obtained by batch processing (204 L) by the scavenging- precipitation process at room temperature and <2 mg/L for hot processing at 60°C. Softening to 5 to 10 mg/L was obtainable at 90°C using the caustic/soda-ash processes, whereas 10 to 15 mg/L was obtained at room temperature.

Table 3. Polymer flocculating agents evaluated in Process Waste Treatment Plant water-softening tests

Polymer	Charge density	Molecular weight
Betz 1100[a]	Low anionic	High
Purifloc A-23[b]	Anionic	High
Percol 720[c]	Nonionic	Very high
Percol 726	High anionic	High
Percol 728	Medium cationic	Very high
Percol 757	Very high cationic	High

[a]Manufactured by Betz Laboratories, Inc., Trevose, PA.
[b]Manufactured by Dow Chemical Co., USA Specialty Chemicals Department, Atlanta, GA.
[c]Manufactured by Allied Colloids, Suffolk, VA.

Table 4. Results of bench-scale softening processes for Process Waste Treatment Plant wastewater

Constituent	Concentration (mg/L)			
	Lime/ soda-ash process	Caustic/ soda-ash process	Caustic process	Scavenging-precipitation process
	Chemical requirements			
Na_2CO_3	190	95	0	0
$Ca(OH)_2$	125	0	0	0
NaOH	0	70	450	500
Alum	5	0	0	0
Iron	0	0	0	5
Betz 1100 polymer	0.8	0.6	0.3	0.3
	Effluent characteristics			
Total hardness[a]	60	49	14	10
Ca hardness[a]	16	8	5	4
Na	83	80	260	290
Final pH	10.4	10.5	11.9	11.9

[a]Measured in mg/L as $CaCO_3$.

Table 5. Comparison of bench-scale water-softening results

Process	Date	pH	Calcium hardness (mg/L)
Scavenging-precipitation	11/85	12	5
	1/86	12	15 to 35
Caustic	11/85	12	5
	1/86	12	35 to 50
Caustic/soda-ash			
Low Na	11/85	10.5	<10
	1/86	10.5	35 to 80
High Na	11/85	10.5	<10
	1/86	10.5	35 to 80

Conclusions from the jar tests are that either of the scavenging-precipitation, caustic/soda-ash, or caustic softening processes will sufficiently soften ORNL process water when no unusual inhibiting agents are present. The caustic/soda-ash processes are less forgiving when contaminants are present, and laboratory tests indicate that acceptable softening levels may not be achieved with these processes under such conditions. Additional information, such as the sludge filterability and the effect on IX resins, was needed to select the optimum softening process. The results from these tests are described below.

3.2 SLUDGE DEWATERING TESTS

Laboratory-scale dewatering tests were conducted on the sludges generated by the various water-softening processes described in Sect. 3.1. These tests were conducted in the single-frame filter press with a 32-mL capacity, as shown in Fig. 4. The dewatering system consisted of a 3.4-L stainless steel (SS) pressurized feed tank and the filter press, which is a SS membrane holder modified to hold a screen support, filter cloth, and a 7.2-cm-ID Teflon spacer. The feed tank and press were connected to a nitrogen cylinder and in-house air lines with 1.27-cm-OD polyethylene tubing. The system was normally operated by pressurizing the feed tank in 170-kPa increments over a 30-min period to 620-kPa and holding it at that pressure for the remainder of the run, typically for 1.5 h. In initial tests, the filter cake was then removed from the press and dried, along with a feed sample, at 104°C to constant weight in a convection oven to determine the total solids contents. The cakes were typically firm next to the cloth but were wet at the entrance to the press. In industrial applications, wet cakes are often eliminated by passing air through the filter press before sludge removal. Therefore, some dewatering tests included passing 380-kPa air through the cake for 30 min prior to removal from the press. Two types of filter cloths were used in the tests: (1) a POW-0920 polypropylene sample from Crosible, Inc., and (2) a Feon 162 Dynel cloth sample available from in-house stores.

The results of the dewatering tests are given in Tables 6 and 7. The first eight tests (summarized in Table 6) were run at 620-kPa pressure for varying lengths of time to obtain effluent flow rates of <2 mL/min. This approach was used to determine the filtration time required to produce a dewatered cake. The procedure led to large amounts of variability in the data, and no significant conclusions could be drawn concerning the amount of time required to reduce the water content of the sludges. The results did indicate that the scavenging-precipitation sludge could only be dewatered to 10-20 wt % solids without air-drying. Data from the plate-and-frame filter press at the PWTP (Sect. 4.1.2) indicated that cakes containing 20 to 25% solids could be obtained if air

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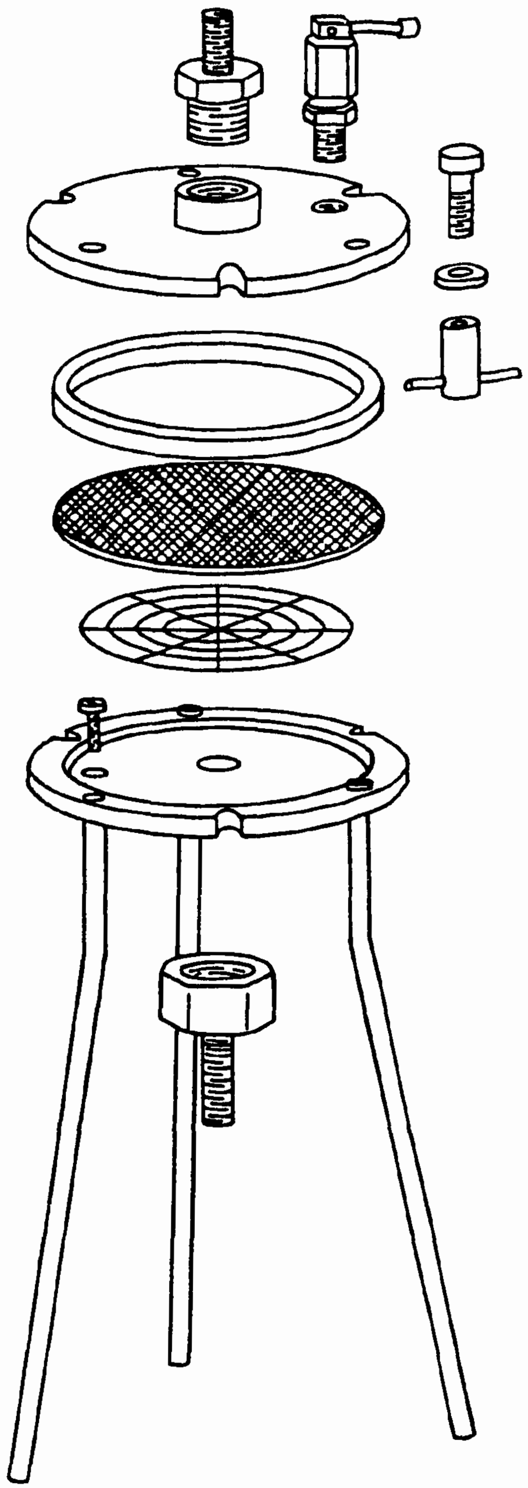

Fig. 4. Exploded view of laboratory-scale single-plate filter press.

Table 6. Results of dewat

Run number	Softening process	Filter cloth	Pretreatment	Filtration time (h)	Air ti (l
SP-01	Scavenging precipitation	POW-0920	None	1.0	0
C-01	Caustic	POW-0920	None	2.9	0
SP-2	Scavenging precipitation	POW-0920	None	1.5	0
SP-3	Scavenging precipitation	Feon 162 Dynel	Air sparged	5.5	0
SP-4	Scavenging precipitation	Feon 162 Dynel	None	1.5	0
SP-5	Scavenging precipitation	Feon 162 Dynel	None	1.9	0
SP-6	Scavenging precipitation	Feon 162 Dynel	None	2.0	0
SP-7	Scavenging precipitation	Feon 162 Dynel	Air sparged	3.3	0
SP-8	Scavenging precipitation	Feon 162 Dynel	None	2.1	0

[a]DE = Diatomaceous earth material.

ring tests without air drying for sludge generated by water softening

dry ne)	Final flow rate (mL/min)	Precoat (g DE[a]/cm²)	Filter aid (g DE/cm²)	Solids in feed (%)	Solids in cake (%)	Volume requirement solids (mL/g)	Cake description
0	-	0.000	0	-	17	3.64	Firm; difficult removal
0	1.1	0.000	0	1	19	2.73	Wet
0	4.3	0.000	0	1	9	6.50	Wet; difficult removal
0	1.3	0.000	0	1	19	2.82	Wet in middle; difficult removal
0	0.8	0.075	0	1	17	3.36	Wet in middle; easy removal
0	2.0	0.013	0	1	14	4.25	Top 1/2 wet; easy removal
0	0.3	0.000	0	1	19	2.71	Top 1/8 wet; difficult removal
0	1.7	0.000	0	1	11	5.56	Top 1/4 wet; difficult removal
5	2.3	0.000	0	2	39	2.15	Dry; difficult removal

Table 7. Results of dewa

Run number	Softening process	Filter cloth	Pretreatment	Filtration time (h)	Air ti (h
SP-9	Scavenging precipitation	Feon 162 Dynel	Contained DE[b]	2.1	0.
SP-10	Scavenging precipitation	Feon 162 Dynel	Contained DE	2.1	0.
SP-11	Scavenging precipitation	Feon 162 Dynel	Contained DE	2.3	0.
SP-12	Scavenging precipitation	Feon 162 Dynel	Contained DE	2.0	0.
SP-13	Scavenging precipitation	Feon 162 Dynel	Contained DE	2.1	0.
SP-14	Caustic	Feon 162 Dynel	None	2.0	0.
SP-15	Caustic	Feon 162 Dynel	None	2.0	0.
SP-16	Caustic	Feon 162 Dynel	None	2.0	0.
SP-17	Caustic	Feon 162 Dynel	None	2.0	0.

[a]DE = diatomaceous earth material.
[b]A diatomaceous earth material was added to the feed at the PWTP.

lering tests with air drying for sludge generated by water softening

dry e)	Final flow rate (mL/min)	Precoat (g DE[a]/cm^2)	Filter aid (g DE/cm^2)	Solids in feed (%)	Solids in cake (%)	Volume requirement solids (mL/g)	Cake description
5	1.9	0.013	0	2	35	2.08	Dry; difficult removal
5	2.2	0.025	0	2	35	1.92	Fairly easily removed
5	2.0	0.050	0	2	42	1.72	Dry; easily removed
5	0.3	0.000	15	3	52	1.07	Dry
5	2.3	0.000	0	2	40	1.77	Dry; fairly easily removed
5	2.0	0.000	0	3	57	0.96	Dry; slight scraping to remove
5	2.3	0.013	0	3	59	0.98	Dry; easily removed
5	2.7	0.025	0	3	53	1.04	Dry; easily removed
5	2.7	0.019	0	3	59	1.01	Dry; easily removed

drying was used. Adding a precoat of Celite, a diatomaceous earth material commonly used as a filter aid, to the filter cloth before filtration improved the cake release from the filter cloth. Too much error was detected in the dewatering data to determine whether adding Celite as a precoat or a body feed significantly improved dewatering. Ferrous sulfate used in the scavenging-precipitation process produced a gelatinous iron hydroxide sludge that was hard to dewater. An attempt was made to improve the characteristics of the sludge by oxidizing it to ferric oxide before filtration. Air-sparging the sludge for 4 d did not significantly improve the dewatering characteristics.

The operating procedure was revised to include filtration at 620 kPa for 1.5 h, followed by air drying at 380 kPa for 30 min. The results of tests using this procedure are given in Table 7. The feed slurry for subsequent filter aid tests using the scavenging precipitation process was obtained from the reactor/clarifier at the PWTP (see Sect. 4.1.2). Although this feed initially contained some Celite, it was used to obtain more accurate effects of precoats and body feeds. Using 0.050 g/cm^2 of Celite as a precoat significantly improved cake release from the filter cloth, whereas 0.025 and 0.013 g/cm^2 did not. The precoat did not increase the total solids content of the cake appreciably. Adding ~15 g/L of Celite as a filter aid increased the solids content from ~40 to ~50% (compared with 25% for sludge containing no Celite).

Sludges resulting from using water softened by the caustic process produced cakes containing 57 wt % solids without the use of filter aids and were much easier to filter than the sludge containing iron hydroxide. A minimal amount of precoat was needed to improve the cake release (0.013 g/cm^2). The caustic/soda-ash sludge was not tested, but it is expected to perform similarly and possibly better than the caustic sludge. This assumption is based on the qualitative results of a scoping vacuum filtration study that produced results similar to the pressure filtration tests for the caustic and scavenging-precipitation sludges.

Laboratory- and full-scale tests indicated that (1) the iron did not improve softening under normal operating conditions when a sludge blanket was present and (2) it should be eliminated to improve the dewatering process. When the iron is removed from the scavenging- precipitation process, the caustic process described above is obtained. However, contaminants such as detergents occasionally enter the PWW and inhibit the softening process. Tests discussed in Sect. 3.1 indicated that, under these conditions, iron enhances the removal of calcium and magnesium. Therefore, the caustic/soda-ash and scavenging-precipitation processes were used in IX column tests. Because iron in the precipitation step will not affect the performance of IX, the caustic process was dropped from further consideration in small-scale IX tests.

3.3 SORPTION TESTS

Small-scale IX column tests were made using fresh and softened feedwater to quickly select inorganic and organic IX materials that would have potential application in the process flowsheet. These trials were conducted to (1) compare the loading performance of the various sorbents, (2) determine the effects of some of the process variables, and (3) estimate the performance of full-scale conditions.

The materials tested in these scoping studies were selected based on column tests made during cleanup of high-activity-level water at Three Mile Island[9] and equilibrium constants for Cs^+ and Sr^{2+} as a function of several individual competing ions (including H^+, NH_4^+, Na^+, K^+, Mg^{2+}, and Ca^{2+}).[13] Mercer indicates that the Mg^{2+} concentration would not seriously affect IX performance; however, Na^+, K^+, and Ca^{2+} would have significant effects. Because the concentration of K^+ in ORNL process water is low, it was not considered further.

Equilibrium distribution coefficients calculated for several ion exchangers based on Mercer's data are shown as a function of Na^+ and Ca^{2+} concentrations in Table 8. They indicate that (1) the best performance for sorption of Cs^+ would be obtained by using the clinoptilolite and chabazite zeolites; (2) the Cs^+ could be sorbed efficiently ($K_d > 10^3$) from either softened or unsoftened water; and (3) the Sr^{2+} could be sorbed best from softened water, although the chabazite zeolite might sorb Sr^{2+} efficiently from unsoftened water. Although the zeolites are efficient for removal of Cs^+ and Sr^{2+}, they are not known to be effective for removal of the minor contaminants, cobalt, ruthenium, zirconium-niobium, and the rare earths.

Experimental, small-scale column tests were made to continue the screening of ion exchangers for potential use in an improved process. Distribution coefficients were obtained from experimental data by the following IX model.[14] The general equation for the reaction kinetics of fixed-bed IX is as follows:

$$- \frac{ZX}{ZN}_{NT} = \frac{ZY}{ZNT}_{N} = X(1 - Y) - RY(1 - X), \quad (1)$$

where X and Y are the dimensionless concentrations of the solute ion in the fluid and solid phases, respectively, and R is the separation factor. The variable X is defined as C/C_0, where C and C_0 are the concentrations of the solute ion of interest in the effluent and feed, respectively. The variable Y is defined as q/q^*, where q is the actual concentration in the solid phase and q^* is the concentration in the solid phase when it is

Table 8. Calculated distribution coefficients for process waste treatment

Ion-exchange material	No softening[a]	Low-sodium softening[b]	High-sodium softening[c]
		K_d for cesium	
Clinoptilolite	1.9E5	8.0E4	4.0E4
Linde AW-500[d]	6.9E4	1.2E5	7.6E4
Linde 4AX	3.0E3	4.4E3	2.6E3
Dowex 50-X12[e]	9.4E1	2.5E2	2.3E2
Amberlite IR-200	7.0E2	1.6E3	1.3E3
		K_d for strontium	
Clinoptilolite	4.0E3	2.7E4	2.3E4
Linde AW-500[d]	1.0E4	4.5E4	2.5E4
Linde 4AX	5.0E3	3.5E4	3.1E4
Dowex 50-X12[e]	2.8E3	2.0E4	1.9E4
Amberlite IR-200	3.2E3	2.4E4	2.2E4

[a]Calcium = 40 ppm; sodium = 10 ppm.
[b]Calcium = 5 ppm; sodium = 100 ppm.
[c]Calcium = 5 ppm; sodium = 200 ppm.
[d]Now marketed by Linde Division of Union Carbide as Ionsiv IE-95.
[e]Similar to HCR-S strong-acid cation resin manufactured by Dow Chemical Co.

in equilibrium with fluid at the inlet concentration, C_o. When the concentration of the solute ion is small relative to the concentration of the replaceable ion in the feed, R approaches unity and the isotherm is linear.

The variable N represents the length of the exchange column in transfer units and is defined by the expression

$$N = k_d q_b K_a / (f/v) , \tag{2}$$

where K'_d is the distribution coefficient when X = 1, ρ_b is the bulk density of the ion exchanger, K_a is the mass-transfer coefficient characteristic of the system, f is the rate of flow of solution through the column, and v denotes the overall volume of the sorbent bed, including the void spaces. The throughput parameter, T, is defined to be

$$T = (V/v) / K'_d q_b , \tag{3}$$

where V is the volume of solution processed through the column and V/v is the number of bv of solution that have passed through the bed.

When ρ_b is constant, the volume-based distribution coefficient is defined as $K_d = q_v/C_o$, where q_v is the concentration of the solute ion per unit volume of sorbent bed and C_o is the concentration in the feed. Equations (2) and (3) can then be expressed as

$$N = K_d K_a / (f/v) \tag{4}$$

and

$$T = (V/v) / K_d . \tag{5}$$

When Eq. (1) is integrated for IX beds, assuming reversible second-order reaction kinetics,[15] the solution is

$$X = C/C_o = \frac{J(RN, NT)}{J(RN,NT) = [1 - J(N, RNT)]\ exp[(r-1)N(T-1)]}, \qquad (6)$$

where J is a mathematical function related to the Bessel function.

For the large values of RN obtained for small-scale resin columns, $C/C_o = \sim 0.5$ when $T = 1$ and is independent of RN. Therefore, K_d is $\sim V/v$ at the point where $C/C_o = 0.5$. This characteristic implies that plots of experimental data on logarithmic-probability graphs will be linear. Therefore, K_d can be approximated by obtaining the 50% point on experimental breakthrough curves or by extrapolating experimental data on logarithmic-probability plots of C/C_o and V/v.

Distribution coefficients obtained by this method were used to compare IX materials for possible use at the PWTP. Experimental column tests were formed using 1.3-cm (0.5 in.)-OD columns that contained 6.5 to 20 mL of material with length-to-diameter ratios of 2.3 to 7.1 and residence times of 1 to 10 min. Fresh process wastewater and water softened in 204-L batches by the caustic/soda-ash and scavenging-precipitation processes were used as feed for these columns. The sorption materials and IX resins that were evaluated in these small-scale tests are listed in Table 9. All samples were obtained from commercial vendors except the lithium-aluminum. This material was an experimental sample prepared at ORNL by treating aluminum oxide spheres produced by the sol-gel process with a lithium formate solution at a pH of 9 to 10. The spheres, air dried and calcined at 450°C, exhibited a high strontium K_d in laboratory tests when the material was equilibrated with a salt solution containing high concentrations of cesium and strontium. Unfortunately, the material degraded in distilled water during column loading, resulting in very low sorption capacities for cesium and strontium. The material was not considered further.

Composite samples of the effluent from the IX treatment were collected over 8- to 12-h periods and were analyzed for ^{90}Sr, ^{137}Cs, and gross beta. Breakthrough curves were obtained by plotting the mean throughput measured in bv as opposed to percentage breakthrough. Breakthrough is defined as C/C_{om}, where C_{om} is the mean feed concentration for the run. For those samples, the strontium breakthrough curve was determined using tracer quantities of ^{85}Sr.

The data from these tests are listed in Appendix B and summarized in this section. The experimentally determined K_ds are shown in Tables 10 and 11 for each water-softening process tested. In many column tests, ^{137}Cs had not begun to break through at the time of shutdown. For those tests, K_ds are listed as greater than the total number of bed volumes that had passed through the column at that point. With the exception of

Table 9. Sorption and ion-exchange materials tested in the Process Waste Treatment Plant flowsheet

Material	Manufacturer	Cost ($/ft^3)	Description
Zeolon 400	Norton Chemicals	150	Clinoptilolite
Zeolon 500	Norton Chemicals	150	Natural chabazite-erionate mixture
Zeolon 700	Norton Chemicals	150	Ferriorite
Zeolon 900	Norton Chemicals	150	Synthetic mordenite
Linde 4A	Union Carbide	150	Inorganic zeolite
Linde A-51	Union Carbide	170	Inorganic zeolite
Ionsiv IE-95	Union Carbide	165	Synthetic chabazite
PDZ-140-D	Tenneco Speciality Minerals	15	Natural Na^+-rich clinoptilolite
PDZ-150-D	Tenneco Speciality Minerals	15	Natural K^+-rich clinoptilolite
PDZ-300	Tenneco Speciality Minerals	15	Natural chabazite
"CH"	Chem Nuclear[a]	5	Natural clinoptilolite
HCR-S	Dow Chemical Co.	67	Strong-acid resin
Amberlite IRC-184	Rohm & Haas	165	Weak-acid cation resin
Doulite CS-100	Diamond Shamrock	230	Weak-acid cation resin
Dowex TG-650-G12	Dow Chemical Co.		Strong-acid cation resin
Dowex XFS-43230	Dow Chemical Co.		Radium-selective resin
Lithium-aluminum	ORNL		Experimental micro-spheres

[a]Sample obtained from Chem Nuclear from an unknown manufacturer in Oregon.

Table 10. Experimentally determined cesium distribution coefficients[a]

Ion-exchange material	Unsoftened water[b,c]	Caustic/ soda-ash softened water[b,d]	Scavenging-precipitation softened water[b]
Zeolon 400	21,000		
Zeolon 500	>15,000		
Zeolon 700	>8,500		
Zeolon 900	>14,000		
Ionsiv IE-95[f]	>15,000	>18,000	13,000[e]
PDZ-300-AL[f]	>9,000		
PDZ-300-D[f]	>4,000		
PDZ-300-17[f]	23,000		
PDZ-140-D	>8,000	19,000	14,000
PDZ-150-D			
"CH"	>2,000	15,000	10,500[g]
Linde 4A		8,400	3,400[e]
Linde A-51	3,600		
TG-650-G12	1,000		
XFS-43230	470		
HCR-S		430	100[e]
ICR-84		400	160[g]
CS-100		500	3,600[e]
Lithium-aluminum	<400		

[a]Greater than sign indicates no breakthrough at the maximum throughput measured in bed volumes of water processed at shutdown.

[b]Calcium and total hardness data were obtained by wet-chemistry analysis. Average values for the individual components do not sum to the total hardness because of inherent errors in the analytical techniques.

[c]Average cation concentrations of 50 ppm Ca, 12 ppm Mg, and 30 ppm Na, and total hardness of 150 ppm as $CaCO_3$.

[d]Average cation concentrations of 5 ppm Ca, 3 ppm Mg, and 150 ppm Na, and total hardness of 27 ppm as $CaCO_3$.

[e]Average cation concentrations of 5 ppm Ca, 1 ppm Mg, and 270 ppm Na, and total hardness of 18 ppm as $CaCO_3$.

[f]PDZ-300-17 is a sample of the PDZ-300 zeolite bought for the PWTP. PDZ-300-AL and PDZ-300-D are test samples that are not supposed to be different but are probably from different sites.

[g]Average cation concentrations of 1 ppm Ca, 0.05 ppm Mg, and 300 ppm Na, and total hardness of 4 ppm as $CaCO_3$.

Table 11. Experimentally determined strontium distribution coefficients

Ion-exchange material	Unsoftened water[a,b]	Caustic/ soda-ash softened water[b,c]	Scavenging-precipitation softened water[b]
Zeolon 400	370		
Zeolon 500	2,000		
Zeolon 700	320		
Zeolon 900 .	300		
Ionsiv IE-95	2,200	3,800	1,000[d]
PDZ-300-AL	2,000		
PDZ-300-D	3,000		
PDZ-300-17	3,100		
PDZ-140-D	800	15,000	10,500[e]
PDZ-150-D			
"CH"	350	13,000	36,000[e,f]
Linde 4A		13,000	12,000[d]
Linde A-51	800		
TG-650-G12	1,500		
XFS-43230	540		
HCR-S		7,000	6,800[d]
IRC-84		15,000	26,000[e,f]
CS-100		500	3,800[d]
Lithium-aluminum	<400		

[a]Average cation concentrations of 50 ppm Ca, 12 ppm Mg, and 30 ppm Na, and total hardness of 150 ppm as $CaCO_3$.

[b]Calcium and total hardness data were obtained by wet-chemistry analysis. Average values for the individual components do not sum to the total hardness because of inherent errors in the analytical techniques.

[c]Average cation concentrations of 5 ppm Ca, 3 ppm Mg, and 150 ppm Na, and total hardness of 27 ppm as $CaCO_3$.

[d]Average cation concentrations of 5 ppm Ca, 1 ppm Mg, and 270 ppm Na, and total hardness of 18 ppm as $CaCO_3$.

[e]Average cation concentrations of 1 ppm Ca, 0.05 ppm Mg, and 300 ppm Na, and total hardness of 4 ppm as $CaCO_3$.

[f]Distribution coefficients determined by extrapolation from the 10 to 20% breakthrough point.

^{90}Sr for the "CH" clinoptilolite, the data follow the same trends as the calculated distribution coefficients in Table 8, but most of the actual strontium values are an order of magnitude lower than predicted.

Table 10 indicates that all the zeolites had high sorption capacities for cesium, except for the two Linde A materials. They are expected to have K_ds of ~20,000 for unsoftened water and 10,000 to 20,000 for softened water. Table 11 indicates that chabazites, Ionsiv IE-95 and PDZ-300, were the best materials tested for strontium removal from fresh basin water, having distribution coefficients of 2,000 to 3,000. Distribution coefficients were not determined for PDZ-150-D and IX resins because changing feed compositions affected the breakthrough curves. The data indicated that resins did not remove strontium as well as chabazites; thus, no additional tests were performed on resins with unsoftened water. The effects of drastic changes in the feed stream will be discussed in detail in the paragraphs that follow.

The breakthrough curves for the three most promising zeolites at 6- to 7-min residence times are shown in Figs. 5 and 6. Figure 5 indicates that the chabazites, whether natural or synthetically derived, have exceedingly high cesium sorption capacities; as seen in Fig. 6, they exhibit similar capacities for strontium removal. Zeolon 500, a chabazite-erionite mixture, had a slightly lower strontium capacity. When the ^{90}Sr and ^{137}Cs breakthrough curves are plotted on logarithmic-probability graphs, they yield linear curves—possibly with slight curvatures in the initial breakthrough region (Figs. 7 and 8), indicating that they fit the above model with reasonable accuracy. Figure 9 shows that the major effect of increasing the residence time from 1 to 6 min is to extend initial breakthrough and increase the slope of the breakthrough curve while the distribution coefficient remains constant.

A major area that must be addressed before zeolites can be used to treat PWTP wastewater is the degree to which they can accommodate fluctuations in the feed stream. Some contaminants, such as phosphate ions, are known to complex with radioactive ions so they become nonionic and are not sorbed by IX materials. Figures 10 and 11 show that phosphate ions have little effect on ^{90}Sr removal by IE-95. The breakthrough curve (Fig. 10) indicates that these ions are not sorbed by IE-95 even when present in 140-ppm quantities, which are well above the concentrations of all nonradioactive ions present in the feed. The data in Fig. 11(b) show that phosphate ions present in the feed do not inhibit the strontium sorption capacity of the zeolite.

Concentrated spikes of radioactive materials have occasionally entered the PWTP feed stream as a result of operations such as decontamination of research facilities. Variations in the concentrations of ^{90}Sr (between 2000 and 8000 Bq/L) and ^{137}Cs (between 300 and 1000 Bq/L) were common during the test period, as noted in Appendix B. These fluctuations created no problem as long as the feed concentration changed gradually during a run. Rapid changes in feed concentrations had detrimental effects on

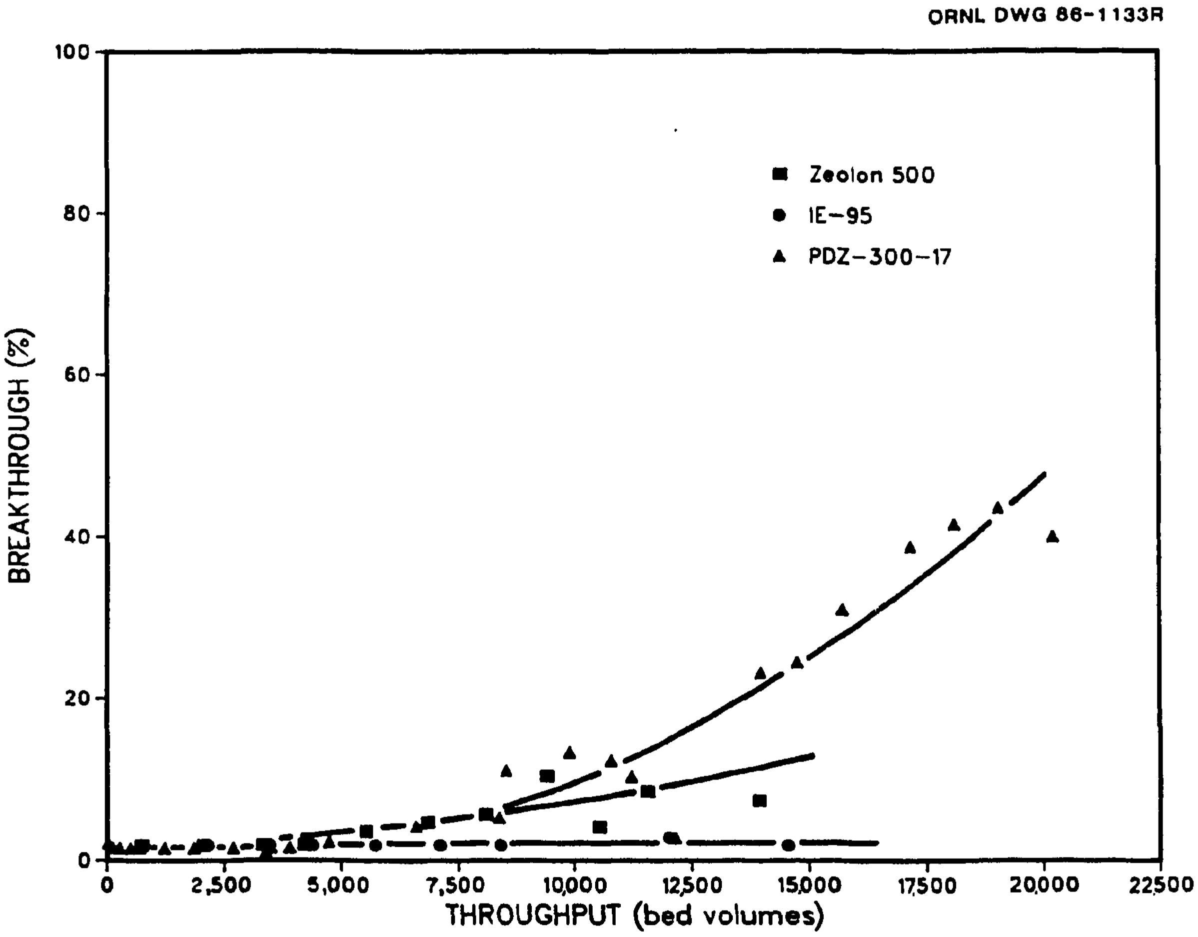

Fig. 5. Cesium breakthrough curves for unsoftened Process Waste Treatment Plant feed.

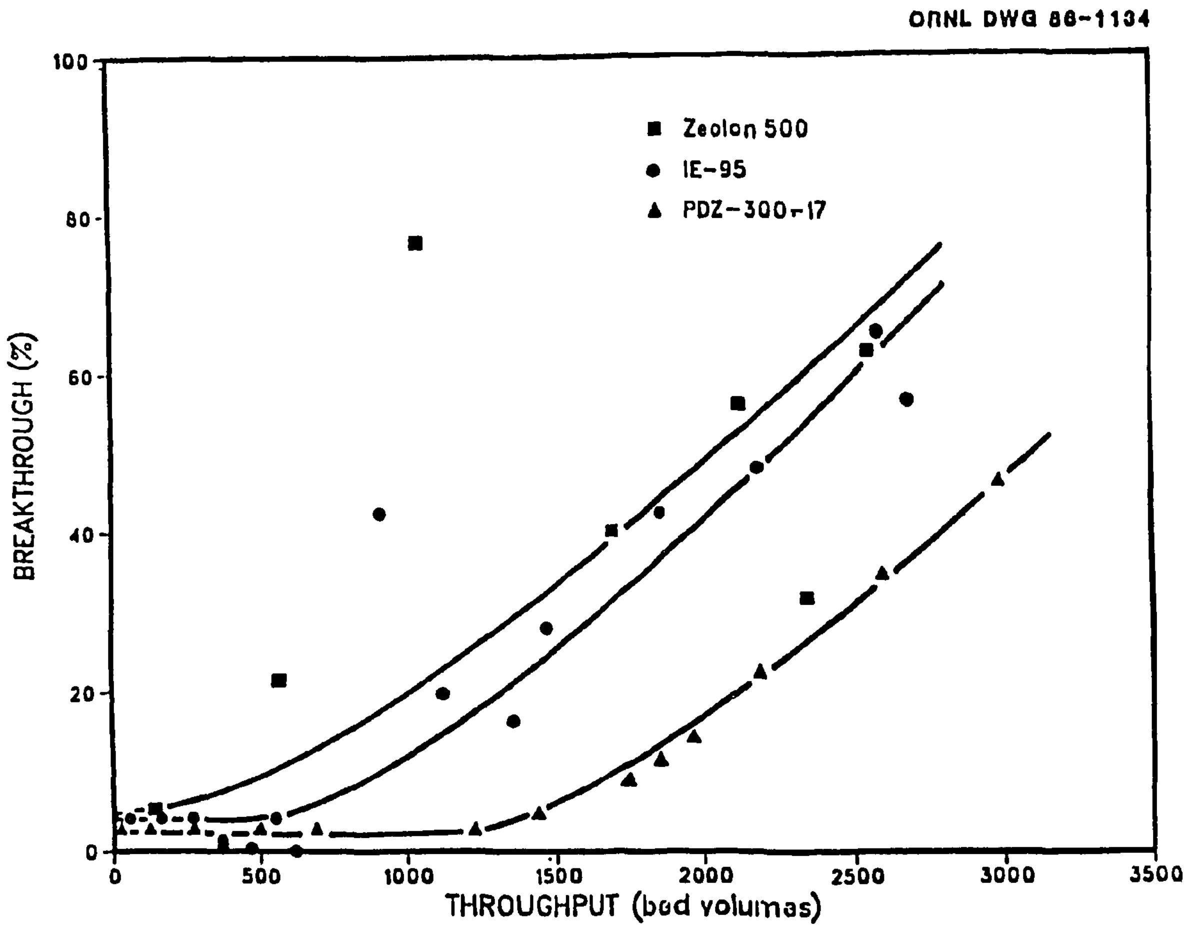

Fig. 6. Strontium breakthrough curves for unsoftened Process Waste Treatment Plant feed.

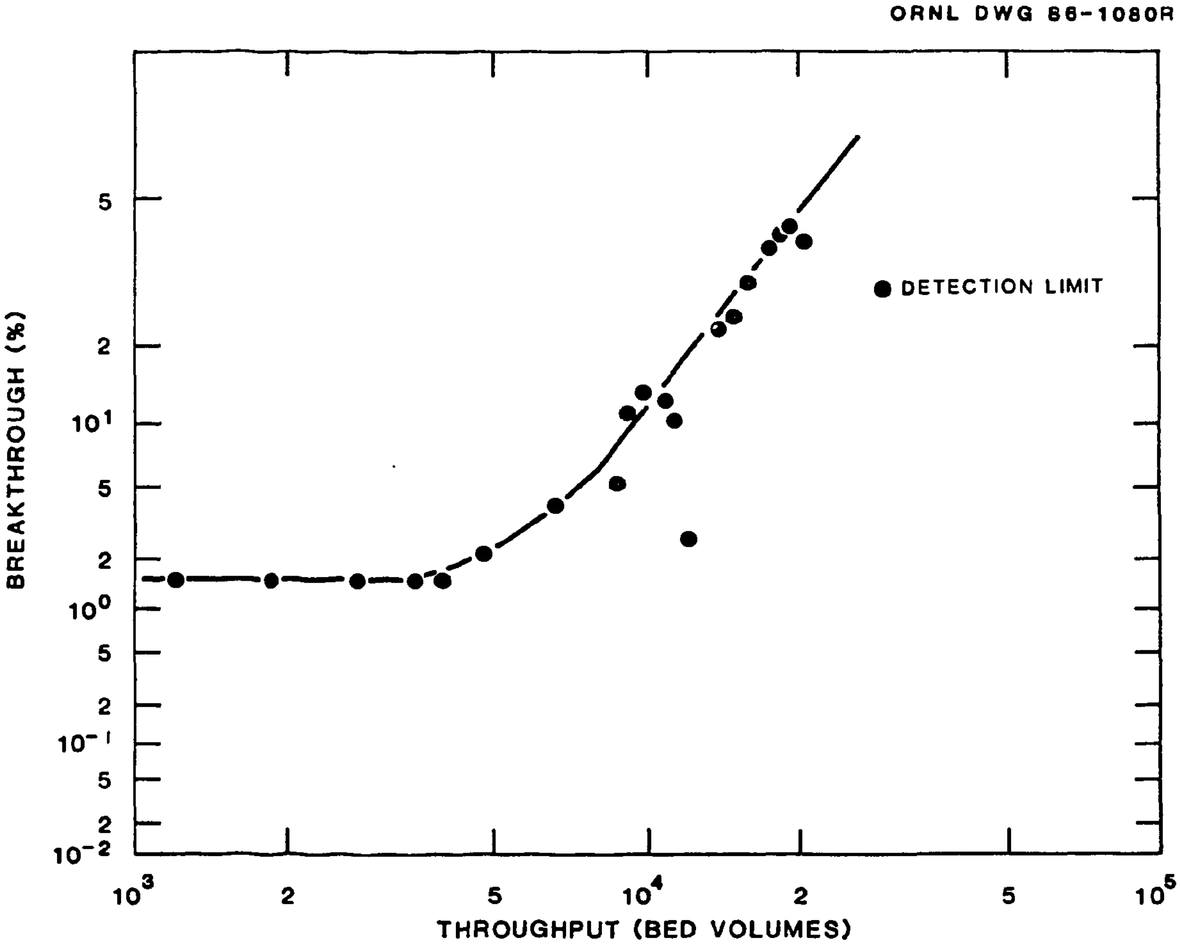

Fig. 7. Cesium logarithmic-probability graph for PDZ-300-17 using unsoftened Process Waste Treatment Plant feed.

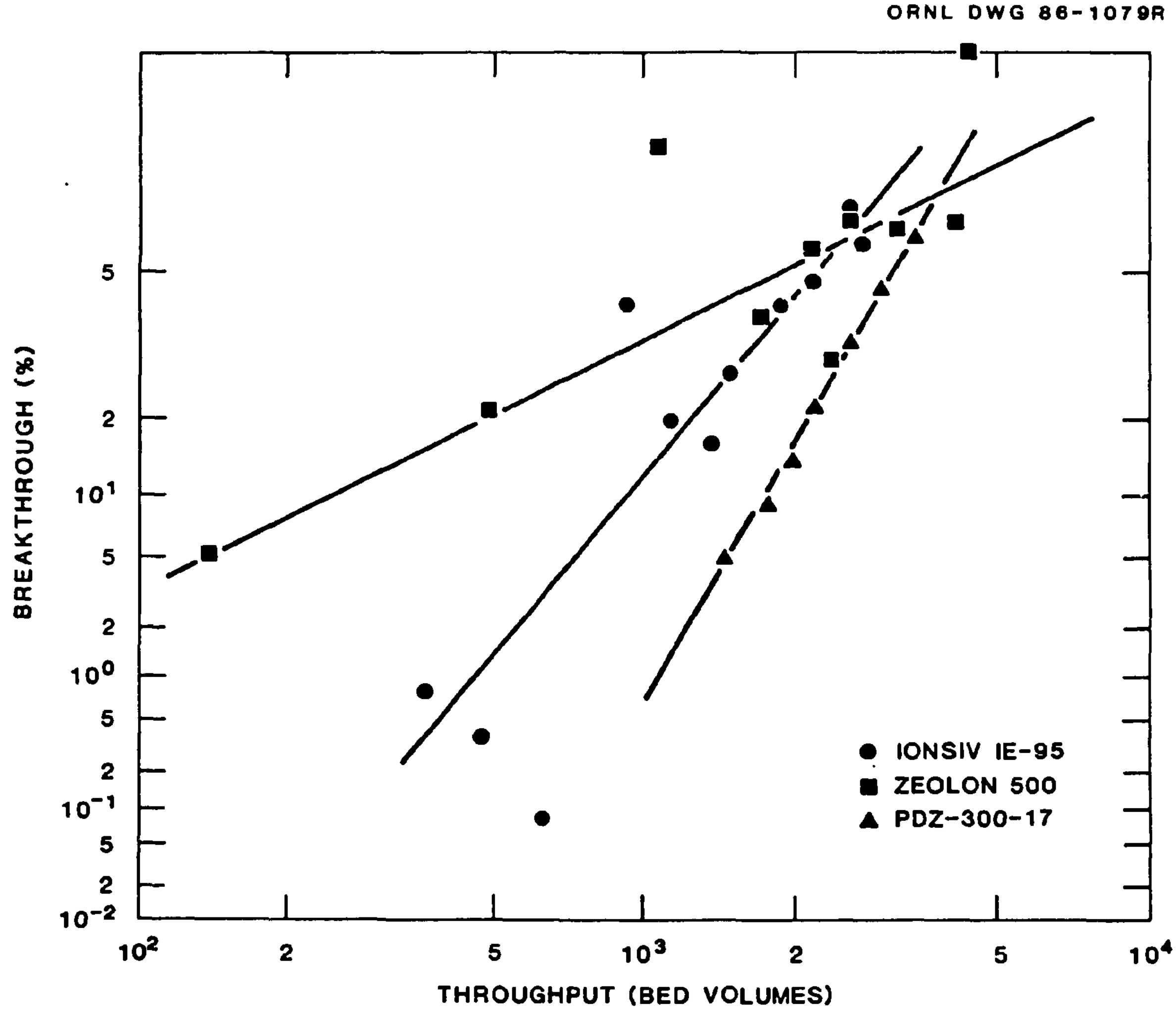

Fig. 8. Strontium logarithmic-probability graphs for unsoftened Process Waste Treatment Plant feed.

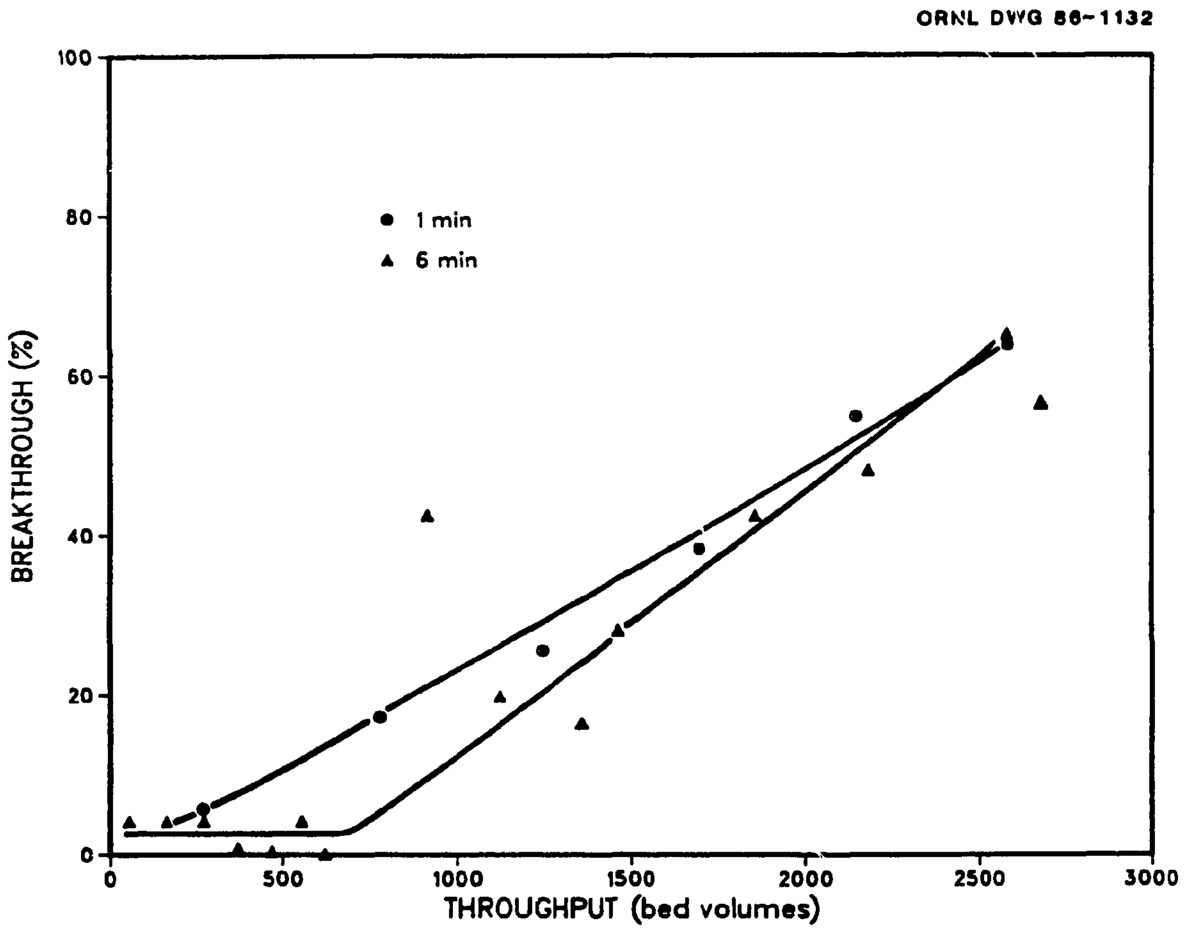

Fig. 9. Effect of residence time on ^{90}Sr breakthrough curves for Ionsiv IE-95.

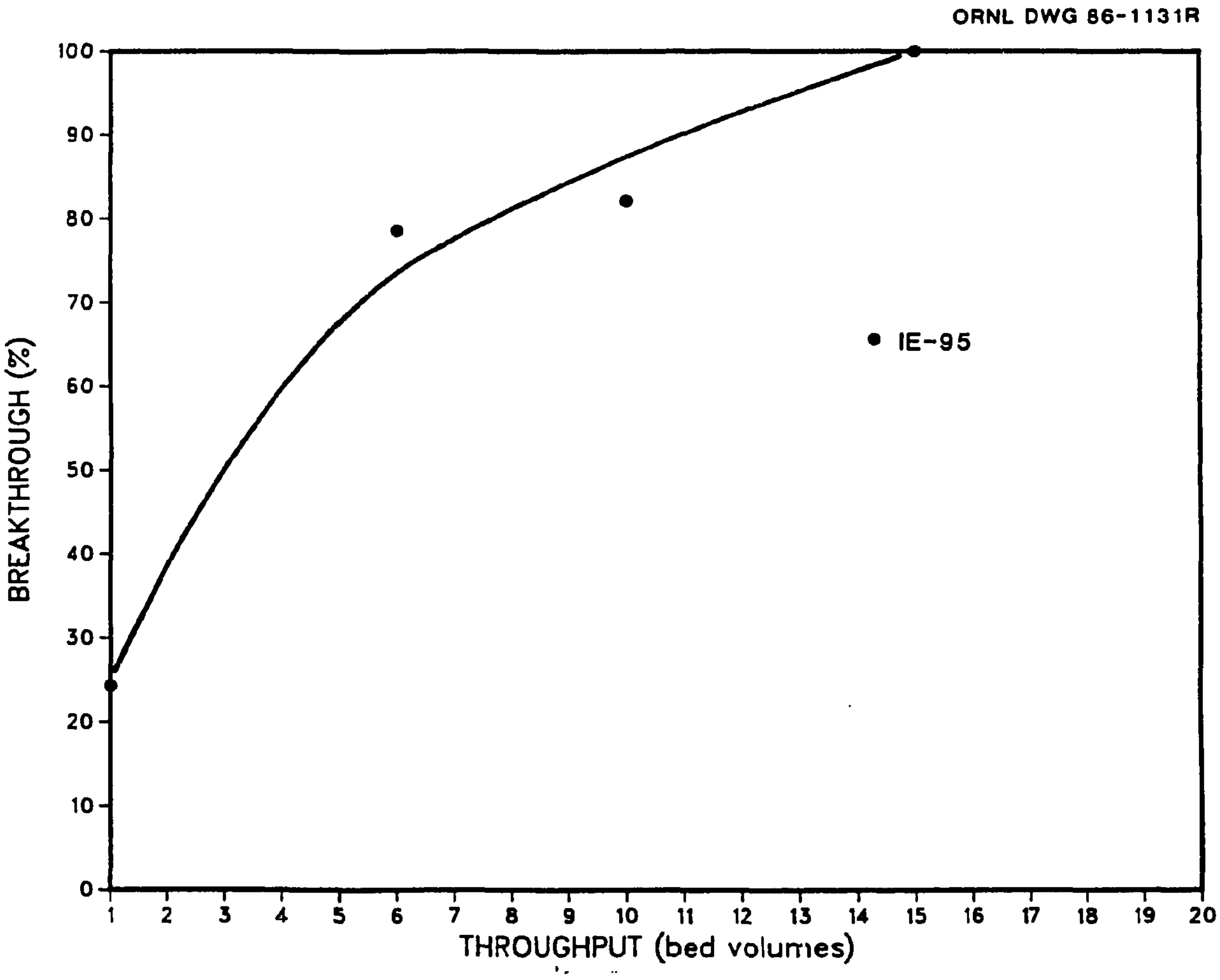

Fig. 10. Phosphate breakthrough curve for Ionsiv IE-95.

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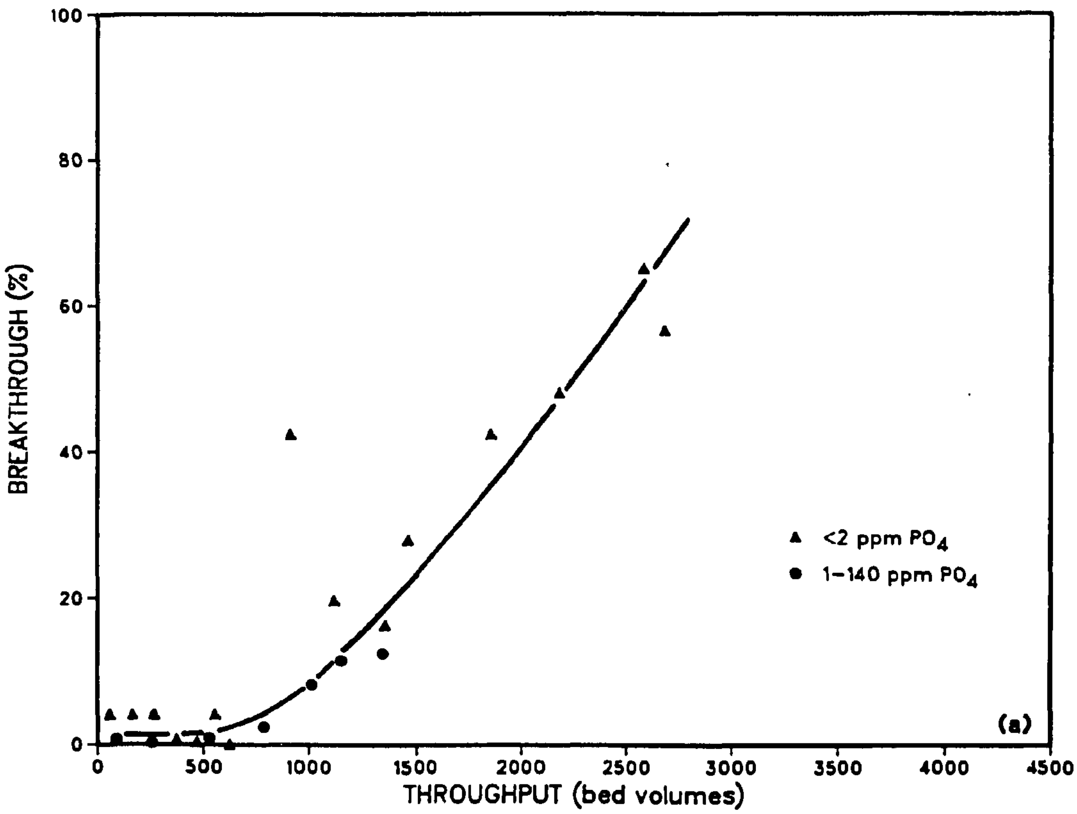

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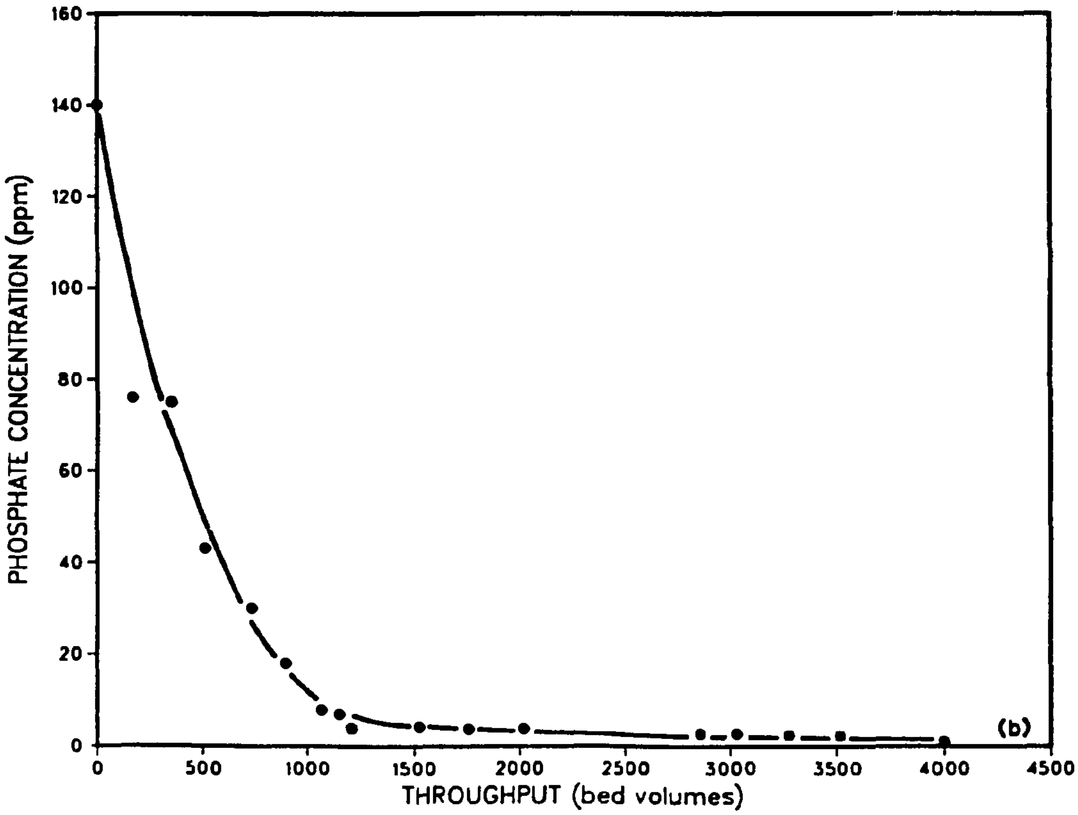


Fig. 11. Effect of phosphate concentration on strontium breakthrough. (a) Breakthrough curve; (b) variable phosphate concentration in feed.

zeolites and strong- and weak-acid resins. Breakthrough curves, such as those for IE-95 and PDZ-300 shown in Fig. 12, were obtained when the composition of the feed stream exponentially decreased from 22,000 Bq/L ^{90}Sr and 12,000 Bq/L ^{137}Cs to 2000 and 1000 Bq/L, respectively, during the run. Early breakthrough can be attributed to elution of the radionuclides from the zeolites by the feed solution when the concentration of the radionuclides in the feed fell below the equilibrium value created by the initial concentrated feed.

In general, softening water before IX lowers the strontium and cesium sorption capacities of chabazites whereas it increases the capacities of clinoptilolites, Linde A zeolites, and the resins. Tables 10 and 11 show that a trade-off exists between increasing the sodium concentration and reducing the total hardness in the water. Most sorption materials have higher loading capacities for caustic/soda-ash softened water (150 mg/L sodium and 27 mg/L total hardness) than for water treated by the scavenging-precipitation process (300 mg/L sodium and 4 to 18 mg/L total hardness).

The exceptions to the above observation are the "CH" clinoptilolite for ^{90}Sr removal, CS-100, and IRC-84. Better performance was expected for CS-100 with the high-pH scavenging-precipitation process because the resin contains phenolic groups that ionize at pH 12 to remove cesium. The threefold increase in strontium capacity for the "CH" zeolite with scavenging-precipitation softened water over caustic/soda-ash processed water was not anticipated. Mercer's data and the experimental data for similar zeolites indicate that the performance should decrease, and additional tests must be made to confirm the results.

Amberlite IRC-84 has sorption capacities to enable the resin to remove both monovalent and multivalent cations extremely well, but its affinity for divalent cations is much greater than its affinity for monovalent cations.[16] The capacity of the resin is very sensitive to the hardness and bicarbonate alkalinity of the feed, as indicated by the breakthrough curves in Fig. 13. Decreasing the total hardness from 27 to 18 mg/L significantly improved the strontium capacity as the column loaded with divalent cations (indicated by negligible volume change during loading). When the hardness was lowered to 4 mg/L, the resin exhibited an extremely high capacity for strontium, and it immediately loaded with sodium. Converting the resin from its original H^+ form to the Na^+ form resulted in degassing in the column and swelling to ~210% of the original resin volume. In subsequent tests, this problem was avoided by converting the resin before column loading. Degassing and swelling were not noticed in tests with any other sorption material.

The breakthrough curves for the most promising materials tested on softened water are shown in Figs. 14 and 15. They indicate that IRC-84 has an extremely high capacity for strontium removal from scavenging-precipitation softened water but very little ^{137}Cs sorption capacity. Zeolites in the Linde A series and clinoptilolites, such as PDZ-140 and

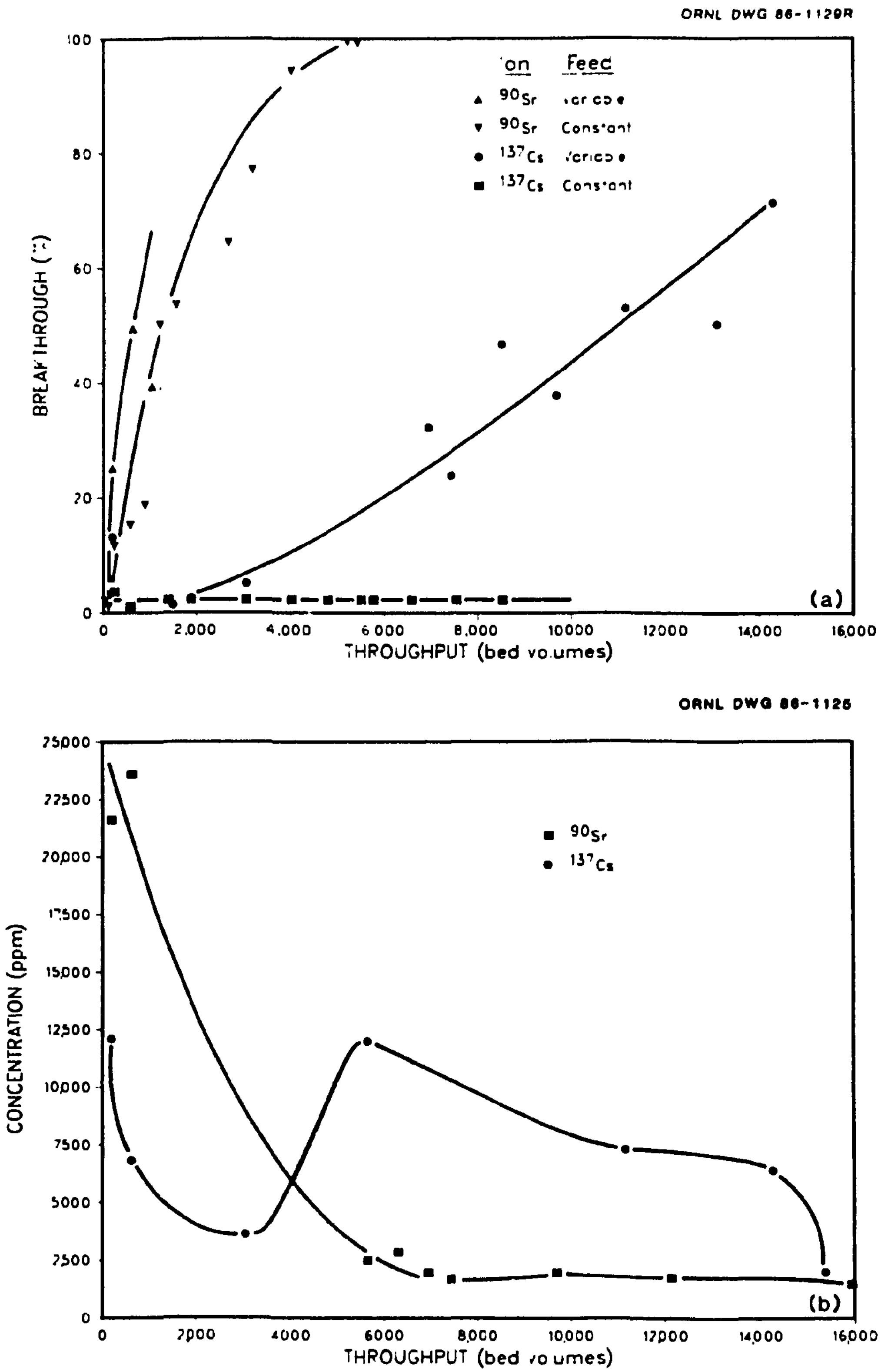


Fig. 12. Effect of radionuclide concentration in feed on Ionsive IE-95 breakthrough. Constant feed concentration: 3500 Bq/L ^{90}Sr and 440 Bq/L ^{137}Cs. (a) Breakthrough curve; (b) variable feed concentration.

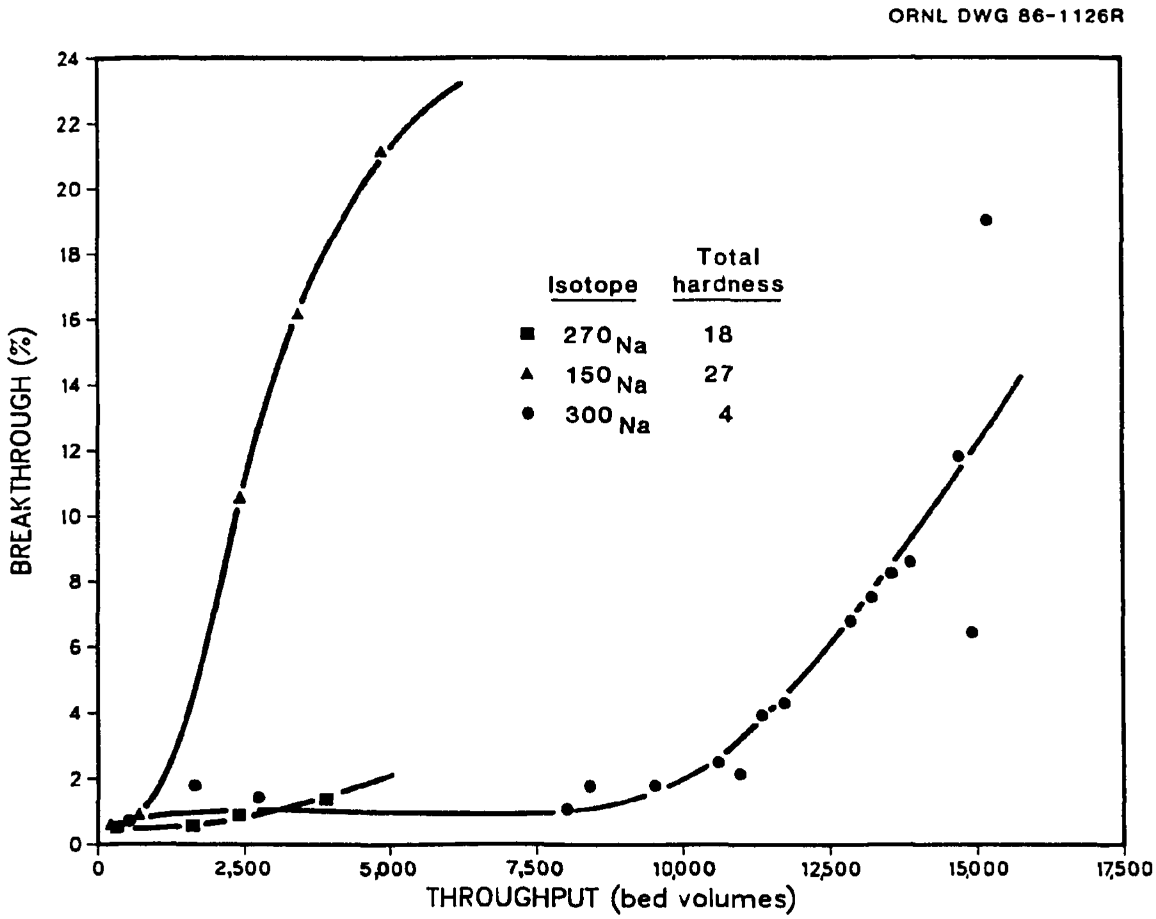


Fig. 13. Effect of hardness on strontium breakthrough curves for IRC-84 resin.

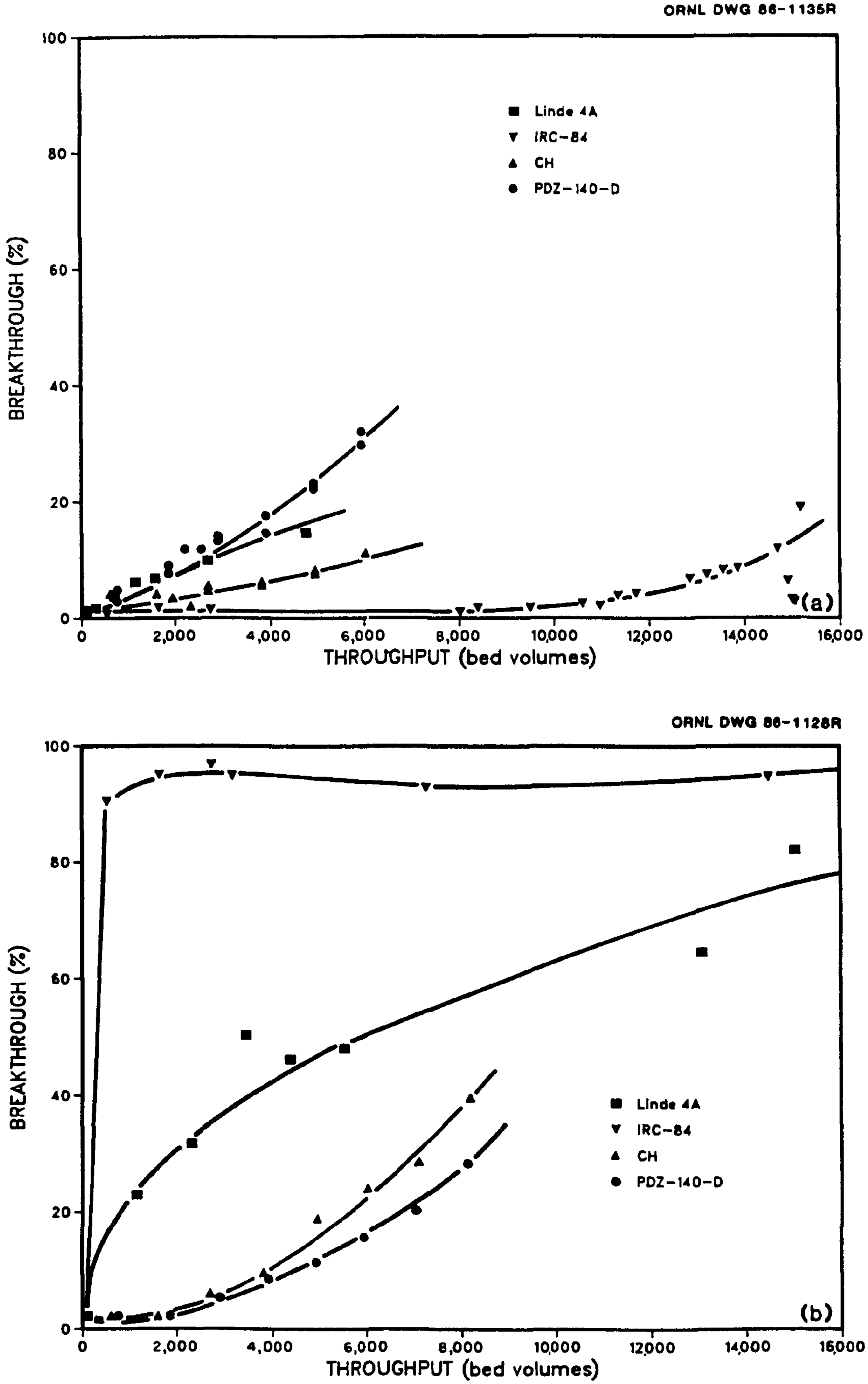
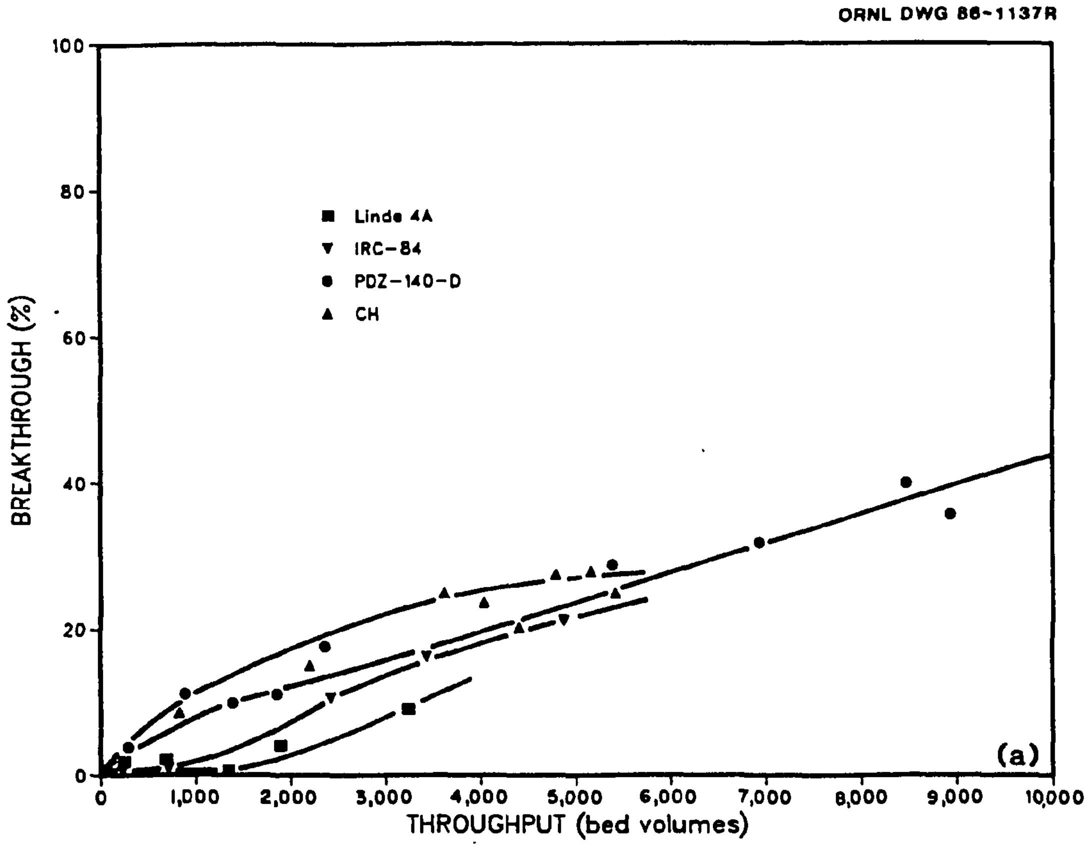


Fig. 14. Breakthrough curves for scavenging-precipitation softened water. (a) Strontium; (b) cesium.



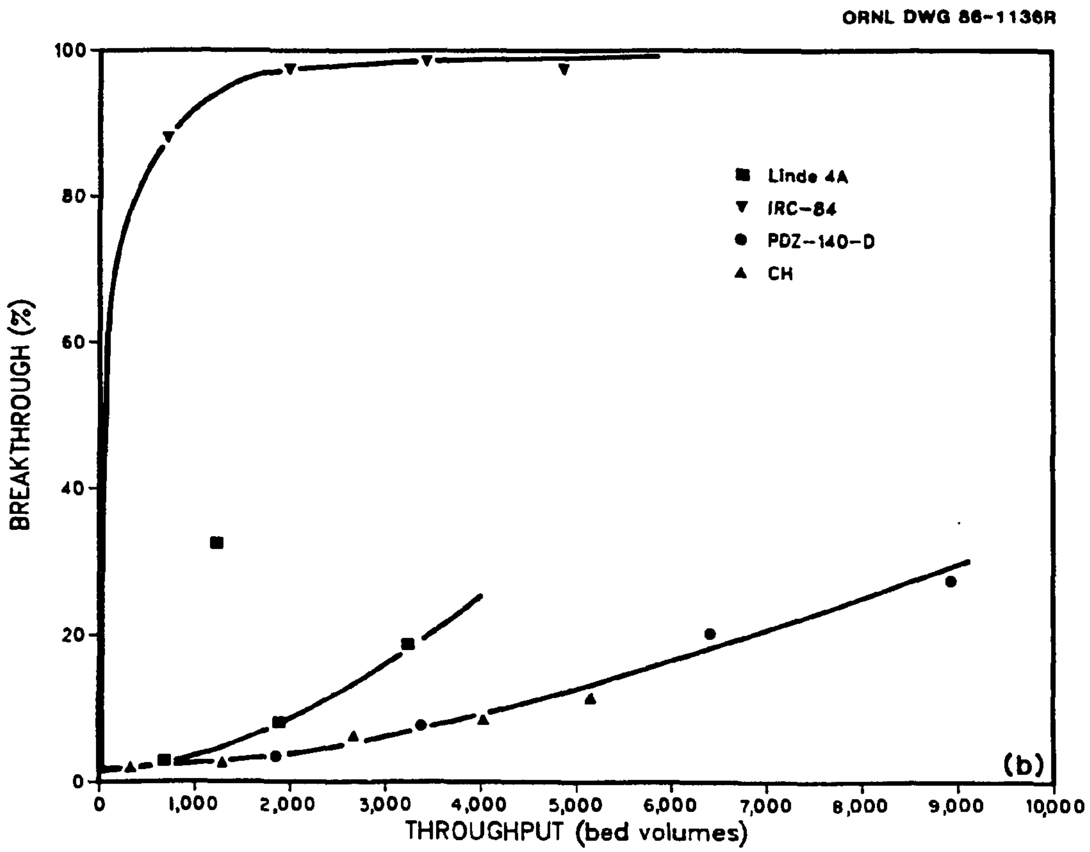


Fig. 15. Breakthrough curves for caustic/soda-ash softened water. (a) Strontium; (b) cesium.

"CH," have lower strontium capacities (except for the questionable strontium capacity of "CH" with scavenging-precipitation softened water), but they also have the ability to remove cesium.

The strontium breakthrough curves, except for the Linde 4A scavenging-precipitation curve, were based on ^{85}Sr rather than ^{90}Sr. The feed for these tests was softened in 204-L batches and spiked with tracer quantities of ^{85}Sr immediately before the tests were performed. The breakthrough curves were affected by changes in ^{85}Sr concentrations between feed batches, as shown in Fig. 16. For those tests, the distribution coefficients were estimated by extrapolating the data from the first batch of feed plotted on logarithmic-probability graphs. Comparison of ^{85}Sr and ^{90}Sr breakthrough curves for "CH" zeolite in Fig. 17 indicates that this approach is valid.

Evaluation of the previously discussed data indicates that several materials have the potential to remove ^{90}Sr and/or ^{137}Cs. All zeolites are good sorbents for Cs^{+}. The tests also confirmed that the chabazites (Zeolon 500, Ionsiv IE-95, and Tenneco PDZ-300) could effectively remove Sr^{2+} from unsoftened process water, although a column residence time of ~10 min would be required because of the relatively slow kinetics of the ion exchange. Clinoptilolite zeolites, HCR-S strong-acid resin, and IRC-84 weak-acid resin effectively removed ^{90}Sr from softened feed. Clinoptilolites were the only materials that removed both ^{90}Sr and ^{137}Cs from softened feed.

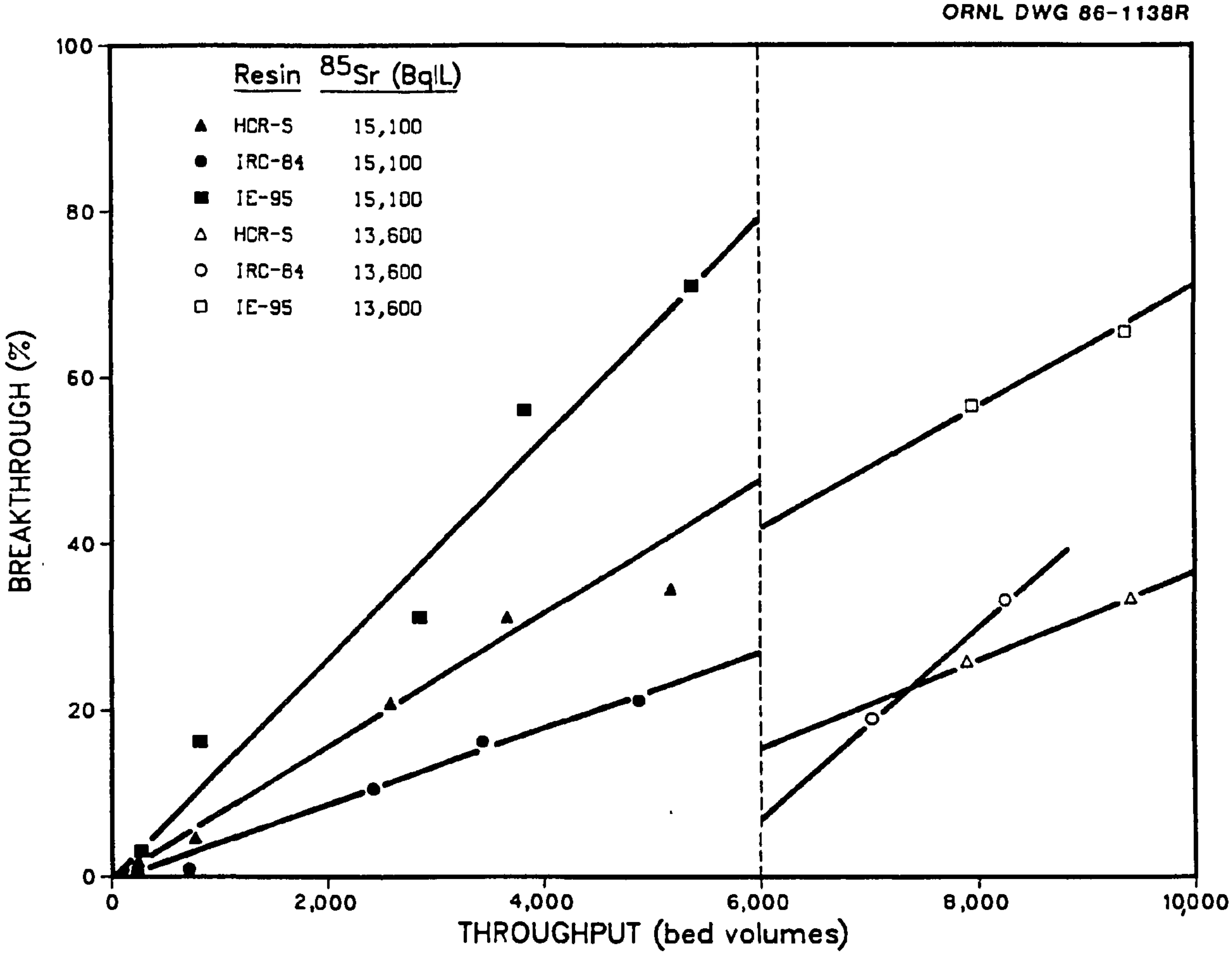


Fig. 16. Effect of ^{85}Sr tracer concentration on strontium breakthrough curve for caustic/soda-ash softened water.

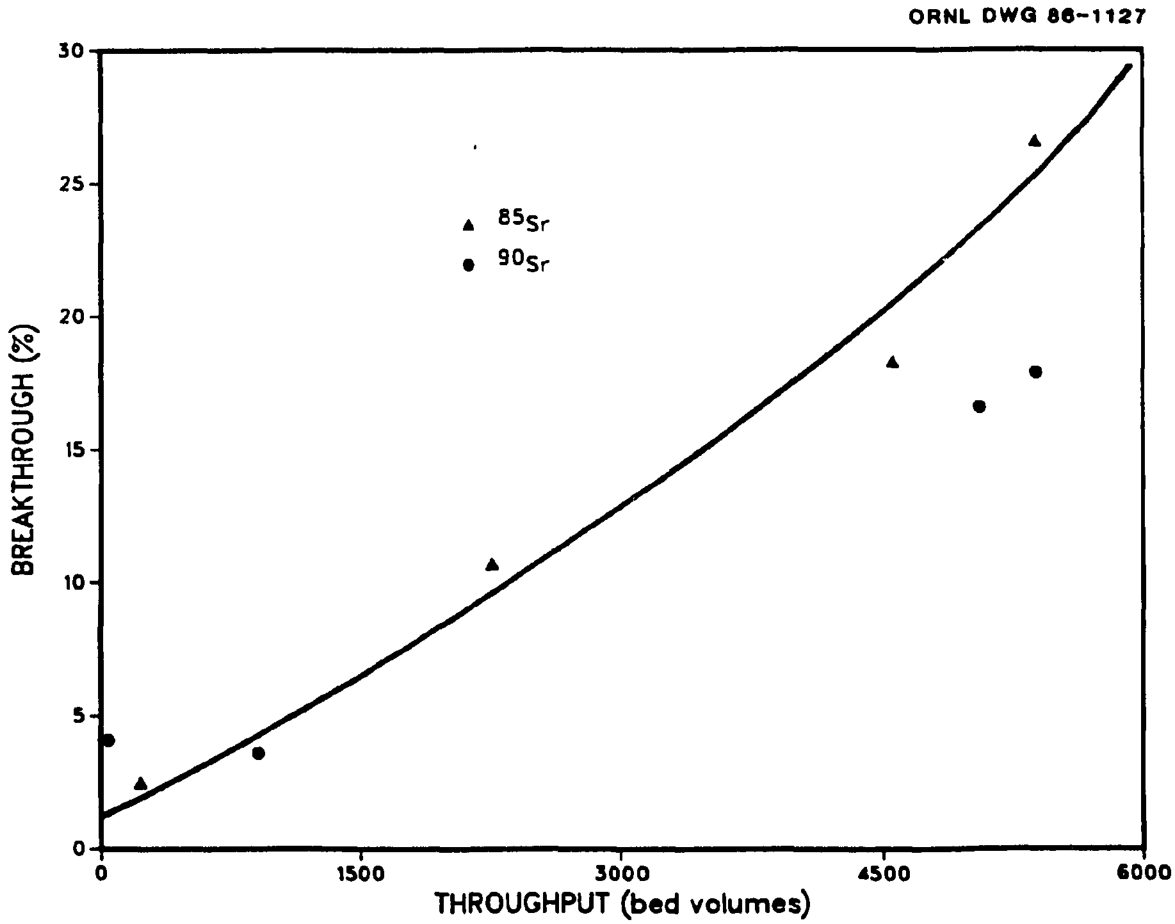


Fig. 17. Breakthrough curves for ^{85}Sr tracer and ^{90}Sr for "CH" zeolite with caustic/soda-ash water.

4. FLOWSHEET DEVELOPMENT

These data were used to develop five potential process flowsheets using some or all of the unit operations shown in Fig. 2. The alternative process flowsheets shown in Figs. 18-22 were developed for fixed-bed IX columns. The most simple proposed flowsheet (Fig. 18) uses a chabazite, such as PDZ-300 or IE-95, to remove both cesium and strontium. Upon strontium breakthrough, the zeolites would be disposed of as solid low-level waste (LLW). If several zeolite columns were used in series, this process has the potential of being a simple and economical decontamination method that would produce only one type of solid waste.

The flowsheet in Fig. 19 uses the materials with the maximum sorption capacities for ^{137}Cs and ^{90}Sr, respectively. It includes all unit operations shown in Fig. 2: a chabazite column for ^{137}Cs removal, followed by a caustic water softener for magnesium and calcium removal, and a column containing IRC-84 (a regenerable weak-acid resin) for ^{90}Sr removal. Because laboratory tests have indicated that IRC-84 may result in operational problems typically associated with weak-acid resins (i.e., swelling, degassing, and degrading), a similar flowsheet (Fig. 20) was developed that replaces IRC-84 with HCR-S, a more forgiving strong-acid resin but with a lower strontium loading capacity. Both of these processes would generate three solid wastes (spent resins, zeolites, and precipitated sludge) and LLLW associated with resin regeneration.

An alternative flowsheet (Fig. 21) proposes that a clinoptilolite, such as PDZ-140 or "CH," be used to remove both Cs and Sr after Ca and Mg have been removed from the feed by chemical precipitation. Although the Cs and Sr distribution coefficients are only one-half to one-third of the materials selected for use in Fig. 19, the flowsheet is simplified by eliminating one unit operation shown in Fig. 2. The process also eliminates LLLW and only generates two solid wastes: sludge and zeolite. The experimental data indicate that selection of the softening process could significantly affect the life of the clinoptilolite columns. Both the caustic and caustic/soda-ash softening methods should be considered in the initial evaluation of this flowsheet.

The final flowsheet (Fig. 22) to be considered for the PWTP includes a fixed-bed zeolite column for cesium removal and a continuous countercurrent IX column containing TG-650-G12, a strong-acid resin, for strontium removal.[17] Although the data from the small-scale column tests indicate that the resin does not have large enough strontium loading capacities from unsoftened water to warrant consideration for potential use in fixed-bed columns, the increased efficiency of the continuous column allows ^{90}Sr removal without the use of a water softener. Since the sorption capacity of the resin for ^{90}Sr is higher than that of the competing ions (Fig. 23), the weaker ions will be replaced by ^{90}Sr as the feed moves through the countercurrent column. The ions are separated in this manner such that ^{90}Sr is concentrated to a higher degree than in fixed-bed columns. The

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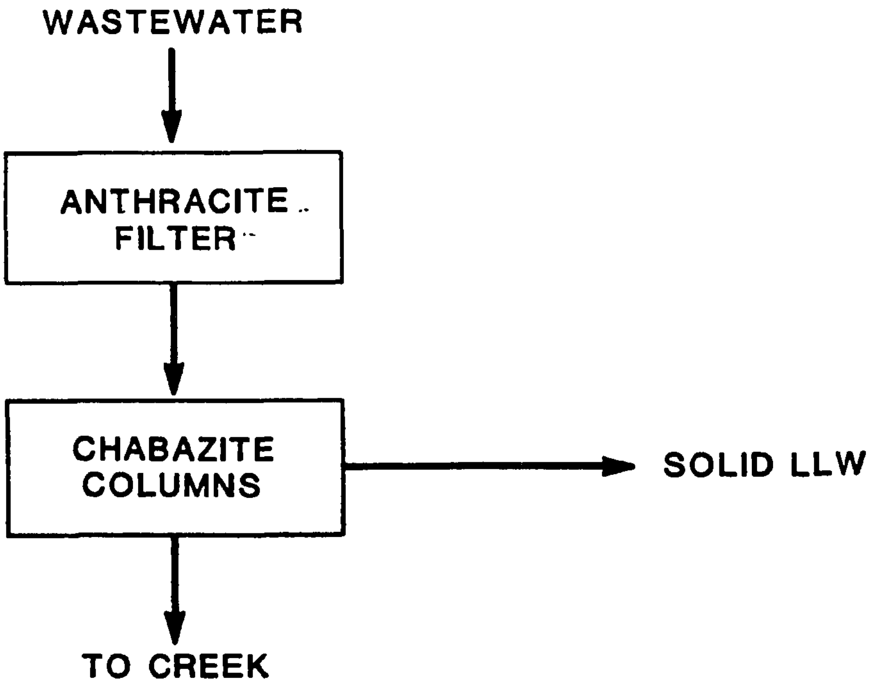

Fig. 18. Proposed zeolite flowsheet for the Process Waste Treatment Plant.

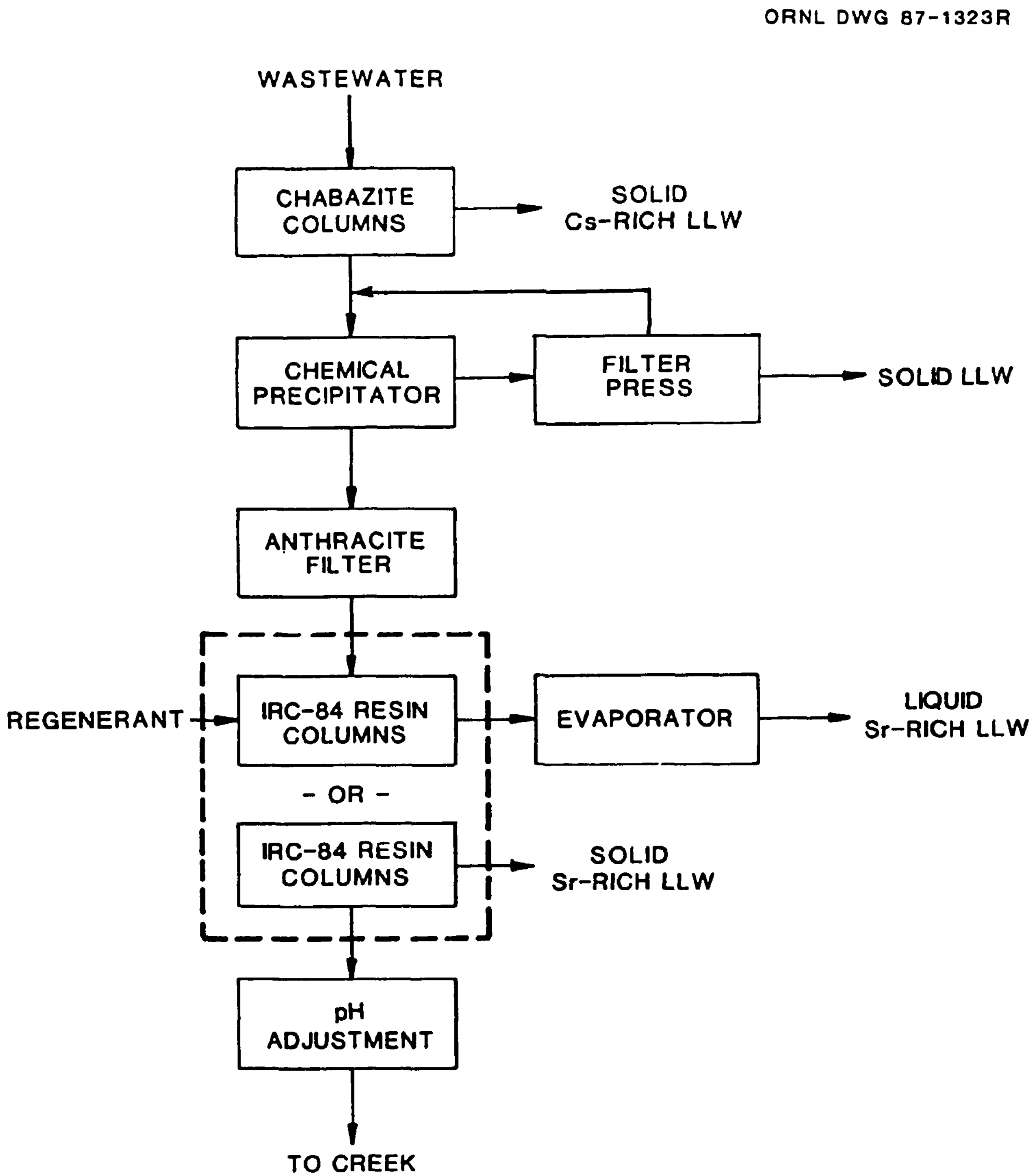

Fig. 19. Proposed zeolite/weak-acid resin flowsheet for the Process Waste Treatment Plant.

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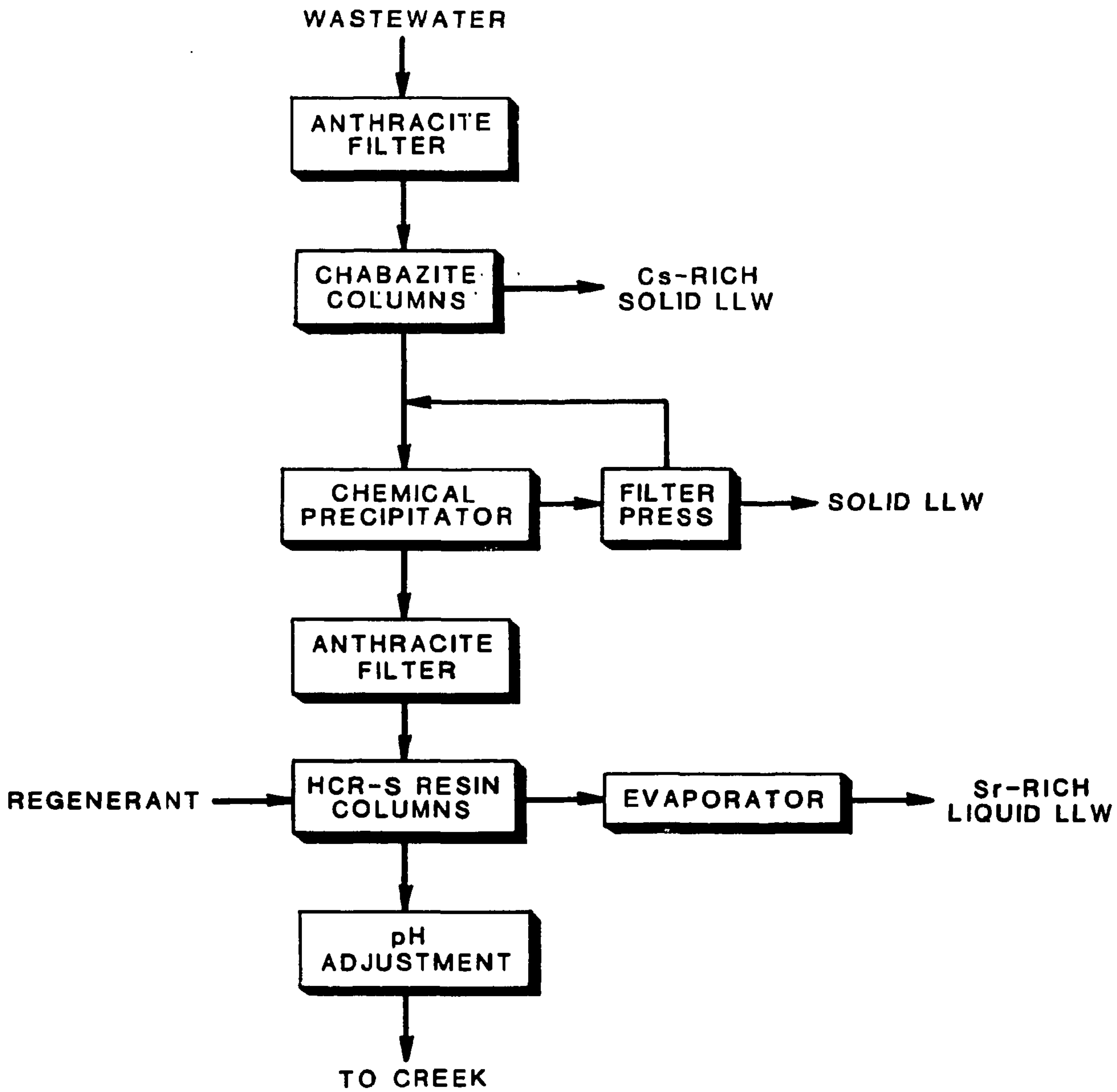

Fig. 20. Proposed zeolite/strong-acid resin flowsheet for the Process Waste Treatment Plant.

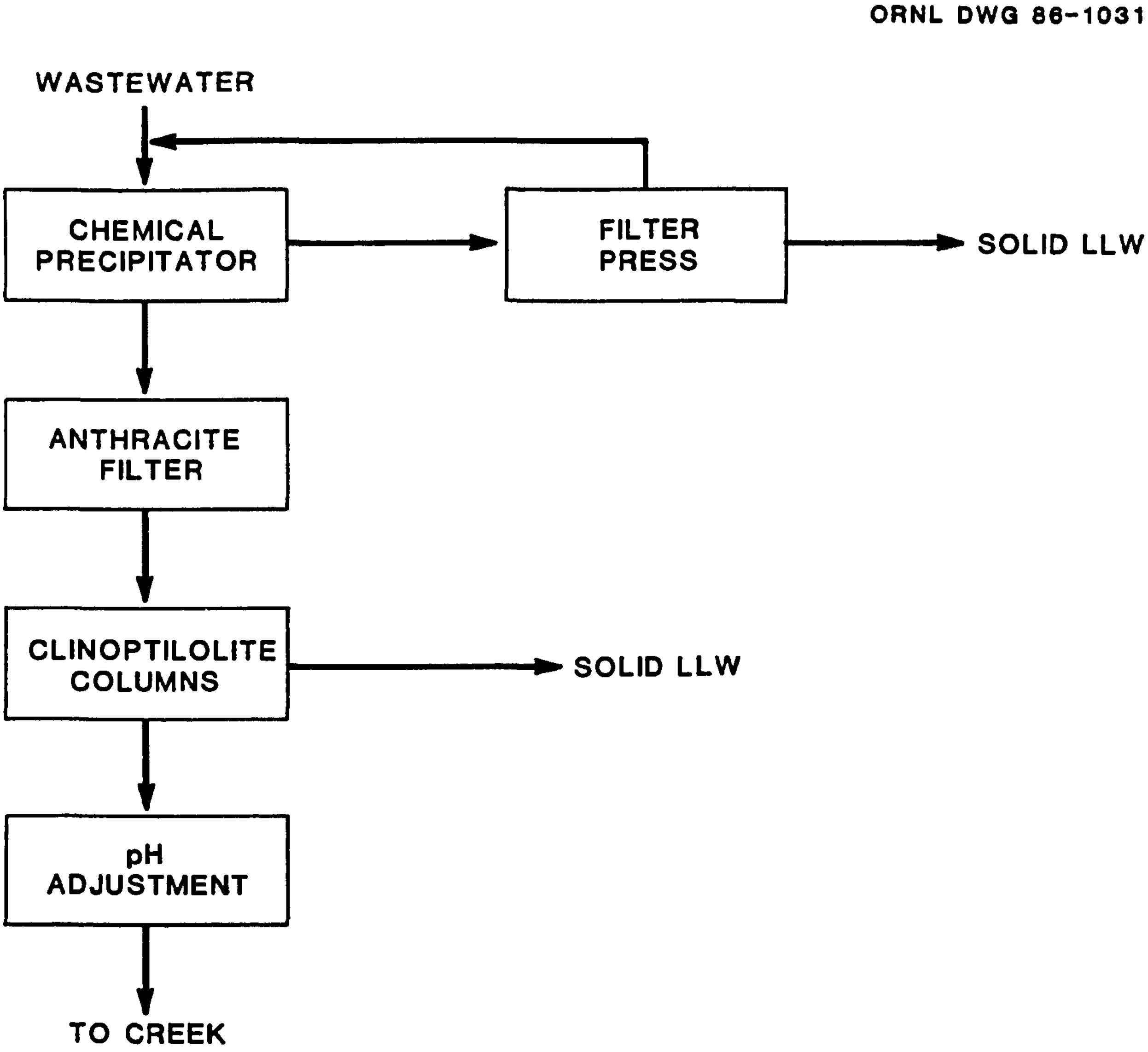

Fig. 21. Proposed softener/zeolite flowsheet for the Process Waste Treatment Plant.

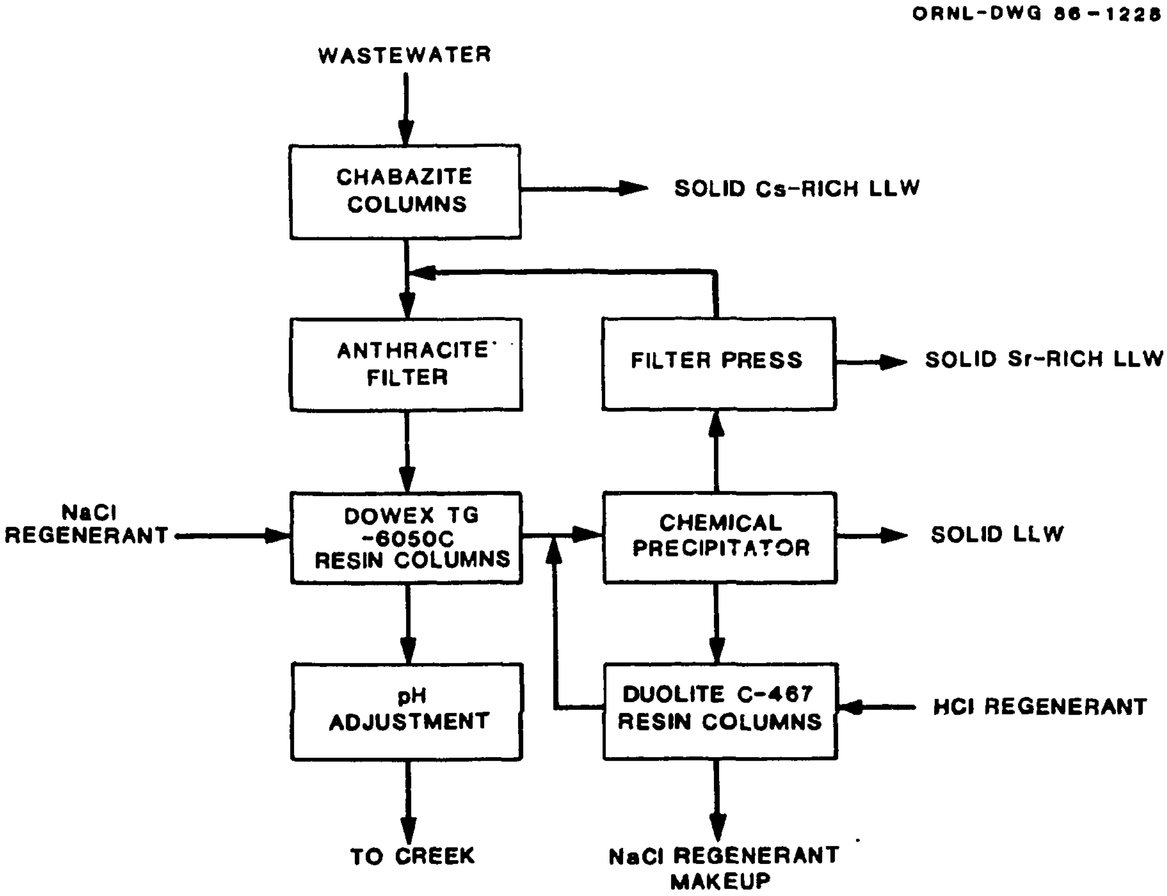

Fig. 22. Proposed continuous-countercurrent ion-exchange flowsheet for the Process Waste Treatment Plant.

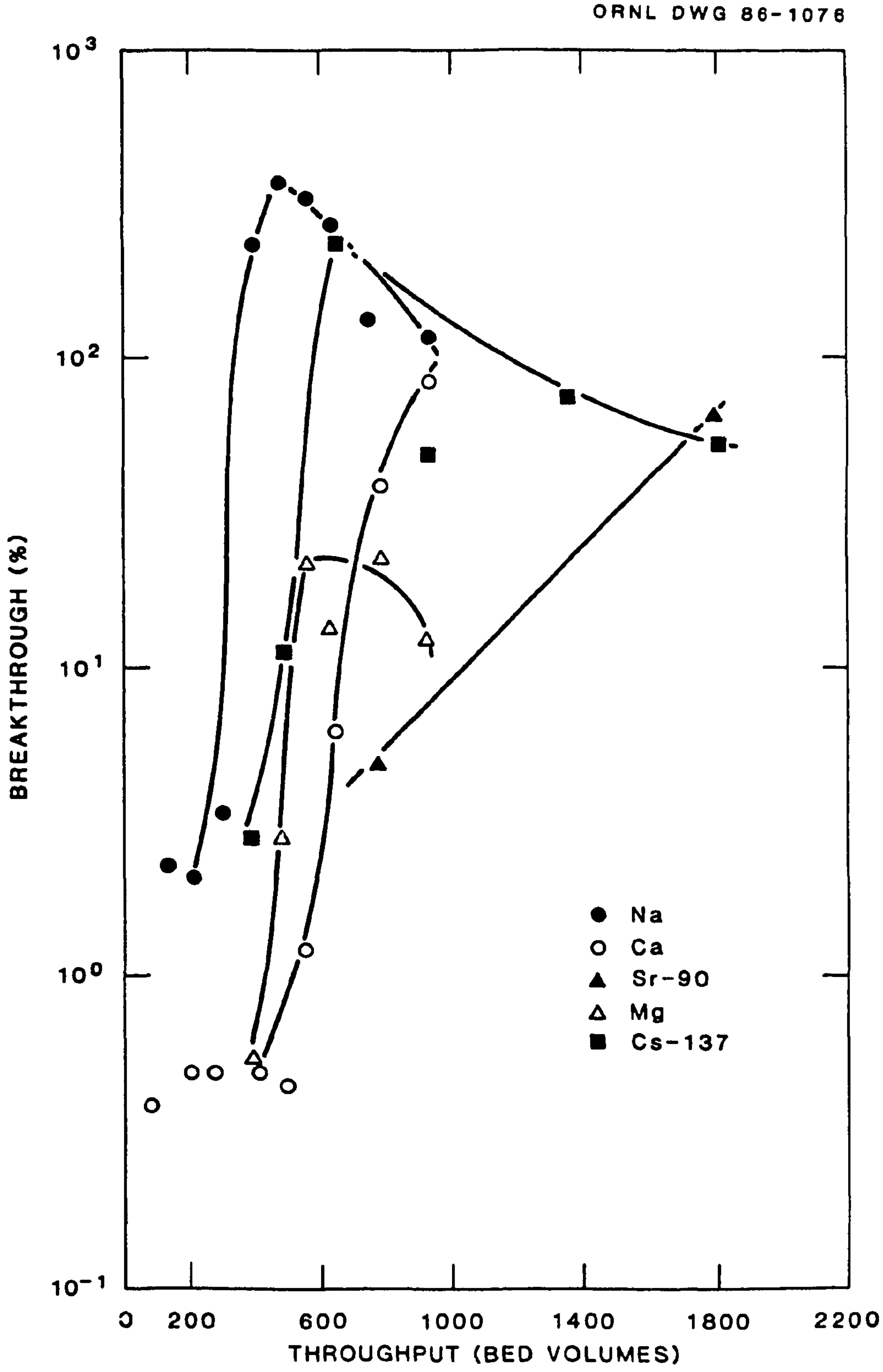

Fig. 23. Breakthrough curves for TG-650-G12 resin.

^{90}Sr is stripped off the resin and precipitated by traditional softening processes. The process produces three types of solid wastes: spent zeolite, resin, and sludge.

Each of the flowsheets is considered to have potential for use in decontaminating process water. Economical analyses and large-scale testing are needed to determine the most efficient flowsheet for use in the PWTP. Such tests for Figs. 18 and 20 are summarized in Sect. 5.

5. LARGE-SCALE TESTING

The flowsheets shown in Figs. 18 and 20 have been tested at the PWTP using pilot- and full-scale equipment. Startup and initial operation of these processes are summarized next.

5.1 STRONG-ACID ION-EXCHANGE FLOWSHEET

The strong-acid flowsheet shown in Fig. 20 has been implemented at full scale using existing equipment from the previous SPIX process. The precipitator, described in Sect. 3, was reinstalled at the head end of the PWTP to soften the feed for the existing IX columns. The sludge removed from the precipitator is dewatered in a plate-and-frame filter press. The remainder of the decontamination process is the same as in the FIX process. A detailed schematic of the treatment process is shown in Fig. 24. This upgrade has reduced the total waste generation from 184 m^3/year of liquid LLW to 122 m^3/year of LLW, of which only 23 m^3/year is liquid waste.

Results obtained during startup and initial operation (March through July 1986) of each unit operation in the process are summarized below. The detailed data are listed in Appendix C.

5.1.1 Reactor/Clarifier

The steel precipitator, manufactured by the Permutit Company, is a sludge-blanket clarifier that consists of a mixing-coagulation zone, a sludge-filter zone, and a clear zone, as shown in Fig. 25. Raw water and chemicals (caustic and ferrous sulfate) enter at the top of the precipitator's mixing coagulation compartment through an inlet trough that distributes the feed along the length of the unit. Polymer is added at the beginning of the inlet trough. Coagulation of the precipitate occurs as the water flows slowly downward into the mixing zone, where an agitator mixes the feed with previously formed sludge. In the lower portion of the mixing zone, the slurry passes under a baffle and flows upward through the sludge blanket and settling chevron to the collector at the top. As the upflow zone expands, the water velocity decreases until the flow cannot support the sludge particles and clear water separates from the sludge. Chevrons have been installed in the upper portion of this zone to allow a maximum flow of 40 m^3/h through the unit. The clarified effluent passes into an outlet flume and out of the unit.

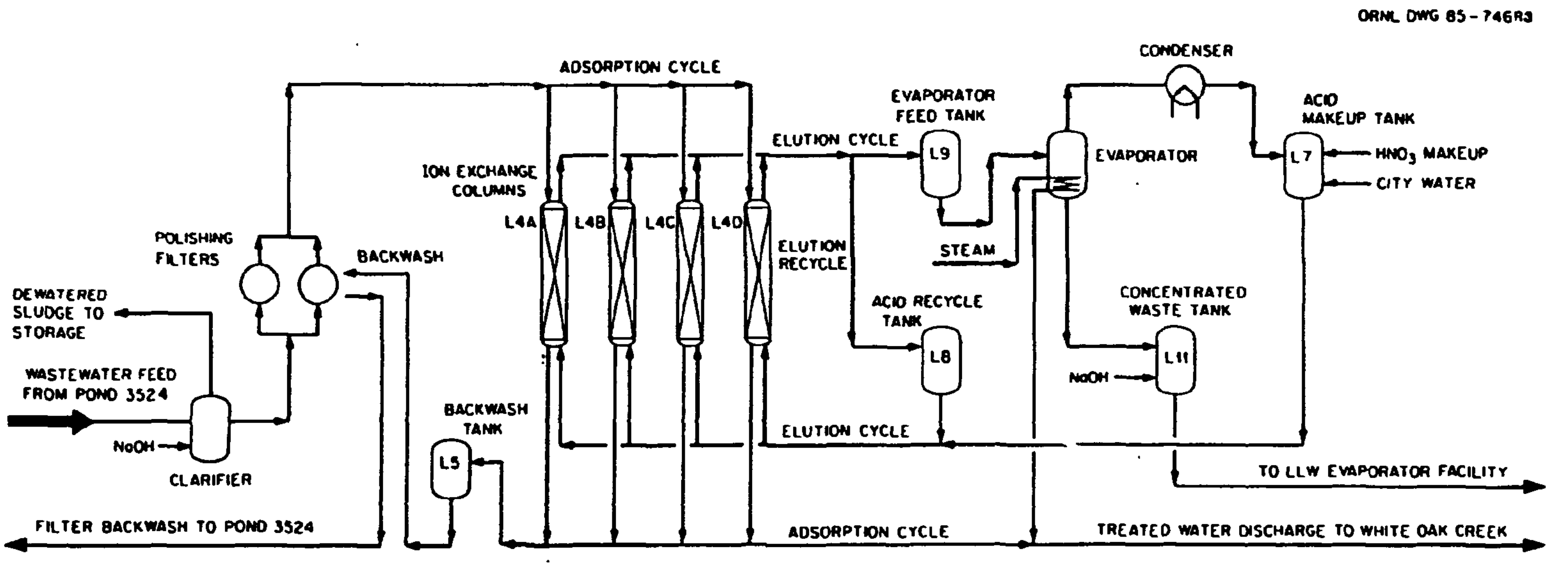

Fig. 24. Schematic of full-scale zeolite/strong-acid resin flowsheet.

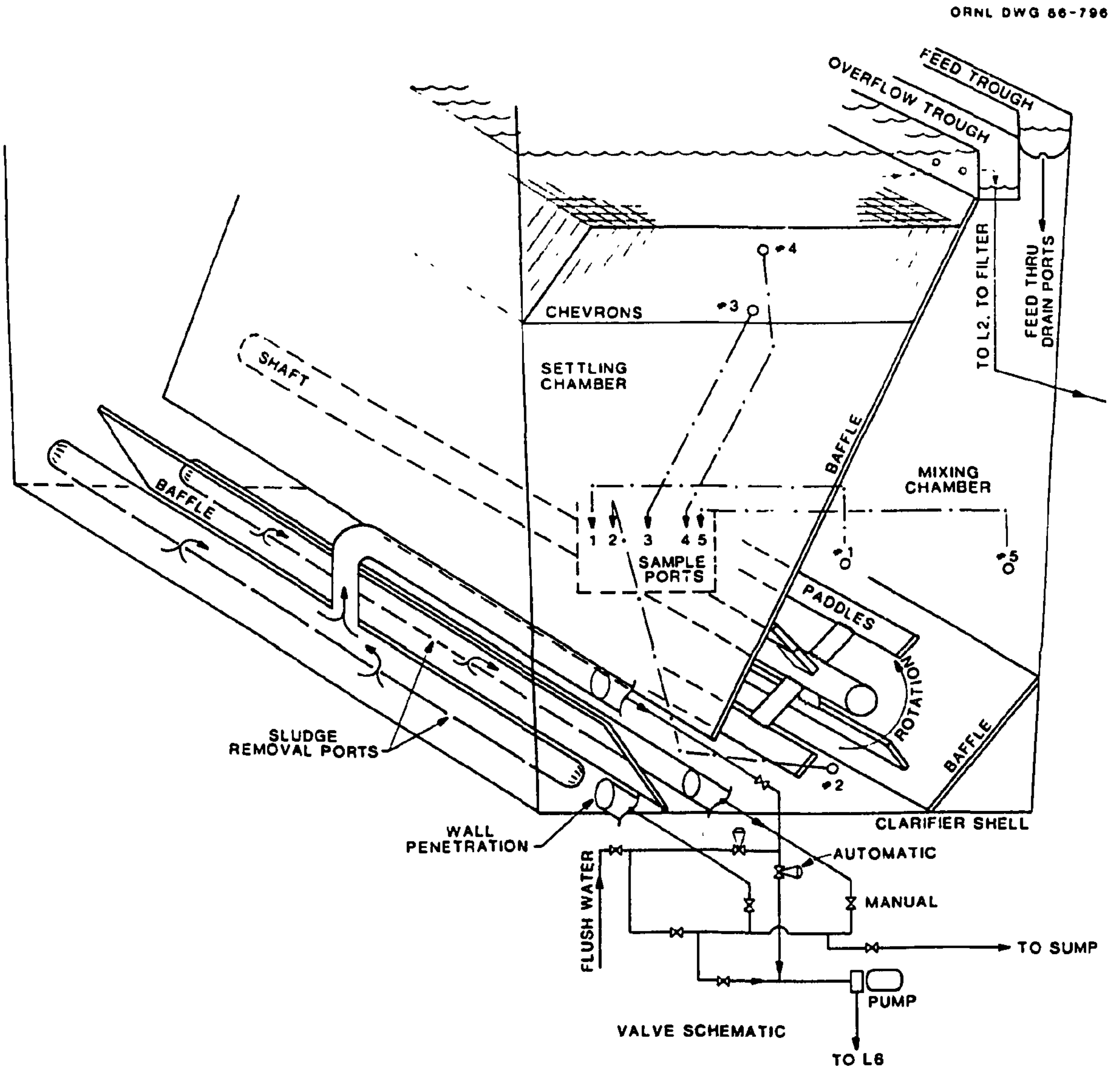

Fig. 25. Schematic of reactor/clarifier installed at the Process Waste Treatment Plant.

Sludge is intermittently withdrawn from the sludge zone through a diaphragm valve that is on a timer and automatically controlled. The discharge line is automatically reverse-flushed after each withdrawal. Heavy sludge can also be removed manually through a port located at the bottom of the mixing zone.

Operation of the reactor/clarifier began in February 1986 using the scavenging-precipitation softening process. The system was operated continuously with a throughput ranging from 17 to 25 m^3/h. The average residence time in the precipitator ranged between 1.1 to 1.7 h. The pH of the clarifier was maintained between 11.3 and 11.8 (average of 11.6), and the effluent had a total hardness of 5 to 10 mg/L (average of 7.3) as $CaCO_3$ after 1 month of operation.

The iron was eliminated from the process after several weeks of operation because of difficulty in maintaining its flow and because its absence generated less sludge. From April 25, 1986, to July 16, 1986, iron was only added to the softening process when the total hardness in the effluent was >10 ppm (~20% of the operating time). The average total hardness was 8.4 mg/L during this period. Furthermore, sludge produced during this period was dense (primarily $CaCO_3$) and accumulated in the bottom of the clarifier. The unit was shut down, the sludge was removed and dewatered, and the system was restarted using the scavenging-precipitation process. Iron was added regularly after July 28, 1986, to eliminate the accumulation of sludge in the clarifier. Although this operational problem was attributed to the change in density and texture of the sludge when iron was eliminated from the feed, excess polymer in the clarifier could also have changed the sludge characteristics.

The results of the full-scale operation agreed with the data from the laboratory-scale tests. Although more calcium and magnesium were removed by the clarifier during full-scale operation than in the jar tests, the trends in softening ability and the characteristics of the resulting sludges were predicted. The full-scale data also confirm that adding of iron improves the softening when contaminants are present in the feed.

Some of the radionuclides are precipitated or otherwise removed during the softening step. Table 12 shows the radionuclide content of the wastewater at different steps in the flowsheet (Fig. 24). These data indicate that the precipitation step removes ~65% of the gross beta, 70% of the ^{90}Sr, and 20% of the ^{137}Cs from the wastewater. The results further show that the clarifier will also remove a significant fraction of the ^{60}Co and ^{152}Eu. An additional 5% of the activity is removed by the anthracite filters before the water is fed to the IX columns.

5.1.2 Filter Press

A J-630-05 model plate-and-frame filter press manufactured by JWI, Inc., was installed to dewater the sludge generated in the softening process. The filter press is equipped with seventeen 630-mm chambers that have a capacity of 0.0085 m^3 per

Table 12. Removal of radionuclides in the softening and filtration steps

Radionuclide[a]	Concentration (Bq/L) Plant feed	Clarifier effluent	Filter effluent	Removal (%) Clarifier	Filter
GB[b]	2900	1100	1000	62	4
^{90}Sr	1900	580	540	70	2
^{137}Cs					
^{152}Eu					
^{60}Co					
GB[c]	3100	1100	850	65	8
^{90}Sr	1800	480	440	73	3
^{137}Cs	382	304	282	20	6
^{152}Eu	38	<10	<10		
^{60}Co	20	<10	<10		
GB[d]					
^{90}Sr					
^{137}Cs	791	570	577	28	0
^{152}Eu					
^{60}Co					

[a]GB = gross beta.
[b]Sample taken on May 21, 1986.
[c]Sample taken on June 6, 1986.
[d]Sample taken on July 30, 1986.

chamber. The capacity of the press can be expanded from 0.144 m^3 to 0.42 m^3 by installing of 33 additional plates. The polypropylene plates, lined with polypropylene filter cloths, are center fed and have a four-corner discharge. The outside edges are gasketed for leak-resistant operation at a maximum feed pressure of 790 kPa. The system is equipped with an air blowdown system to remove excess water and loosen the filter cake at the end of a run. The press is mounted on an elevated platform with a cake discharge hopper installed underneath for automatic discharge to standard 0.2-m^3 (55-gal) drums.

The system is powered by an air-operated diaphragm feed pump. The filter cloth is normally precoated with filter aid to facilitate the cake release from the filter cloth. At startup, a slurry containing 1.4 to 2.3 kg of Celite, a diatomaceous earth material, is fed through the filter press. After the precoat is added, the sludge is fed to the press by an automatic pump-control system. The feed pressure is automatically increased from 0 to 790 kPa in 170-kPa increments. The system is also automatically shut down when the press reaches the maximum feed pressure. (The total operating time is ~1.5 h.) Air is then blown through the corner discharge ports for a minimum of 2 h to remove excess water from the cake. The filter cake is manually removed from the filter cloths using nylon spatulas. The cake is transferred from the collection hopper into standard 0.2-m^3 drums for storage.

Operating data for the filter press from March 1986 through July 1986 are listed in Appendix C, summarized in Table 13, and discussed next. The estimated generation rates are based on the actual waste volumes (measured in number of 0.2-m^3 drums used per volume of wastewater treated) and do not reflect mass or compacted volumes generated.

The filter press was run from March 8, 1986, to March 17, 1986, without filter aid. The sludge generated by the scavenging-precipitation process was voluminous and hard to dewater. The filter cake contained only 20 to 30% solids and had to be scraped off the filter cloth using spatulas. From March 18, 1986, to April 16, 1986, Celite was added as a body feed to the filter press feed (~1 g/L) in an effort to increase dewatering and improve sludge release. The solids content of the sludge increased to 35 to 50%, but the waste generation increased because of the additional Celite. The filter cake was still hard to remove from the filter cloth, so the filter aid was added as a precoat (0.013 to 0.022 g/cm^2) rather than as body feed after April 17, 1986, for both the scavenging-precipitation and caustic sludges. Subsequently, the filter cakes were easier to remove, and the total solids content ranged from 40 to 50%. These data confirmed the results from the laboratory-scale tests when the cakes were air-dried before removal.

The clarifier operated in a steady-state mode from July 28, 1986, to August 7, 1986, using the scavenging-precipitation process. During this time, 1.7 m^3 of sludge was generated per 6050 m^3 of wastewater processed. Based on these values, 85 m^3 (3000 ft^3) of sludge would be generated per year by the scavenging-precipitation process, assuming

Table 13. Filter-press operation

Date	Sludge type[a]	Filter aid	Wastewater generation rate (L/m^3)	Average solid content (%)	Average drum surface reading (mR/h)
March 8 to March 17	SP	None	0.28	26	20
March 18 to April 16	SP	BF	0.34	42	12
April 17 to April 24	SP	PC		37	6
April 25 to July 27	SP-C	PC	0.17	47	6
July 28 to August 7	SP	PC	0.28	38[b]	4[b]

[a]SP = scavenging-precipitation softening process; C = caustic softening process; BF = body feed; and PC = precoat.

[b]Based on data taken from July 28, 1986, to September 1, 1986.

that 0.57 m^3 (150 gal) of wastewater was processed per hour. The solids content of the filter cake was slightly lower than that obtained when Celite was added as a body feed, but the waste generation was lower because less Celite was used.

From April 25, 1986, to July 27, 1986, iron was only added to the softening process when the total hardness in the effluent exceeded 10 ppm as $CaCO_3$ (~20% of the operating time). The total amount of dewatered sludge produced during this period (sludge continuously processed plus that removed from the clarifier during cleanup) was 8.5 m^3 per 50,000 m^3 of water treated. Based on these values, 51 m^3 (1800 ft^3) of sludge would be generated per year. These values are conservative estimates of the volume that would be generated by the caustic and caustic/soda-ash processes. The actual volumes would have been lower if no iron had been present. The processes without iron clearly produce the smallest amount of sludge for disposal.

5.1.3 Ion-Exchange Columns

Before March 1986, the ORNL process wastewater was treated by the FIX treatment method. In the process, one to two 1.37-m^3 columns containing HCR-S resin were operated in parallel to obtain flow rates of 17 to 25 m^3/h. The resin columns were taken off-line when calcium was detected in the effluent because hardness breakthrough occurs immediately before the ^{90}Sr breakthrough. After a throughput of ~400 bv (540 m^3), the columns were regenerated with ~2.7 *M* HNO_3. The eluate was recycled or concentrated by evaporation and transferred to the LLLW treatment system.

The clarifier extended the life of IX columns by eliminating the calcium and magnesium ions, the major ions that compete with the radionuclides for sites on the resin, and by reducing the radionuclide concentration in the feed. After the precipitator/clarifier was installed at the front end of the process, the throughput ranged from 800 to 12,000 bv (see Appendix C). The columns are loaded with ~ 4.4×10^{-10} g of ^{90}Sr per gram of resin at that point.

The average throughput per column of 3260 bv (4380 m^3) requires that each column be regenerated every 5 to 8 d for flow rates from 17 to 25 m^3/h. The improved performance of the columns has reduced the average annual waste generation rate from 184 m^3 of liquid LLW to 23 m^3 of liquid waste and 99 m^3 of solid waste, for a total of 122 m^3 of LLW.

Because the life of the columns has been extended, pressure buildup across the resin beds has become a problem. Backwashing of the columns tends to eliminate the problem, but it also mixes the resin bed. Backwashing can lead to ^{90}Sr leakage through the column even though calcium breakthrough has not occurred. Experimental data indicate that ^{90}Sr leakages as high as 100 Bq/L have occurred after backwashing.

The pressure increase may be caused by postprecipitation from the clarifier or accumulation of polymer on the resin. Polymer buildup could occur if excess polymer were used in the clarifier. The operating procedures and/or equipment design may need modification to ensure maximum resin life.

5.2 CHABAZITE FLOWSHEET

The chabazite flowsheet shown in Fig. 18 is also being tested at pilot and full scales. Skid-mounted equipment has been purchased from the Chem-Nuclear Company to test this flowsheet and to develop techniques for operating a series of reusable columns. The results from these tests are listed in Appendix C and are summarized in Sects. 5.2.1 and 5.2.2.

5.2.1 Full-Scale Units

In December 1985 and January 1986, a significant spike occurred in the concentrations of ^{90}Sr and ^{137}Cs entering the PWTP. During January and February 1986, two throwaway full-scale columns (3.7 m^3 each) containing Ionsiv IE-95 zeolite were operated in series to treat process wastewater with the following concentrations:

Radionuclide	Range (Bq/L)	Average (Bq/L)
^{90}Sr	2400 to 7100	4300
^{137}Cs	318 to 720	500

A total of 6700 m^3 (1810 bv) of process wastewater was treated at a flow rate that gave an average residence time of ~13 min in each column. At the end of the test, the ^{90}Sr effluent concentration from the second column reached 310 Bq/L. No breakthrough was detected for ^{137}Cs at this point. Logarithmic-probability plots of the ^{90}Sr breakthrough curves for both columns are shown in Fig. 26. Based on these data, the K_d for ^{90}Sr is ~1700, compared with 2200 based on laboratory-scale data reported in Sect. 4.1.3.

5.2.2 Pilot-Scale Units

Because the zeolite was not loaded to capacity at shutdown, a more efficient flowsheet for Fig. 19, consisting of a series of four smaller columns, is being tested. The inexpensive natural chabazite, PDZ-300, is being tested at 10% plant scale in 0.57-m^3 columns. During the initial period of operation, the algae growth in the equalization basin

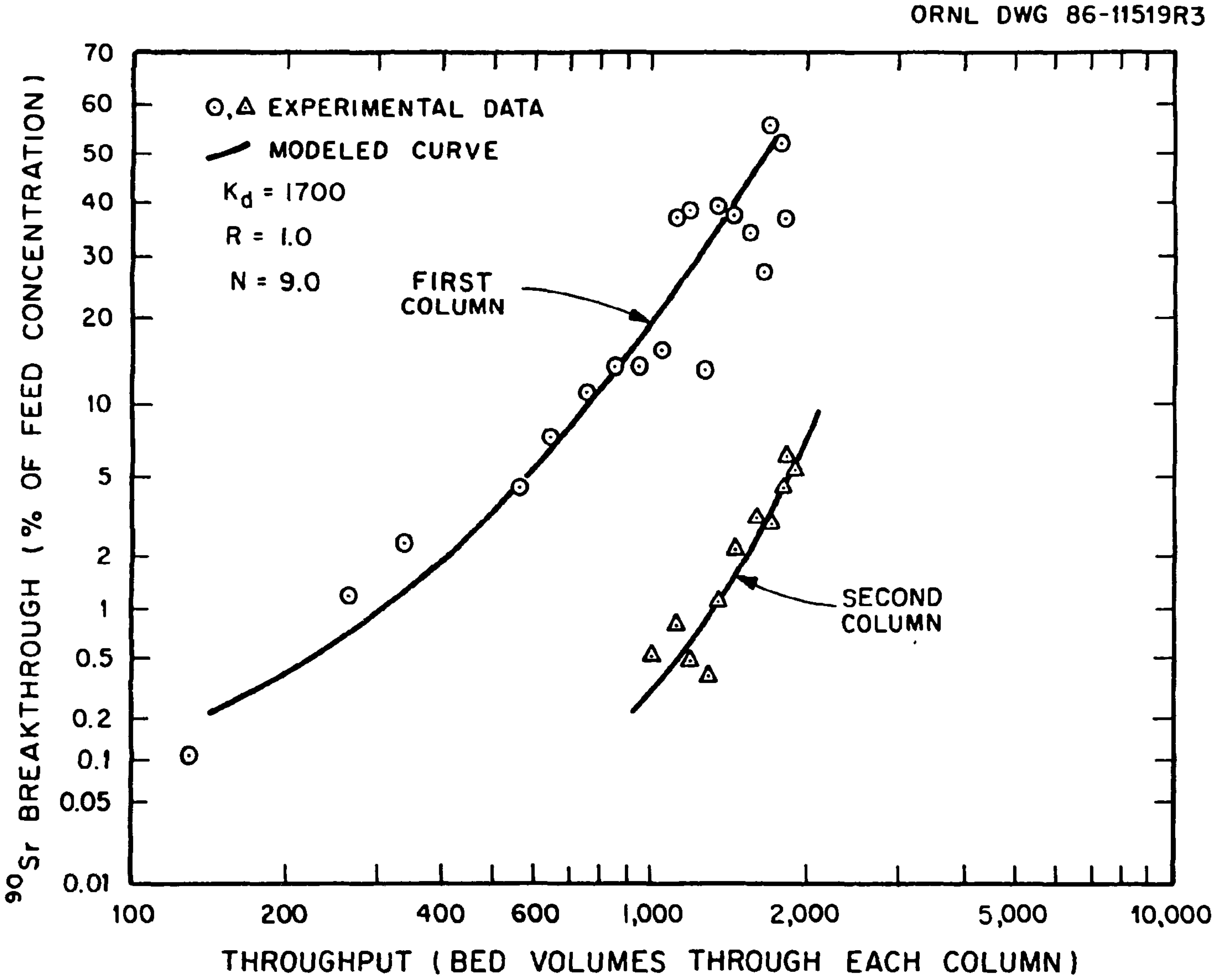

Fig. 26. Strontium breakthrough curve for full-scale columns containing Ionsiv IE-95.

that feeds the PWTP was extremely high. Therefore, one of the 3.7-m^3 Chem Nuclear Company columns (loaded to ~50% capacity for ^{90}Sr) was placed upstream of the PDZ-300 columns to act as a filter. Therefore, part of the radionuclides were removed by the filter as indicated below.

Radionuclide	Feed range (Bq/L)	After filter range (Bq/L)
Gross beta	3100 to 3700	780 to 2700
^{90}Sr	1200 to 2900	690 to 2100
^{137}Cs	380 to 460	<10

The nominal flow rate through the four units in series is 15 gal/min, which gives the wastewater 10 min of residence time in each column.

The first zeolite column reached the 50% breakthrough point after ~6500 bv had been processed. At that point, the second unit was at ~5% breakthrough, and the third and fourth units were both well below 1% breakthrough. The columns were shut down after processing 8200 bv of wastewater because algae had partially plugged the first PDZ-300 unit. This column was emptied and refilled with fresh material. Less than 2% of the used zeolite was left in the vessel after sluicing. The used material read 10 mR/h at the surface of a plastic container. The zeolite was loaded with 43 Bq/L of ^{152}Eu and 26 Bq/L of ^{137}Cs. The gross alpha reading was <4 Bq/g, whereas the gross beta was 36,800 Bq/g. The system will be restarted when the zeolite filter can be replaced with a new sand filter.

The performance of the system with PDZ-300 (^{90}Sr distribution coefficient of 6500) is much better than that obtained with IE-95, and the results are better than the predicted values based on laboratory-scale data. This finding may be caused by slower diffusion through the natural material and indicates that equilibrium may not have been reached in the small-scale column tests using PDZ-300. It may also have been caused by the lower ^{90}Sr feed concentration (~3000 vs 1000 Bq/L).

6. CONCLUSIONS AND RECOMMENDATIONS

Improved treatment processes are being developed at ORNL to treat slightly contaminated process wastewater. Laboratory-scale tests have determined that a number of zeolites are excellent sorption materials (with distribution coefficients up to 23,000) for ^{137}Cs from unsoftened process water. Chabazites have the best sorption capacity for ^{90}Sr under the same conditions, but the reaction kinetics are relatively slow. Treatment with chabazites alone would require the use of a number of columns operated in series. Several materials are good sorbents for ^{90}Sr when the feed has been softened to remove calcium and magnesium ions. For example, clinoptilolites and weak-acid resins have loading capacities of 10,000 to 25,000 bv.

Two softening processes have been found that reduce the calcium and magnesium ion concentrations (the major ions that compete with the radionuclides for adsorption sites on IX materials) in the feed from ~50 and 10 mg/L, respectively, to <5 mg/L each. The caustic/soda-ash process has the advantage of minimizing the sodium concentration in the softened water, which is easily dewatered. Thus, the major advantage of the scavenging-precipitation process is its ability to accommodate fluctuations in the feed stream more easily.

Five flowsheets have been developed for potential upgrade of the PWTP based on these results. Two of these, the chabazite and the strong-acid flowsheets, have been successfully tested on pilot or full scales. The remaining flowsheets should be tested on a pilot scale. Economic evaluations should be made for each flowsheet to assess the impact of a plant upgrade. Development studies are needed to determine packaging processes of the spent sorbents for permanent disposal. Potential treatment processes include heat treatment and solidification. The zeolites are a nonhazardous aluminosilicate clay that can possibly be heat-treated to reduce the volume by a factor of ~2 and to reduce the leachability of the ^{90}Sr and ^{137}Cs.[18] The sludge can easily be solidified in concrete for disposal.[19] Economic analyses, additional pilot-scale testing of the flowsheets, and postprocessing will be addressed in the next phases of this project.

Improvements made at the PWTP based on these tests have already reduced the LLW generated by treatment of process wastewater to 66% of the original volume. Proposed processing methods could eliminate all LLLW and reduce the solid waste by an additional one-third.

7. ACKNOWLEDGMENTS

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8. NOMENCLATURE

C = concentration of solute in effluent, g-mol/cm^3
C_o = concentration of solute in feed, g-mol/cm^3
f = flow rate through column, cm^3/s
K_a = mass transfer coefficient, 1/s
K_d = distribution coefficient, dimensionless
K'_d = distribution coefficient, cm^3/g
N = number of mass transfer units, dimensionless
q = concentration of solute in solid, g-mol/g
q^* = concentration of solute in solid at equilibrium, g-mol/g
q_v = concentration of solute per unit volume of sorbent bed, g-mol/cm^3
R = separation factor, dimensionless
T = throughput parameter, dimensionless
V = effluent volume, cm^3
v = sorbent bed volume, cm^3
X = concentration of solute in fluid phase, dimensionless
Y = concentration of solute in solid phase, dimensionless

Greek Letter

ρ_b = bulk density of sorbent, g/cm^3

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APPENDIX A

RESULTS OF JAR TESTS

APPENDIX A

RESULTS OF JAR TESTS

The experimental data obtained from laboratory-scale water- softening tests are given in Tables 14-20. The composition of the unsoftened feed from the PWTP is listed in Table 14. Tables 15-18 contain the results of jar tests using each softening process. After these tests were completed, a contaminant entered the PWTP feed stream, inhibiting softening. Table 19 contains the results of jar tests used to determine ways of overcoming the inhibitor, and Table 20 summarizes the results of tests run to determine its source. The data include the chemical requirements, the type of spike used to nucleate precipitation, reaction time, precipitant volume, pH, and chemical analyses. The types of nucleating materials used to seed these jar tests include sludge generated from a previous test and $CaCO_3$ prepared by reacting lime and soda ash. Tests made before February 7, 1986, were probably spiked with $CaCO_3$ containing bicarbonate. This fact should not have affected most tests because small quantities were used (~400 mg/L). Effects of bicarbonate were noted in Runs 35 and 36, listed in Table 19, when larger amounts of the seed slurry were used. In subsequent tests, this problem was eliminated by washing the slurry with distilled water before precipitation.

Table 14. Feed samples for water-softening jar tests

Sample No.	Date (1985)	Water hardness (mg/L $CaCO_3$)[a]			ICP[b] analyses (mg/L)			Alkalinity (mg/L $CaCO_3$)	
		pH	Ca	Total	Ca	Mg	Na	Carbonate	Total
1-6	10/14	9.1	116	139				27	129
7-4	10/16	9.1	102	148				10	127
4-7	10/17	8.5	117	140					
5-7	10/18	8.5	107	141					
10-1	10/24	8.2	113	157					
11-7	10/25	7.8	125	162					
14-7	11/04	8.5	156	173	50	11	13		
17-5	11/07	8.5	126	162	50	10	20		
22-7	11/15	8.7	45	171	47	11	20		

[a]Number of milligrams of $CaCO_3$ per liter.
[b]Inductively coupled plasma spectrometry.

Table 15. Water-softening

Sample No.	Date (1985)	Chemical requirements (mg/L wastewater) Na_2CO_3	NaCH	$Ca(OH)_2$	Alum	Fe^{3+}	Polymer	Polymer Type	Spike	Reaction time (min)	Floc volume (mL/0.8 L W
10-5	10/24			138						20	1
10-6	10/24			238						20	2.2
13-6	11/01			938						80	10.0
1-1	10/14	125								20	NM[a]
1-2	10/14	188								20	NM[a]
1-3	10/14	250								20	NM[a]
1-4	10/14	375								20	NM[a]
1-5	10/14	500								20	NM[a]
22-1	11/15		450				0.1	Betz 1100		80	2.2
21-3	11/13		450				0.3	Betz 1100		80	3.0
21-4	11/13		450				0.6	Betz 1100		80	2.5
14-6	11/04		750							20	11.5
13-1	11/01		900						Sludge	80	4.5

[a]Not measureable.

jar tests using individual chemicals

Final pH	Water hardness (mg/L $CaCO_3$) Unfiltered Ca	Unfiltered Total	Filtered Ca	Filtered Total	ICP analyses (mg/L) Unfiltered Ca	Unfiltered Mg	Unfiltered Na	Filtered Ca	Filtered Mg	Filtered Na	Alkalinity (mg/L $CaCO_3$) Carbonate	Total	Comments
10.5	53												
11.0	90												
12.0	344		471	548	260		15	240		15			
9.6													Solids did not filter out
9.9													Solids did not filter out
10.3	72										93	317	
10.2			33								102	369	
10.4			30								146	464	
12.0	8	18			4	1	260	1		260			
11.9	12	14			5		260	3		260			
11.9	14	16			5		250	4		250			
12.0	19	25	12	22	9	1	350	6		340			
12.0	4	42	2	12	3	2	470	1		470			

Table 16. Lime/soda-a

Sample No.	Date (1985)	Chemical requirements (mg/L watewater)						Polymer type	Spike	Reaction time (min)
		Na_2CO_3	NaOH	$Ca(OH)_2$	Alum	Fe^{3+}	Polymer			
2-1	10/15	125		106						20
2-3	10/15	188		75						20
4-4	10/17	188		169		5				20
4-5	10/17	188		188		10				20
4-6	10/17	188		263		30				20
14-1	11/04	188		131	5					20
4-1	10/17	188		131	5					20
4-2	10/17	188		144	10					20
4-3	10/17	188		175	30					20
2-5	10/15	250		88						20
2-2	10/15	125		156						20
2-4	10/15	188		125						20
14-2	11/04	188		413	5					20
2-6	10/15	250		225						20
13-4	11/01	188		188	5				$CaCO_3$	80
13-3	11/01	188		188	5					80
21-5	11/13	188		100	5		0.3	Betz 1100		80
21-6	11/13	188		113	5		0.6	Betz 1100		80
22-2	11/15	188		125	5		0.8	Betz 1100		80
20-3	11/12	188		94	5		1.0	Betz 1100		80
20-4	11/12	188		106			1.0	Betz 1100		80
17-1	11/07	188		350	5		1.0	Betz 1100		80
17-2	11/07	188		344	5		1.0	Purifloc A23		80
17-3	11/07	188		338	5		1.0	Percol 757		80
17-4	11/07	188		344	5		1.0	Percol 758		80

-ash water-softening jar tests

on	Floc volume	Final	Water hardness ($mg/L\ CaCO_3$)				ICP analyses (mg/L)						Alkalinity ($mg/L\ CaCO_3$)	
			Unfiltered		Filtered		Unfiltered			Filtered				
	($mL/0.8\ L\ H_2O$)	pH	Ca	Total	Ca	Total	Ca	Mg	Na	Ca	Mg	Na	Carbonate	Total
	0.6	10.4	19										56	152
	0.5	10.5	14										81	209
	4.8	10.6	10		10									
	5.0	10.5	10		8									
	12.0	10.6	8		8									
	1.9	10.5	28	57	14	47	6	7	100	5	7	100		
	2.0	10.5	20		18									
	2.3	10.5	17		14									
	3.0	10.5	5		6									
	0.6	10.6	12										100	253
	2.6	11.2	24										92	142
	2.0	11.2	20										131	196
	7.0	11.5	24	40	21	28	11	1	99	9	0	100		
	1.8	11.2	17										131	252
	6.5	10.8	4	30	5	17	3	3	203	1	3	190		
	2.0	10.6	11	36	9	39	4	7	96	4	7	90		
		10.4	13	56			8	8	98	5	8	92		
		10.3	15	60			8	8	95	5	8	90		
	2.5	10.8	16	22			5	6	90	5	6	88		
	1.2	10.5	18	56			8	8	92	6	2	120		
	0.5	10.3	16	66			11	9	91	6	8	110		
	4.5	11.5	32	34			11	1	95	12	1	140		
	7.0	11.5	25	28			9	1	96	9	1	110		
	8.0	11.5	17	22			9	1	92	9	1	170		
	8.0	11.5	28	30			12	1	92	10	0	94		

Table 17. Caustic/soda

Sample No.	Date (1985)	Chemical requirements (mg/L watewater)						Polymer type	Spike	Reaction time (min)
		Na_2CO_3	NaOH	$Ca(OH)_2$	Alum	Fe^{3+}	Polymer			
3-1	10/16	125	340						$CaCo_3$	20
3-3	10/16	188	33							20
3-5	10/16	250	31							20
5-5	10/18	250	172						$CaCO_3$	20
14-3	11/04	250	109		5					20
5-1	10/18	250	165		5					20
5-2	10/18	250	180		10					20
5-3	10/18	250	180			5				20
5-4	10/18	250	187			10				20
3-2	10/16	125	100							20
3-4	10/16	188	100							20
3-6	10/16	250	87							20
14-4	11/04	250	265							20
7-2	10/16	525	200			5				20
7-3	10/16	525	400			5				20
23-5	12/09	63	70				0.6	Betz 1100	$CaCO_3$	80
23-6	12/09	63	65				0.8	Betz 1100	$CaCO_3$	80
23-3	12/09	94	65				0.6	Betz 1100	$CaCO_3$	80
23-4	12/09	94	65				0.8	Betz 1100	$CaCO_3$	80
19-1	11/11	125	60						$CaCO_3$	80
22-5	11/15	125	55				0.3	Betz 1100	$CaCO_3$	80
22-6	11/15	125	55				0.6	Betz 1100	$CaCO_3$	80
23-2	12/09	125	60				0.8	Betz 1100	$CaCO_3$	80
19-2	11/11	188	55						$CaCO_3$	80
5-6	10/18	250	173							60
13-5	11/01	250	50						$CaCO_3$	80
22-3	11/15	250	40				0.3	Betz 1100	$CaCO_3$	80
22-4	11/15	250	40				0.6	Betz 1100	$CaCO_3$	80
23-1	12/09	250	38				0.8	Betz 1100	$CaCO_3$	80
20-1	11/12	250	65			5	1.0	Betz 1100		80
20-2	11/12	250	65			5	1.0	Purifloc A23		80
19-6	11/11	250	55			5	1.0	Percol 720		80
19-5	11/11	250	55			5	1.0	Percol 726		80
19-4	11/11	250	55			5	1.0	Percol 728		80
19-3	11/11	250	55			5	1.0	Percol 757		80

[a]Not measureable.

Soda-ash water-softening jar tests

…ation time (…in)	Floc volume (mL/0.8 L H_2O)	Final pH	Water hardness (mg/L $CaCO_3$) Unfiltered Ca	Water hardness Unfiltered Total	Water hardness Filtered Ca	Water hardness Filtered Total	ICP analyses (mg/L) Unfiltered Ca	ICP Unfiltered Mg	ICP Unfiltered Na	ICP Filtered Ca	ICP Filtered Mg	ICP Filtered Na	Alkalinity (mg/L $CaCO_3$) Carbonate	Alkalinity Total
20	NM[a]	10.4	113										105	268
20	NM[a]	10.5	84										112	318
20	NM[a]	10.5	44										120	319
[illegible]	2.5	10.5	14		13									
[illegible]	1.4	10.4	33	71	30	71	13	9	150	13	9	160		
20	5.5	10.4	28		30									
20	10.0	10.4	22		23									
20	5.5	10.4	20		23									
20	8.0	10.4	16		13									
20	NM[a]	11.0	82										146	321
20	NM[a]	11.0	64										182	355
20	NM[a]	11.0	54										175	388
20	8.2	11.5	10	16	7	19	4	1	240	4	1	230		
20	11.5	11.5	19										361	672
20	7.5	11.9	8										565	893
80	1.0	9.6	17	61										
80	1.0	9.6	17	63										
80	1.0	9.8	12	58										
80	0.9	9.8	14	61										
80	NM[a]	10.4	39	50	12		11	8	280	3	9	320		
80		10.5	6	53			5	8	450	2	8	500		
80		10.5	6	49			4	8	450	2	8	520		
80	1.0	9.9	14	58										
80	NM[a]	10.5	10	51			4	8	290	3	9	310		
60	1.8	10.5	30		34									
80	7.0	10.6	4	33	4	22	5	4	270	1	4	260		
80	2.4	10.5	7	43			3	8	490	2	8	520		
80	2.0	10.5	8	47			3	8	490	2	8	520		
80	0.9	10.2	16	66										
80	1.4	10.5	27	66			10	8	150	10	8	150		
80	1.3	10.4	19	56			7	8	150	7	8	180		
80	1.5	10.4	25	60			9	9	150	10	9	160		
80	1.4	10.4	21	62			9	9	150	9	9	160		
80	0.8	10.4	24	58			9	9	150	10	9	150		
80		10.4	18	54			6	9	150	6	9	160		

Table 18. Scavenging-preci

Sample No.	Date (1985)	Chemical requirements (mg/L watewater)						Polymer type	Spike	Reaction time (min)	Floc volume (mL/0.8 L H_2O)	F
		Na_2CO_3	NaOH	$Ca(OH)_2$	Alum	Fe^{3+}	Polymer					
10-4	10/24		100			5			$CaCO_3$	20	1.9	1
10-3	10/24		400			5			Sludge	20	10.0	1
10-2	10/24		400			5			$CaCO_3$	20	4.2	1
7-1	10/16		400			5				20	10.5	1
11-1	10/25		1000			5				20	13.0	1
11-2	10/25		1000			5				35	10.0	1
11-3	10/25		1000			5				50	8.5	1
11-4	10/25		1000			5				65	7.5	1
13-2	11/01		800			5			Sludge	80	12.0	1
11-6	10/25		1000			5				95	8.0	1
11-5	10/25		1000			5				80	7.0	1
15-1	11/05		700			5	1.0	Betz 110		80	5.5	1
16-1	11/06		700			5	3.0	Betz 110		80	5.0	1
21-1	11/13		500			5	0.3	Betz 1100		80	5.0	1
21-2	11/13		450			5	0.6	Betz 1100		80	2.5	1
15-2	11/05		700			5	1.0	Purifloc A23		80	5.5	1
16-2	11/06		700			5	3.0	Purifloc A23		80	7.0	1
15-6	11/05		700			5	1.0	Percol 720		80	6.0	1
15-5	11/05		700			5	1.0	Percol 726		80	7.5	1
15-4	11/05		700			5	1.0	Percol 728		80	6.0	1
16-4	11/06		700			5	3.0	Percol 728		80	7.0	1
15-3	11/05		700			5	1.0	Percol 757		80	7.0	1
16-3	11/06		700			5	3.0	Percol 757		80	7.0	[illegible]

recipitation water-softening jar tests

		Water hardness (mg/L $CaCO_3$)				ICP analyses (mg/L)						Alkalinity (mg/L $CaCO_3$)		
	Final	Unfiltered		Filtered		Unfiltered			Filtered					
)	pH	Ca	Total	Ca	Total	Ca	Mg	Na	Ca	Mg	Na	Carbonate	Total	Comments
	10.3	48												
	11.6	10												
	11.6	12												
	12.0	43										399	925	
	12.1	32	45											Kinetics test
	12.0	18	25											
	12.1	19	32											
	12.0	13	26											
	12.0	4	26	2	10	3	1	450	2	0	550			
	12.0	10	29											
	12.0	11	39											
	12.0	5	11	3	11	2	0	390	2	0	390			
	12.0	13	26			9	0	400	9	0	450			Clumps clung to equipment sides
	11.9	10	10			3	0	300	2	0	290			
	11.9	10	13			4	0	260	4	0	260			
	11.9	5	17	3	9	2	1	380	2	0	390			
	12.0	15	25			9	0	410	9	0	470			Clumps clung to equipment sides
	12.0	3	17	3	7	2	0	400	2	0	390			
	12.0	3	11	3	9	3	1	390	2	0	390			
	12.0	2	17	1	9	3	0	390	2	0	400			
	12.0	8	21			8	0	420	7	0	420			Clumps clung to equipment sides
	11.9	3	17	3	9	4	1	370	1	0	360			Clumps clung to equipment sides
	11.9	6	15			5	0	420	5	0	420			Clumps clung to equipment sides

Table 19. Jar tests to im

Sample No.	Date (1986)	Chemical requirements (mg/L wastewater)					Spike
		Na_2CO_3	Fe^{3+}	Polymer	Type	NaOH to pH	
25-1	1/17	250	0	0.8	Betz 1100	10.6	[illegible]
25-2	1/17	125	0	0.8	Betz 1100	10.6	
25-3	1/17	94	0	0.8	Betz 1100	10.5	[illegible]
25-4	1/17	94	0	0.0		10.5	Sludge
25-5	1/17		5	0.3	Betz 1100	12.1	Sludge
25-6	1/17		5	0.0		12.2	Sludge
25-7	1/17		0	0.0		10.5	
27-1	1/20	125	0	0.8	Betz 1100	12.0	
27-2	1/20	94	0	0.8	Betz 1100	12.0	
27-3	1/20	94	0	0.0		12.0	
27-4	1/20		5	0.3	Betz 1100	12.0	
27-5	1/20		5	0.0		12.0	
27-5	1/20		0	0.3	Betz 1100	12.0	
29-1	1/22	250	0	0.0		10.5	Sludge
29-2	1/22	125	0	0.0		10.5	Sludge
29-3	1/22	94	0	0.0		10.5	Sludge
29-4	1/22		0	0.0		12.0	Sludge
32-1	1/27	250	0	0.8	Betz 1100	10.5	Sludge + $CaCO_3$
32-2	1/27	94	0	0.8	Betz 1100	10.5	Sludge + $CaCO_3$
32-3	1/27		5	0.3	Betz 1100	12.0	Sludge + $CaCO_3$
33-1	1/29	250	0	0.8	Betz 1100	10.5	
33-2	1/29	94	0	0.8	Betz 1100	10.8	
33-3	1/29		5	0.3	Betz 1100	12.0	
33-4	1/29	250	0	0.8	Betz 1100	10.8	
33-5	1/29	94	0	0.8	Betz 1100	11.0	
33-6	1/29		5	0.3	Betz 1100	11.1	
33-7	1/29	250	0	0.8	Betz 1100	10.5	
33-8	1/29	94	0	0.8	Betz 1100	10.5	
33-9	1/29		5	0.3	Betz 1100	12.0	
33-10	1/29		0	0.3	Betz 1100	12.0	
33-11	1/29		0	0.0			
33-12	1/29		0	0.0			
34-1	1/30	250	0	0.8	Betz 1100	10.5	Sludge
34-2	1/30	94	0	0.8	Betz 1100	10.5	Sludge
34-3	1/30		5	0.3	Betz 1100	12.0	Sludge
34-4	1/30	250	0	0.8	Betz 1100	10.5	Sludge
34-5	1/30	94	0	0.8	Betz 1100	10.5	Sludge
[illegible]-6	1/30		5	0.3	Betz 1100	12.0	Sludge
[illegible]	1/30	250	0	0.8	Betz 1100	10.5	Sludge
34-8	1/30	94	0	0.8	Betz 1100	10.5	Sludge
34-9	1/30		5	0.3	Betz 1100	12.0	Sludge
34-10	1/30		0	0.3	Betz 1100	12.0	Sludge
35-1	1/30	94	0	0.8	Betz 1100	10.5	2000 mg/L CaC
35-2	1/30	94	0	0.8	Betz 1100	10.5	400 mg/L CaCO
35-3	1/30	94	0	0.8	Betz 1100	10.5	20 mg/L $CaCO_3$
35-4	1/30		0	0.3	Betz 1100	12.0	2000 mg/L CaC
35-5	1/30		0	0.3	Betz 1100	12.0	400 mg/L CaCO
35-6	1/30		0	0.3	Betz 1100	12.0	20 mg/L $CaCO_3$
36-1	1/31		0	0.3	Betz 1100	12.3	40 mg/L $CaCO_3$

... improve softening of contaminated water

	Reaction Time		[illegible]	[illegible]	Total 2)	Comments
	80	95		108	136	1/13 PWPT feed + 0.6 ppm detergent
	80	94				1/13 PWTP feed + 0.6 ppm detergent
	80	95				1/13 PWTP feed + 0.6 ppm detergent
	80	95				1/13 PWTP feed + 0.6 ppm detergent
	80	89				1/13 PWTP feed + 0.6 ppm detergent
	80					1/13 PWTP feed + 0.6 ppm detergent
	80	95				Blank
	320	39				1/20 PWTP feed
	320	41				1/20 PWTP feed
	320	35				1/20 PWTP feed
	320	16				1/20 PWTP feed
	320	16				1/20 PWTP feed
	320	35				1/20 PWTP feed
	60	97				PWTP feed + 3 ppm decolorizing powder
	60	79				PWTP feed + 3 ppm decolorizing powder
	60	81				PWTP feed + 3 ppm decolorizing powder
	60	51				PWTP feed + 3 ppm decolorizing powder
$CaCO_3$	60	74				PWTP feed
$CaCO_3$	60	77				PWTP feed
$CaCO_3$	60	22				PWTP feed
	20	8				Synthetic water
	20	15				Synthetic water
	20	13				Synthetic water
	20	13				Synthetic water + 1.25 ppm KNOX60 detergent
	20	30				Synthetic water + 1.25 ppm KNOX60 detergent
	20	18				Synthetic water + 1.25 ppm KNOX60 detergent
	20	77				PWTP feed
	20	99				PWTP feed
	20	36				PWTP feed
	20	14				PWTP feed
	20	67				Synthetic water blank
	20	96				PWTP feed blank
	20	11				Synthetic water
	20	18				Synthetic water
	20	5				Synthetic water
	20	16				Synthetic water + 1.25 ppm KNOX60 detergent
	20	31				Synthetic water + 1.25 ppm KNOX60 detergent
	20	17				Synthetic water + 1.25 ppm KNOX60 detergent
	20	56				PWTP feed
	20	114				PWTP feed
	20	15				PWTP feed
	20	45				PWTP feed
$CaCO_3$	60	26				$CaCO_3$ contained HCO_3
aCO_3	60	14				$CaCO_3$ contained HCO_3
CO_3	60	34				$CaCO_3$ contained HCO_3
$CaCO_3$	60	44				$CaCO_3$ contained HCO_3
aCO_3	60	13				$CaCO_3$ contained HCO_3
CO_3	60	30				$CaCO_3$ contained HCO_3
CO_3	80	18				$CaCO_3$ contained HCO_3, pH probe changed

Table 1

R

Sample No.	Date (1986)	Chemical requirements (mg/L wastewater)					Spike
		Na_2CO_3	Fe^{3+}	Polymer	Type	NaOH to pH	
36-2	1/31		0	0.3	Betz 1100	12.3	80 mg/L $CaCO_3$
36-3	1/31		0	0.3	Betz 1100	12.3	200 mg/L $CaCO_3$
36-4	1/31		0	0.3	Betz 1100	12.3	800 mg/L $CaCO_3$
36-5	1/31		0	0.3	Betz 1100	12.3	1200 mg/L $CaCO_3$
36-6	1/31		0	0.3	Betz 1100	12.4	1600 mg/L $CaCO_3$
35-1	1/30	94	0	0.8	Betz 1100	10.5	2000 mg/L $CaCO_3$
35-2	1/30	94	0	0.8	Betz 1100	10.5	400 mg/L $CaCO_3$
35-3	1/30	94	0	0.8	Betz 1100	10.5	20 mg/L $CaCO_3$
35-4	1/30		0	0.3	Betz 1100	12.0	2000 mg/L $CaCO_3$
35-5	1/30		0	0.3	Betz 1100	12.0	400 mg/L $CaCO_3$
35-6	1/30		0	0.3	Betz 1100	12.0	20 mg/L $CaCO_3$
38-1	2/07		5	0.3	Betz 1100	11.9	
38-2	2/07	425	5	0.3	Betz 1100	11.9	
38-3	2/07	1063	5	0.3	Betz 1100	11.7	
38-4	2/07	425	5	0.3	Betz 1100	11.9	800 mg/L $CaCO_3$
38-5	2/07	1063	5	0.3	Betz 1100	11.9	800 mg/L $CaCO_3$
38-6	2/07		2	0.2	Betz 1100	11.8	
38-7	2/07		0	0.0		8.8	
39-1	2/11		5	0.3	Betz 1100	11.8	
39-2	2/11		5	0.3	Betz 1100	11.8	
39-3	2/11		5	0.3	Betz 1100	11.8	
39-4	2/11		5	0.3	Betz 1100	11.9	
39-5	2/11		0	0.3	Betz 1100	11.8	
39-6	2/11		0	0.3	Betz 1100	11.9	

ɔle 19. (continued)

Reaction time (min)	Water hardness (mg/L $CaCO_3$)		Alkalinity (mg/L $CaCO_3$)		Comments
	Ca	Total	Carbonate	Total	
80	16				$CaCO_3$ contained HCO_3
80	13				$CaCO_3$ contained HCO_3
80	15				$CaCO_3$ contained HCO_3
80	10				$CaCO_3$ contained HCO_3
80	12				$CaCO_3$ contained HCO_3
60		57			$CaCO_3$ did not contain HCO_3
60		98			$CaCO_3$ did not contain HCO_3
60		93			$CaCO_3$ did not contain HCO_3
60		24			$CaCO_3$ did not contain HCO_3
60		35			$CaCO_3$ did not contain HCO_3
60		47			$CaCO_3$ did not contain HCO_3
80		78			2/07 PWTP feed
80		47			2/07 PWTP feed
80		47			2/07 PWTP feed
80		20			2/07 PWTP feed
80		14			2/07 PWTP feed
80		93			2/07 PWTP feed
80		150			Blank
80	8				Synthetic water
80	5				Synthetic water containing 0.01 vol % sewage
80	5				Synthetic water containing 0.06 vol % sewage
80	5				Synthetic water containing 0.001 vol % sewage
80	7				Synthetic water containing 0.001 vol % sewage
80	7				Synthetic water containing 0.06 vol % sewage

Table 20.

Sample No.	Date (1986)	Chemical requirements (mg/L wastewater)				
		Na_2CO_3	Fe^{3+}	Polymer	Agent	NaOH to pH
40-1	2/14		5	0.3	Betz 1100	11.9
40-2	2/14	1063	5	0.3	Betz 1100	11.9
40-3	2/14	94		0.8	Betz 1100	10.7
40-4	2/14		5	0.3	Betz 1100	11.9
40-5	2/14	1063	5	0.3	Betz 1100	11.8
40-6	2/14	94		0.8	Betz 1100	10.7
40-7	2/14					9.1
40-8	2/14					8.3
41-1	2/28					9.1
41-2	2/28					9.1
42-1	3/04		5	0.3	Betz 1100	11.7
42-2	3/04		5	0.3	Betz 1100	11.8
42-3	3/04		5	0.3	Betz 1100	11.9
42-4	3/04		5	0.3	Betz 1100	11.9
42-5	3/04		5	0.3	Betz 1100	11.8
42-6	3/04		5	0.3	Betz 1100	11.8
43-1	3/04		5	0.3	Betz 1100	11.7
43-2	3/04		5	0.3	Betz 1100	11.8
43-3	3/04		19	0.3	Betz 1100	11.9
43-4	3/04		5	0.3	Betz 1100	11.9
43-5	3/04			0.3	Betz 1100	11.8
43-6	3/04		5	0.3	Betz 1100	11.8
43-7	3/04					9.4
43-8	3/04					7.1
43-9	3/04					8.7
43-10	3/04					7.5
43-11	3/04					7.4
43-12	3/04					2.1
43-13	3/04					7.5
44-2	3/12		5	0.3	Betz 1100	11.9
44-3	3/12		5	0.3	Betz 1100	11.9
44-4	3/12		5	0.3	Betz 1100	12.0
44-5	3/12					6.9
44-6	3/12					8.6
44-7	3/12					2.4
45-1	3/13		5	0.3	Betz 1100	11.9
45-2	3/13		5	0.3	Betz 1100	11.8
45-3	3/13		5	0.3	Betz 1100	12.0
45-4	3/13		5	0.3	Betz 1100	11.9
46-1	3/26		5	0.3	Betz 1100	11.8
46-2	3/26			0.3	Betz 1100	11.8
46-3	3/26	125		0.6	Betz 1100	10.5
46-4	3/26		5	0.3	Betz 1100	11.8
46-5	3/26			0.3	Betz 1100	11.8
46-6	3/26	125		0.6	Betz 1100	10.5
46-7	3/26					9.2
47-1	3/27		5	0.3	Betz 1100	11.7
47-2	3/27		5	0.3	Betz 1100	11.9
47-3	3/27		5	0.3	Betz 1100	11.9

20. Jar tests to determine source of contaminated water

Spike	Reaction time (min)	Water hardness (mg/L $CaCO_3$) Ca	Water hardness (mg/L $CaCO_3$) Total	Alkalinity (mg/L $CaCO_3$) Carbonate	Alkalinity (mg/L $CaCO_3$) Total	Comments
	80	45				PWTP feed
	80	23				PWTP feed
	80	49				PWTP feed
	80	34				Main feed source
	80	6				Main feed source
	80	90				Main feed source
	80	99		14	174	PWTP feed
	80	93			149	Main feed source
						PWTP feed, boiled
		75				Blank
	80	74	72			PWTP feed
	80	28				Main feed source
	80	97	96			Manhole 209 water
	80	29	20			Manhole 210 water
	80	2				Bldg. 3517 water
	80	6	6			Pumping station 1 water
	80	53				PWTP feed + 4 mg/L H_2O_2
	120	45				PWTP feed + 20 mg/L H_2O_2
	120	29				PWTP feed
	80	74				PWTP feed
	80	53				PWTP feed
	80	18	19			Manhole 243 water
	80	97				PWTP feed blank
	80	101				Main feed source
	80	97				Manhole 209 blank
	80	72				Manhole 210 blank
	80	19				Manhole 243 blank
	80	4				Bldg. 3517 blank
	80	136				Pumping station 1 blank
	80	65				Bldg. 3517 water
	80	61				Manhole 25 water
	80	47				Manhole 240 water
	80	86				Bldg. 3517 blank
	80	70				Manhole 25 blank
	80	84				Manhole 240 blank
$CaCO_3$	80	26				Bldg. 3517 water
$CaCO_3$	80	8				Manhole 25 water
$CaCO_3$	80	74				Manhole 240 water
$CaCO_3$	80	8				Manhole 243 water
	80	51				PWTP feed
	80	49				PWTP feed
	80	51				PWTP feed
$CaCO_3$	80	8				PWTP feed
$CaCO_3$	80	8				PWTP feed
$CaCO_3$	80	20				PWTP feed
	80	51				Blank
$CaCO_3$	80	4				Manhole 243 water
$CaCO_3$	80	10				Manhole 209 water
$CaCO_3$	80	10				Bldg. 2026 water

Sample No.	Date (1986)	Chemical requirements (mg/L wastewater)					
		Na_2CO_3	Fe^{3+}	Polymer	Type	NaOH to pH	
47-4	3/27		5	0.3	Betz 1100	12.0	CaCO
47-5	3/27					7.1	
47-6	3/27					7.6	
47-7	3/27					7.4	
47-8	3/27					9.3	
48-1	4/23		5	0.3	Betz 1100	11.9	CaCO
48-2	4/23		5	0.3	Betz 1100	11.9	CaCO
48-3	4/23		5	0.3	Betz 1100	12.2	CaCO
48-4	4/23					8.3	

Table 20. (continued)

Spike	Reaction time (min)	Water hardness (mg/L $CaCO_3$)		Alkalinity (mg/L $CaCO_3$)		Comments
		Ca	Total	Carbonate	Total	
$CaCO_3$	80	10				Bldg. 3517 water
	80	8				Manhole 243 blank
	80	78				Manhole 209 blank
	80	99				Bldg. 2026 blank
	80	62				Bldg. 3517 blank
$CaCO_3$	80	6				PWTP feed
$CaCO_3$	80	10				PWTP feed + 0.043 M Na silicate
$CaCO_3$	80	4				PWTP feed + 0.173 M Na silicate
	80	96				Blank

APPENDIX B

RESULTS OF SORPTION COLUMNS TESTS

APPENDIX B
RESULTS OF SORPTION COLUMN TESTS

The experimental data obtained from laboratory-scale sorption column tests are given in Tables 21-38. Variations in the radionuclide concentrations in the feed were typical throughout the test period. Therefore, the resin tests are grouped according to the time during which the tests were run and the type of water-softening pretreatment. Tables containing pertinent information on the feed for a given set of resin tests are followed by tables containing the experimental results. Composite samples of the column effluent were collected over periods of 8 to 12 h. The experimental data include the mean residence time, the total liquid throughput measured in bed volumes of resin, radionuclide content, and fractional breakthrough of radionuclides through the column for each sample that was analyzed for radionuclide concentrations. Fractional breakthrough values were calculated by normalizing the effluent concentrations by the mean feed concentrations for each set of tests, except for the data in Tables 23 and 24. The concentrations in the feed varied significantly during this run, and the actual feed data were used to calculate the breakthrough values. The phosphate concentrations are only given in Tables 25 and 27, which list levels that vary appreciably from 1 mg/L.

Table 21. Composition of unsoftened feed for ion-exchange tests in Table 22

Date	Gross beta (Bq/L)	^{60}Co (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
11/16/85									
11/16/85	2657	57	361						
11/16/85									
11/19/85									
11/19/85	2416	50	443						
11/19/85									
11/20/85	4200	60	620	1600					
11/20/85									
11/20/85									
11/22/85		45	420	1600	154	120	8.4	48	13
11/22/85					154	120	8.4	48	13
11/22/85					154	120	8.4	48	13
11/25/85	4600	42	800	1500					
11/25/85									
11/25/85									
Average composition	3468	51	529	1567	154	120	8.0	48	13

Table 22. *Ion-exchange column test results for unsoftened feed to the Process Waste Treatment Plant for November 1985*[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)				Fractional breakthrough			
				Gross beta	^{60}Co	^{137}Cs	^{90}Sr	Gross beta	^{60}Co	^{137}Cs	^{90}Sr
Zeolon 400	11/15/85	1.1	261				710				0.45
	11/16/85	1.0	764	1932	55	10		0.56	1.08	0.02	
	11/16/85	1.0	764	3000			1500	0.87			0.96
	11/16/85	1.1	1232				1440				0.92
	11/17/85	1.1	2123	2657	80	10		0.77	1.57	0.02	
	11/18/85	1.3	3377	2174	51	10		0.63	1.00	0.02	
	11/18/85	1.1	4225	2416	49	19		0.70	0.96	0.04	
	11/19/85	1.1	5569	2174	35	31		0.63	0.69	0.06	
	11/20/85	1.1	6900	1691	40	30		0.49	0.79	0.06	
	11/21/85	1.1	8158		39	103			0.77	0.19	
	11/22/85	1.2	9505			38				0.07	
	11/23/85	1.6	10593			54				0.10	
	11/25/85	1.2	12029			88				0.17	
	11/26/85	1.2	14072			109				0.21	
Zeolon-500	11/16/85	1.0	725	483	36	10		0.14	0.71	0.02	
	11/16/85	1.0	725	810			300	0.23			0.19
	11/16/85	1.1	1177				420				0.27
	11/16/85	1.1	1622				640				0.41
	11/17/85	1.2	2052	1691	59	10		0.49	1.16	0.02	
	11/17/85	1.2	2052	1800			760	0.52			0.49
	11/17/85	1.1	2475				850				0.54
	11/17/85	1.1	2906				1100				0.70
	11/18/85	1.2	3321				1200				0.77
	11/18/85	1.2	3321	1208	43	10		0.35	0.85	0.02	

Table 22. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)				Fractional breakthrough			
				Gross beta	^{60}Co	^{137}Cs	^{90}Sr	Gross beta	^{60}Co	^{137}Cs	^{90}Sr
Zeolon-500	11/18/85	1.0	3755				1200				0.77
	11/18/85	1.1	4206	1932	59	10	1030	0.56	1.16	0.02	0.66
	11/19/85	1.2	4631				1240	0.79			
	11/19/85	1.0	5069				1210				0.77
	11/19/85	1.1	5519	2174	10	19		0.63	0.20	0.04	
	11/20/85	1.1	6837	2416	27	25		0.70	0.53	0.05	
	11/21/85	1.1	8082		46	30			0.91	0.06	
	11/22/85	1.2	9398			55				0.10	
	11/23/85	1.5	10521			22				0.04	
	11/24/85	1.6	11535			45				0.09	
	11/26/85	1.3	13924			39				0.07	
Zeolon-900	11/15/85	1.1	258				900				0.57
	11/16/86	1.1	740	2174	10	10		0.63	0.20	0.02	
	11/16/85	1.1	740	3900			1700	1.12			1.09
	11/16/85	1.1	1185				1490				0.95
	11/17/85	1.2	2043	2657	52	10		0.77	1.02	0.02	
	11/18/85	1.2	3292	2657	42	10		0.77	0.83	0.02	
	11/18/85	1.1	4160	2174	38	10		0.63	0.75	0.02	
	11/19/85	1.1	5442	2174	10	10		0.63	0.20	0.02	
	11/20/85	1.1	6729	2657	10	10		0.77	0.20	0.02	
	11/21/85	1.1	7942		38	10			0.75	0.02	
	11/24/85	1.4	11330			10				0.02	
	11/26/85	1.3	13669			10				0.02	

Table 22. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)				Fractional breakthrough			
				Gross beta	^{60}Co	^{137}Cs	^{90}Sr	Gross beta	^{60}Co	^{137}Cs	^{90}Sr
Linde A-51	11/15/85	1.0	296	860	36	35	390	0.25	0.71	0.07	0.25
	11/16/85	0.9	861	1208	58	106		0.35	1.14	0.20	
	11/16/85	0.9	861	2100	43	95	960	0.61	0.85	0.18	0.61
	11/16/85	0.9	1382	3000	51	140	1200	0.87	1.00	0.26	0.77
	11/16/85	1.0	1883	3500	57	170	1400	1.01	1.12	0.32	0.89
	11/17/85	1.0	2372	2657	70	201		0.77	1.38	0.38	
	11/17/85	1.0	2372	3700	55	220	1700	1.07	1.08	0.42	1.09
	11/17/85	1.0	2861				1950				1.24
	11/17/85	1.0	3355				1970				1.26
	11/18/85	1.0	3842	2416	56	235	1560	0.70	1.10	0.44	1.00
	11/18/85	1.0	4844	2416	42	326		0.70	0.83	0.62	
IE-95	11/15/85	1.1	268				90				0.06
	11/16/85	1.0	778	483	58	10		0.14	1.14	0.02	
	11/16/85	1.0	778	680			270	0.20			0.17
	11/16/85	1.1	1243				400				0.26
	11/16/85	1.0	1697				600				0.38
	11/17/85	1.1	2147				860				0.55
	11/17/85	1.1	2147	1449	56	10		0.42	1.10	0.02	
	11/17/85	1.1	2586				1000				0.64
	11/17/85	1.1	3029				1200				0.77
	11/18/85	1.1	3478				1300				0.83
	11/18/85	1.1	3478	1932	56	10		0.56	1.10	0.02	
	11/18/85	1.0	3939				1810				1.16
	11/18/85	1.1	4395	2416	53	10	1700	0.70	1.04	0.02	1.09
	11/19/85	1.1	4832				1580				1.01

Table 22. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)				Fractional breakthrough			
				Gross beta	^{60}Co	^{137}Cs	^{90}Sr	Gross beta	^{60}Co	^{137}Cs	^{90}Sr
IE-95	11/19/85	1.0	5738	2657	35	10		0.77	0.69	0.02	
	11/20/85	1.1	7105	2416	10	10		0.70	0.20	0.02	
	11/21/85	1.1	8406		29	10			0.57	0.02	
	11/24/85	1.6	12014			15				0.03	
	11/26/85	1.2	14555			10				0.02	
Zeolon-700	11/20/85	1.0	732	2174	10	10	1800	0.63	0.20	0.02	1.15
	11/21/85	1.2	1663				1920				1.23
	11/21/85	1.1	2082	1932	76	10	1880	0.56	1.50	0.02	1.20
	11/24/85	1.3	5869	2899		10		0.84		0.02	
	11/26/85	1.1	8545	1932		13		0.56		0.02	

[a]Feed concentrations are given in Table 21.

Table 23. Composition of unsoftened feed for ion-exchange tests in Table 24

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
12/13/85								
12/13/85	54349	12100	21600					
12/13/85								
12/14/85								
12/14/85	54349	6820	23600					
12/14/85								
12/16/85								
12/16/85	27054	3640						
12/16/85								
12/18/85								
12/18/85								
12/18/85	30435	2510	12000					
12/18/85	27295	2860						
12/18/85								
12/18/85								
12/19/85								
12/19/85	27054	1960						
12/19/85								
12/20/85								
12/20/85	21740	1700						
12/20/85								
12/22/85								
12/22/85	22947	1960						
12/22/85								
12/23/85								
12/23/85								
12/23/85			7800					
12/23/85			7290					

Table 23. (continued)

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
12/23/85								
12/23/85								
12/24/85								
12/24/85	21740	1750						
12/24/85								
12/26/85								
12/26/85			6400					
12/26/85								
12/27/85								
12/27/85								
12/27/85			1990					
12/27/85	14735	1470						
12/27/85								
12/27/85								
12/30/85								
12/30/85	33817	1680						
12/30/85								
1/01/86								
1/01/86	22464	967						
1/01/86								
1/06/86				146	105	10	42	38
1/06/86			6900	146	105	10	42	38
1/06/86				146	105	10	42	38
1/09/86				171	122	10	49	84
1/09/86			7400	171	122	10	49	84
1/09/86				171	122	10	49	84

Table 24. Ion-exchange column test results for unsoftened feed to the Process Waste Treatment Plant for December 1985[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
HCR-S-NEW[b]	12/13/85	2.2	115	11111	5120		0.21	0.43	
	12/14/85	2.0	349	19324	18800		0.41	2.66	
	12/14/85	1.2	675	17392	8620	4420	0.37	1.22	0.23
	12/14/85	1.1	1160	53866	6980		1.14	0.99	
	12/15/85	1.2	1592	53624	6070		1.29	1.37	
	12/16/85	1.0	2816			10200			0.67
HCR-S-OLD[c]	12/13/85	3.2	80	12802	2990		0.24	0.25	
	12/14/85	3.1	237	20290	15800		0.43	2.23	
	12/14/85	1.3	495	30194	9430	4630	0.64	1.33	0.24
	12/14/85	1.1	955	50484	6860		1.07	0.97	
	12/15/85	1.1	1399	51692	6600		1.24	1.48	
	12/16/85	1.0	2602			1390			0.09
PDZ-140-D	12/13/85	1.2	209	12078	178	4760	0.22	0.01	0.22
	12/14/85	1.2	622			7590			0.39
	12/14/85	1.2	1018			8210			0.43
	12/14/85	1.1	1494	37199	349	21000	0.79	0.05	1.09
	12/15/85	1.2	1927	49518	589	15700	1.19	0.13	0.91
	12/16/85	1.0	3066	24880	551		0.68	0.16	
	12/18/85	1.2	5739		661			0.24	
	12/19/85	0.8	7049		1320			0.71	
	12/20/85	1.5	8202		652			0.38	
	12/21/85	1.2	9332		2090			1.23	
	12/22/85	1.3	10581		877			0.52	
	12/23/85	1.3	12117		1220			0.72	
	12/26/85	1.2	15104		1350			0.79	

Table 24. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
PDZ-140-D	12/29/85	1.3	18676	41547	2830		1.91	1.66	
	01/01/86	1.0	22272		485			0.29	
PDZ-300-AL	12/13/85	1.3	201	11836	1580	5410	0.22	0.13	0.25
	12/14/85	1.1	622			9510			0.49
	12/14/85	1.2	1037			7570			0.39
	12/14/85	1.2	1490	39373	98	22500	0.83	0.01	1.17
	12/15/85	1.2	1900	15218	112	21700	0.37	0.03	1.26
	12/16/85	1.1	3059	47827	173		1.31	0.05	
	12/19/85	1.0	6949		595			0.32	
	12/20/85	1.6	7435		406			0.24	
	12/21/85	1.4	8523		794			0.47	
	12/22/85	1.4	9697		642			0.38	
	12/23/85	1.3	11182		898			0.53	
	12/25/85	1.2	13105	25363	853		1.17	0.50	
	12/26/85	1.2	14279		1210			0.71	
	12/29/85	1.3	17981	55315	2280		2.54	1.34	
	01/01/86	1.1	21691		1050			0.62	
IE-95	12/13/85	17.3	15	8937	269		0.17	0.02	
	12/14/85	70.0	103	725	36		0.02	0.01	
	12/18/85	13.4	504	2899	758		0.10	0.27	
	12/18/85	12.3	542			1470			0.12
	12/19/85	9.3	673	9904			0.40		
	12/19/85	22.3	709	8454			0.34		
	12/20/85	24.0	778		16			0.01	
	12/21/85	11.7	892			8350			0.93
	12/23/85	11.2	1138			3570			0.47

Table 24. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
IE-95	12/24/85	10.4	1267	10145			0.47		
	12/25/85	12.5	1374			4090			0.61
	12/26/85	12.0	1484	14735	13		0.68	0.01	
	12/27/85	10.2	1609			13200			2.13
	12/27/85	5.6	1671	13768	13		0.63	0.01	
	12/30/85	11.7	2029	8454			0.39		
	01/01/86	9.7	2300		10			0.01	
	01/07/86	12.0	3062	4348	10		0.20	0.01	
	01/09/86	7.6	3406			9930			1.37
	01/14/86	10.8	4032	16184	10		0.74	0.01	
	01/15/86	9.0	4214	5314	10		0.24	0.01	
IRC-84	12/23/85	1.6	173	3865	1990		0.18	1.17	
	12/24/85	1.2	1284	11836	1700		0.54	1.00	
	12/26/85	1.1	3304	17150	2290		0.79	1.35	
	01/01/86	1.0	10812	26329	1140		1.21	0.67	
PDZ-150-D	12/26/85	2.5	95	6039	24		0.28	0.01	
	12/27/85	1.3	405	2657	11		0.12	0.01	
	12/30/85	1.1	4535	22706	306		1.04	0.18	
	01/01/86	1.0	7111	17392	593		0.80	0.35	
	01/07/86	1.1	14653	10145	4612		0.47	2.71	

[a]Feed concentrations are given in Table 24.
[b]NEW - unused resin.
[c]OLD - regenerated resin.

Table 25. Composition of unsoftened feed for ion-exchange tests in Table 26

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
1/14/86								
1/14/86	9662	531						
1/14/86								
1/15/86								
1/15/86	7247	289						
1/15/86								
1/18/86				150	105	11	42	86
1/18/86				141	100	10	40	47
1/18/86	4831	420		150	105	11	42	86
1/18/86	6522	250		141	100	10	40	47
1/18/86				150	105	11	42	86
1/18/86				141	100	10	40	47
1/19/86								
1/19/86								
1/19/86	6522	285						
1/19/86	8213	276						
1/19/86								
1/19/86								
1/20/86								
1/20/86	5073	755						
1/20/86								
1/22/86	5400		4100					
1/22/86		420						
1/22/86								
1/23/86	5600		4600	150	115	8.7	46	81
1/23/86				150	115	8.7	46	81
1/23/86				150	114	8.7	46	81
1/24/86	5600		4600	189	150	9.6	60	61

Table 25. (continued)

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
1/24/86		710		189	150	9.6	60	61
1/24/86				189	150	9.6	60	61
1/25/86	2100		1100					
1/25/86								
1/25/86								
1/26/86								
1/26/86	5900		4000					
1/26/86		494						
1/26/86		328						
1/26/86								
1/26/86								
1/29/86	3900		3300					
1/29/86								
1/29/86								
1/30/86								
1/30/86	4300		3000					
1/30/86		480						
1/30/86								
1/30/86								
1/30/86								
Average composition	5776	437	3529	158	118	10	47	69

Table 26. Ion-exchange column test results for unsoftened feed to the Process Waste Treatment Plant for January 1986[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
CCR-2	1/09/86	5.4	129			3490			0.99
	1/10/86	6.6	344	1932	677		0.33	1.55	
	1/11/86	6.4	615		435	100		1.00	0.03
	1/14/86	5.7	1187	1449	542		0.25	1.24	
	1/14/86	7.3	1298			460			0.13
	1/15/86	5.4	1509	4831	280		0.84	0.64	
	1/17/86	9.9	1753			3340			0.95
	1/20/86	6.6	2227	9904	509		1.71	1.17	
	1/20/86	6.4	2337			6860			1.94
	1/23/86	8.5	3042	11836	919	6310	2.05	2.11	1.79
IRC-84	1/09/86	5.3	38	1691	604	410	0.29	1.38	0.12
	1/09/86	4.5	153			5030			1.43
	1/10/86	5.6	296	7971	614	2700	1.38	1.41	0.77
	1/10/86	5.9	424	1932	677	430	0.33	1.55	0.12
	1/11/86	5.5	727		393	400		0.90	0.11
	1/14/86	4.3	1442	9662	605		1.67	1.39	
	1/14/86	5.4	1593			6230			1.77
	1/15/86	4.0	1870	11111	217	5330	1.92	0.50	1.51
	1/17/86	5.3	2398	7488	323	4840	1.30	0.74	1.37
	1/20/86	5.8	3028	6522	327		1.13	0.75	
	1/20/86	5.2	3158			4380			1.24
	1/23/86	8.2	3973	7488	10	6700	1.30	0.02	1.90
	1/26/86	7.6	4709	9179	310		1.59	0.71	
	1/27/86	10.7 4915	4700		3900	0.81		1.11	
	1/28/86	9.2	4988	4300		4400	0.74		1.25
	1/28/86	4.9	5116	9420	379		1.63	0.87	

Table 26. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
IRC-84	1/30/86	5.1	5492		427			0.98	
	1/30/86	6.4	5603	3300		1900	0.57		0.54
Zeolon-500	1/09/86	5.6	138			190			0.05
	1/11/86	6.8	565		5	760		0.01	0.22
	1/13/86	7.3	1042	5300		2700	0.92		0.77
	1/14/86	5.4	1157	6763	10		1.17	0.02	
	1/15/86	4.5	1512	2416	10		0.42	0.02	
	1/16/86	4.3	1693			1420			0.40
	1/18/86	6.6	2121			1980			0.56
	1/19/86	6.8	2341			1120			0.32
	1/20/86	7.2	2446	2174	12		0.38	0.03	
	1/20/86	6.4	2551			2220			0.63
	1/23/86	5.5	3151			2140	1.38		0.61
	1/23/86	7.9	3266	7971	10		1.38	0.02	
	1/25/86	8.8	3719			3890			1.10
	1/26/86	7.9	3907	4348	10		0.75	0.02	
	1/27/86	7.6	4103			2200			0.62
	1/28/86	5.4	4344			3180			0.90
	1/30/86	6.2	4670		10			0.02	
	1/30/86	7.9	4760	5300		3700	0.92		1.05
	2/05/86	4.7	4882			2200			0.62
	2/05/86	5.2	5029	3140	10		0.54	0.02	
	2/06/86	6.6	5252	6039	10		1.05	0.02	
PDZ-300-AL	1/09/86	6.0	33			74			0.02
	1/09/86	9.3	104			42			0.01
	1/10/86	27.6	155			110			0.03

Table 26. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
PDZ-300-AL	1/10/86	5.1	241	1208	16	410	0.21	0.04	0.12
	1/11/86	4.9	576		5	540		0.01	0.15
	1/12/86	4.7	882			660			0.19
	1/13/86	4.9	1225			1770			0.50
	1/14/86	3.8	1392	8937	10		1.55	0.02	
	1/14/86	4.9	1559			1890			0.54
	1/15/86	3.6	1879	2899	10		0.50	0.02	
	1/18/86	9.9	2676			2270			0.64
	1/20/86	5.0	3053	3382	10		0.59	0.02	
	1/20/86	5.8	3187			2720			0.77
	1/23/86	9.5	4018	7488	10	3330	1.30	0.02	0.94
	1/26/86	8.4	4782	4590	10		0.79	0.02	
	1/28/86	6.3	5204			3510			0.99
	1/30/86	9.1	5423	3300		3500	0.57		0.99
	1/30/86	10.1	5491		10			0.02	
	1/30/86	17.6	5539	8300		2700	1.44		0.77
	2/05/86	6.0	5764	4831	10		0.84	0.02	
	2/09/86	5.3	6578	2899	10		0.50	0.02	
	2/12/86	5.8	7417			2300			0.65
	2/12/86	6.2	7547	4348	10		0.75	0.02	
	2/17/86	5.2	8532	3140	10		0.54	0.02	
IE-95	1/17/86	7.4	58	242	24		0.04	0.05	
	1/18/86	7.7	164	242	14		0.04	0.03	
	1/18/86	6.0	270	242	14		0.04	0.03	
	1/19/86	8.4	371	80		28	0.01		0.01
	1/19/86	8.4	371	483	10		0.08	0.02	
	1/19/86	6.5	470	110		14	0.02		0.00

Table 26. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
IE-95	1/19/86	6.5	470	242	13		0.04	0.03	
	1/20/86	12.7	555	242	15		0.04	0.03	
	1/20/86	8.9	622	110		3	0.02		0.00
	1/20/86	8.9	622	242	6		0.04	0.01	
	1/22/86	4.9	915	2700		1500	0.47		0.43
	1/22/86	7.7	1121	1300		700	0.23		0.20
	1/23/86	5.2	1241	1208	10		0.21	0.02	
	1/23/88	8.5	1356	2416	10	580	0.42	0.02	0.16
	1/24/86	5.3	1465			990			0.28
	1/25/86	4.5	1641	5300		4000	0.92		1.13
	1/26/86	5.4	1858		10			0.02	
	1/26/86	5.4	1858	1900		1500	0.33		0.43
	1/27/86	6.3	2182	3000		1700	0.52		0.48
	1/29/86	6.0	2584	4000		2300	0.69		0.65
	1/30/86	8.4	2682	2500		2000	0.43		0.57
	1/30/86	6.1	2773		10			0.02	
	1/30/86	8.7	2860	4500		4700	0.78		1.33

[a]Feed concentrations are given in Table 25.

Table 27. Composition of unsoftened feed for ion-exchange tests in Table 28

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
2/07/86	8700		3600	161	120	10.0	48	29
2/07/86		341		161	120	10.0	48	29
2/07/86				161	120	10.0	48	29
2/08/86	6500		3600	163	122	10.0	49	28
2/08/86		318		163	122	10.0	49	28
2/08/86				163	122	10.0	49	28
2/09/86	6300		3700	163	122	10.0	49	32
2/09/86		382		163	122	10.0	49	32
2/09/86				163	122	10.0	49	32
2/10/86	7000		3000	161	117	10.0	47	31
2/10/86		423		161	117	10.0	47	31
2/10/86				161	117	10.0	47	31
2/11/86	5100		3200	154	115	9.5	46	33
2/11/86		384		154	115	9.5	46	33
2/11/86				154	115	9.5	46	33
2/12/86	4100		2700	154	115	9.5	46	33
2/12/86		376		154	115	9.5	46	33
1/12/86				154	115	9.5	46	33
2/13/86	3600		2600	146	110	8.9	44	26
2/13/86		554		146	110	8.9	44	26
2/13/86				146	110	8.9	44	26
2/14/86	3100		2400	146	110	8.9	42	32
2/14/86		519		146	110	8.9	42	32
2/14/86				146	110	8.9	42	32
2/15/86	8500		2500	134	125	9.7	50	36
2/15/86		467		134	125	9.7	50	36
2/15/86				134	125	9.7	50	36
2/16/86	8500		5500	167	128	9.7	51	79

Table 27. (continued)

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
2/16/86		720		167	128	9.7	51	79
2/16/86				167	128	9.7	51	79
2/17/86	9200		7100	167	130	9.1	52	24
2/17/86		574		167	130	9.1	52	24
2/17/86				167	130	9.1	52	24
Average composition	6418	460	3627	156	119	10.0	48	35

Table 28. Ion-exchange column test results for unsoftened feed to the Process Waste Treatment Plant for February 1986[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
IE-95	1/25/86	10.5	87	140		30	0.02		0.01
	1/26/86	6.9	258		10			0.02	
	1/26/86	6.9	258	98		9	0.02		0.00
	1/27/86	7.3	527			35			0.01
	1/28/86	5.4	785			90			0.02
	1/30/86	8.6	1017	230		300	0.04		0.08
	1/30/86	7.9	1095		10			0.02	
	1/30/86	15.3	115[illegible]	560		420	0.09		0.12
	2/05/86	4.7	1346			455			0.13
	2/05/86	5.8	1486	483	10		0.08	0.02	
	2/09/86	5.9	2419	1691	10		0.26	0.02	
	2/12/86	6.3	3190	2899	10	149	0.45	0.02	0.04
	2/17/86	6.4	4369	4106	10	1040	0.64	0.02	0.29
TG650-G12	2/05/86	4.9	78			8			0.00
	2/05/86	9.4	190	242	10		0.04	0.02	
	2/06/86	7.6	373	242	14		0.04	0.03	
	2/07/86	8.4	463	242	53		0.04	0.12	
	2/07/86	10.1	541		416			0.90	
	2/08/86	7.9	622	1208	1140		0.19	2.48	
	2/08/86	4.4	750		810	184		1.76	0.05
	2/09/86	4.5	912	1208	225		0.19	0.49	
	2/10/86	4.9	1376	4831	335		0.75	0.73	
	2/12/86	6.5	1796	6522	285	2360	1.02	0.62	0.65
	2/17/86	5.2	2699	7730	351		1.20	0.76	

Table 28. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
XFS-43230	2/05/86	7.5	53			72			0.02
	2/05/86	9.4	140	242	10		0.04	0.02	
	2/06/86	8.2	223			48			0.01
	2/06/86	6.3	323	966	936		0.15	2.04	
	2/07/86	5.0	453	3140	253		0.49	0.55	
	2/07/86	6.0	586			1940			0.53
	2/08/86	5.6	710	5073	349		0.79	0.76	
	2/08/86	5.5	840			3750			1.03
	2/09/86	7.2	956	6039	352		0.94	0.77	
	2/10/86	5.6	1293	6763	345		1.05	0.75	
	2/12/86	6.7	1647	6522	283	3120	1.02	0.62	0.86
	2/17/86	6.2	2458			1960			0.54
	2/17/86	6.9	2568	6763	341		1.05	0.74	

[a]Feed concentrations are given in Table 27.

Table 29. Composition of unsoftened feed for ion-exchange tests in Table 31

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
3/07/86								
3/07/86	15218	527						
3/07/86								
3/09/86				136	103	8.2	41	65
3/09/86	9179	463		136	103	8.2	41	65
3/09/86				136	103	8.2	41	65
3/13/86			3000					
3/13/86	7971	752						
3/13/86								
3/17/86								
3/17/86	1932	806	3990					
3/17/86								
3/19/86			4600					
3/19/86	7730	823						
3/19/86								
3/24/86								
3/24/86	7971	517						
3/24/86								
Avgerage composition	8333	648	3836	136	103	8.0	41	65

Table 30. Composition of unsoftened feed for ion-exchange tests in Tables 31 and 32

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
3/26/86								
3/26/86	7730	553						
3/26/86								
4/04/86								
4/04/86	7247	539	1500					
4/04/86								
4/17/86								
4/17/86	8213	364	2800					
4/17/86								
5/07/86		370						
5/07/86								
5/07/86								
5/12/86				164	115	12	46	29
5/12/86				164	115	12	46	29
5/12/86				164	115	12	46	29
5/15/86		440	2300					
5/15/86								
5/15/86								
5/21/86				160	115	11	46	24
5/21/86				160	115	11	46	24
5/21/86				160	115	11	46	24
5/23/86				128	87	10	35	29
5/23/86	4590	356		128	87	10	35	29
5/23/86				128	87	10	35	29
5/27/86								
5/27/86	4831	159						
5/27/86								

Table 30. (continued)

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
6/03/86				128	87	10	35	29
6/03/86				128	87	10	35	29
6/03/86				128	87	10	35	29
Average composition	6522	397	2200	145	101	11	41	30

Table 31. Ion-exchange column test results for unsoftened feed to the Process Waste Treatment Plant for March 1986[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
PDZ-300-D	3/07/86	56.3	31	242	15		0.03	0.02	
	3/08/86	8.4	124	242	10		0.03	0.02	
	3/09/86	6.8	264	242	10		0.03	0.02	
	3/10/86	5.8	494	242	10		0.03	0.02	
	3/11/86	7.1	722	242	10		0.03	0.02	
	3/13/86	6.4	1259	242	10		0.03	0.02	
	3/14/86	6.9	1474			400			0.10
	3/16/87	6.2	1789			560			0.14
	3/16/87	6.2	1907	10628	10		1.28	0.02	
	3/17/86	6.1	2024			860			0.22
	3/18/86	6.4	2264			1130			0.29
	3/20/86	6.9	2682			1580			0.41
	3/20/86	7.2	2792	4590	10		0.55	0.02	
	3/22/86	7.7	3088			2020			0.52
	3/24/86	7.3	3512			2520			0.65
	3/24/86	7.6	3599	6280	14		0.75	0.02	
	3/26/86	8.7	3927	5797	10		0.70	0.02	
PDZ-300-17	3/07/86	46.9	27	242	14		0.03	0.02	
	3/08/86	7.9	126	242	10		0.03	0.02	
	3/09/86	6.4	275	242	10		0.03	0.02	
	3/10/86	6.2	501	242	10		0.03	0.02	
	3/11/86	10.5	693	242	10		0.03	0.02	
	3/13/86	6.4	1225	242	10		0.03	0.02	
	3/14/86	7.2	1437			190			0.05
	3/16/86	6.8	1750			350			0.09
	3/16/86	6.8	1857	966	10		0.12	0.02	

Table 31. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
PDZ-300-17	3/17/86	6.6	1966			560			0.14
	3/18/86	6.8	2187			870			0.23
	3/20/86	7.2	2592			1340			0.35
	3/20/86	7.6	2697	3865	10		0.46	0.02	
	3/22/86	6.8	2987			1800			0.47
	3/24/86	6.6	3420			2250			0.58
	3/24/86	7.2	3515	5314	10		0.64	0.02	
	3/26/86	6.6	3920	5314	10		0.64	0.02	
PDZ-300-AL	4/04/86	3.3	3389	5556	4		0.85	0.01	
	4/07/86	3.3	4749	5556	9		0.85	0.02	
	4/11/86	3.5	6606	6763	17		1.04	0.04	
	4/15/86	3.2	8375	9662	21		1.48	0.05	
	4/15/86	3.3	8525	9179	44		0.41	0.11	
	4/17/86	3.6	9227	8213			1.26		
	4/17/86	3.5	9897		53			0.13	
	5/05/86	2.9	10770	49			0.12		
	5/06/86	2.9	11212	41			0.10		
	5/08/86	3.1	12165	11			0.03		
	5/12/86	3.1	13972	92			0.23		
	5/14/86	2.9	14757	97			0.24		
	5/16/86	3.0	15717	123			0.31		
	5/19/86	3.2	17157	154			0.39		
	5/21/86	2.9	18117	7005	165		1.07	0.42	
	5/23/86	3.1	19072	5797	173		0.89	0.44	

Table 31. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
LiAl	3/07/86	1.4	406	3865	2100	4090	0.46	3.24	1.06
	3/08/86	2.7	922	3382	438	1340	0.41	0.68	0.35
	3/09/86	3.1	1312	6280	515	3550	0.75	0.79	0.92
	3/10/86	3.4	1876	5556	560		0.67	0.86	
	3/11/86	2.2	2366	7971	642		0.96	0.99	
	3/11/86	3.5	2632			1810			0.47
	3/13/86	3.6	3215			3390			0.88
	3/13/86	3.6	3413	7247	522		0.87	0.81	

[a]Feed concentrations are given in Tables 29 and 30.

Table 32. Ion-exchange column test results for unsoftened feed to the Process Waste Treatment Plant for March-July 1986[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
"CH"	3/28/86	7.9	123			200			0.09
	3/30/86	5.6	450			2000			0.91
	3/31/86	5.2	736			1810			0.82
	4/03/86	6.6	1164			2690			1.22
	4/04/86	8.3	1428	6763	2		1.04	0.01	
	4/07/86	6.8	2061	5073	2		0.78	0.01	
PDZ-140-D	5/14/86	6.7	75		21			0.05	
	5/15/86	4.1	293	483	10	198	0.07	0.03	0.09
	5/15/86	4.5	500			548			0.25
	5/16/86	4.8	605	2174	10	785	0.33	0.03	0.36
	5/16/86	4.6	703			1110			0.50
	5/16/86	4.7	803			1010			0.46
	5/17/86	5.0	910	2899			0.44		
	5/18/86	4.4	1246	3865			0.59		
	5/19/86	5.9	1560	4590	10		0.70	0.03	
	5/20/86	5.6	1828		10			0.03	
	5/21/86	5.4	2105	3382	10		0.52	0.03	
	5/22/86	4.5	2403	5073	10		0.78	0.03	
	5/23/86	5.4	2700	4106	10		0.63	0.03	
	5/24/86	4.8	2983	4348	10		0.67	0.03	
	5/25/86	11.2 3291	3382	10		0.52	0.03		
	5/26/86	3.5	3570	3865	25		0.59	0.06	
	5/27/86	4.2	3860	3623	10		0.56	0.03	

Table 32. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
PDZ-140-D	5/30/86	7.7	4420	4348	10		0.67	0.03	
	6/02/86	6.0	4988	3865			0.59		
	6/04/86	5.2	5518	3623			0.56		
	6/06/86	5.2	6093		18			0.05	
	6/06/86	4.8	6289	4348			0.67	.	
	6/09/86	5.2	6943		10			0.03	
	6/11/86	11.1	7478	3382			0.52		

[a]Feed concentrations are given in Table 30.

Table 33. Composition of caustic/soda-ash softened feed for ion-exchange tests in Table 34

Feed Batch	Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	^{85}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
9	3/31/86									130
9	3/31/86	3140	1088							130
9	3/31/86									130
9	4/02/86									
9	4/02/86									
9	4/02/86				15087					
12	4/04/86							2.3	5.0	170
12	4/04/86							2.3	5.0	170
12	4/04/86				13630			2.3	5.0	170
12	4/07/86					21.0	9.5	2.8	3.8	
12	4/07/86	14735	443			21.0	9.5	2.8	3.8	
12	4/07/86					21.0	9.5	2.8	3.8	
12	4/08/86					38.1	17.1	5.1	6.9	
12	4/08/86					38.1	17.1	5.1	6.9	
12	4/08/86					38.1	17.1	5.1	6.9	
14	4/14/86					23.0	13.3	2.3	5.3	170
14	4/14/86	1691				23.0	13.3	2.3	5.3	170
14	4/14/86				10951	23.0	13.3	2.3	5.3	170
14	4/15/86									
14	4/15/86			1510						
14	4/15/86									
14	5/20/86									
14	5/20/86		494							
14	5/20/86									
11[a]		6522	675	1510	13223					

[a]Estimated as mean of batches 9, 12, and 14

Table 34. Ion-exchange column test results for caustic/soda-ash softened water[a]

Test material	Date	Feed batch	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L) Gross beta	^{137}Cs	^{90}Sr	^{85}Sr	Fractional breakthrough Gross beta	^{137}Cs	^{90}Sr	^{85}Sr
HCR-S	3/31/86	9	0.9	239				282				0.02
	3/31/86	9	1.0	769				705				0.05
	3/31/86	9	1.0	769	725	721			0.23	0.66		
	4/02/86	9	1.6	2139		1090				1.00		
	4/02/86	9	0.8	2581				3149				0.21
	4/03/86	9	1.0	3662				4700				0.31
	4/03/86	9	1.0	3662	3623	1087			1.15	1.00		
	4/04/86	9	1.0	5162				5217				0.35
	4/04/86	9	1.0	5162	1932	1050			0.62	0.97		
	4/06/86	12	1.0	7896				3525				0.26
	4/07/86	12	1.0	9408				4700				0.34
	4/07/86	12	1.0	9408	2174	410			0.15	0.93		
CS-100	3/31/86	9	1.0	204				3102				0.21
	3/31/86	9	1.1	685				10575				0.70
	3/31/86	9	1.1	685	1449	743			0.46	0.68		
	4/01/86	9	1.1	1169				12126				0.80
	4/01/86	9	1.1	1615				13301				0.88
	4/02/86	9	1.1	2069				13818				0.92
	4/02/86	9	1.1	2069		736				0.68		
	4/02/86	9	1.2	2469				13724				0.91
	4/02/86	9	1.2	2858				13818				0.92
	4/03/86	9	1.3	3246				13583				0.90
	4/03/86	9	1.3	3246	3140	795			1.00	0.73		
	4/03/86	9	1.2	3629				14617				0.97
	4/03/86	9	1.2	4032				14147				0.94
	4/04/86	9	1.3	4428				13395				0.89
	4/04/86	9	1.3	4428	2899	758			0.92	0.70		

Table 34. (continued)

Test material	Date	Feed batch	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L) Gross beta	^{137}Cs	^{90}Sr	^{85}Sr	Fractional breakthrough Gross beta	^{137}Cs	^{90}Sr	^{85}Sr
CS-100	4/07/86	12	1.2	7551	1691	345			0.11	0.78		
IRC-84	3/31/86	9	0.9	231				94				0.01
	3/31/86	9	1.2	708				141				0.01
	3/31/86	9	1.2	708	725	957			0.23	0.88		
	4/02/86	9	1.7	1989		1060				0.97		
	4/02/86	9	0.8	2423				1598				0.11
	4/03/86	9	1.1	3431				2444				0.16
	4/03/86	9	1.1	3431	1691	1072			0.54	0.99		
	4/04/86	9	1.1	4868				3196				0.21
	4/04/86	9	1.1	4868	1932	1060			0.62	0.97		
	4/06/86	12	1.2	7022				2585				0.19
	4/07/86	12	1.3	8245				4841				0.36
	4/07/86	12	1.3	8245	1208	443			0.08	1.00		
	4/09/86	12	1.3	10275				17672				1.30
	4/09/86	12	1.3	10275	2899	371			0.20	0.84		
	4/10/86	11	1.5	10952				18471				1.40
	4/11/86	11	1.3	12060	3140	372			0.48	0.55		
	4/14/86	11	1.2	15760	2416	386			0.37	0.57		
Linde-4A	3/31/86	9	0.9	242				282				0.02
	3/31/86	9	1.5	677				329				0.02
	3/31/86	9	1.5	677	242	31			0.08	0.03		
	4/02/86	9	7.8	1223		354				0.33		
	4/02/86	9	2.7	1339				94				0.01
	4/03/86	9	2.3	1886				611				0.04
	4/03/86	9	2.3	1886	483	88			0.15	0.08		
	4/04/86	9	1.3	3226				1363				0.09

Table 34. (continued)

Test material	Date	Feed batch	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L) Gross beta	^{137}Cs	^{90}Sr	^{85}Sr	Fractional breakthrough Gross beta	^{137}Cs	^{90}Sr	^{85}Sr
Linde-4A	4/04/86	9	1.3	3226	483	204			0.15	0.19		
	4/07/86	12	1.4	6730	483	197			0.03	0.44		
	4/09/87	12	2.1	8507				940				0.07
	4/09/86	12	2.1	8507	483	177			0.03	0.40		
	4/11/86	11	1.8	10065	725	179			0.11	0.27		
	4/14/86	11	3.7	12388				47				0.00
	4/14/86	11	3.7	12388	483	223			0.07	0.33		
	4/15/86	14	1.5	13184				2726				0.25
IE-95	3/31/86	9	0.8	262				470				0.03
	3/31/86	9	1.0	808				2444				0.16
	3/31/86	9	1.0	808	483	10			0.15	0.01		
	4/02/86	9	1.0	2392		12				0.01		
	4/02/86	9	1.0	2851				4700				0.31
	4/03/86	9	1.0	3822				8460				0.56
	4/03/86	9	1.0	3822	2416	17			0.77	0.02		
	4/04/86	9	1.0	5359				10716				0.71
	4/04/86	9	1.0	5359	1932	23			0.62	0.02		
	4/06/86	12	0.9	7951				7708				0.57
	4/07/86	12	1.1	9359				8930				0.66
	4/07/86	12	1.1	9359	1449	30			0.10	0.07		
	4/09/86	12	1.0	11920				13254				0.97
	4/09/86	12	1.0	11920	1691	28			0.11	0.06		
	4/10/86	11	1.3	12715				14100				1.07
	4/11/86	11	1.2	13968	2416	29			0.37	0.04		
	4/14/86	11	1.3	17651	2174	50			0.33	0.07		
CH	4/09/86	11	4.7	46			62				0.04	
	4/10/86	11	1.8	231				423				0.03

Table 34. (continued)

Test material	Date	Feed batch	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L) Gross beta	^{137}Cs	^{90}Sr	^{85}Sr	Fractional breakthrough Gross beta	^{137}Cs	^{90}Sr	^{85}Sr
"CH"	4/10/86	11	1.4	912			54				0.04	
	4/11/86	11	1.6	1239	242	10			0.03	0.01		
	4/12/86	11	1.4	2254				1833				0.14
	4/14/86	11	1.3	4554				3149				0.24
	4/14/86	11	1.3	4554	725	10			0.11	0.01		
	4/14/86	14	1.3	5062			250				0.17	
	4/15/86	14	1.7	5385				2914				0.27
	4/15/86	14	1.7	5385			270				0.18	
PDZ-300-AL	4/10/86	11	5.5	122				141				0.01
	4/11/86	11	2.0	920	242	10			0.04	0.01		
	4/12/86	11	1.4	1635				3384				0.26
	4/14/86	11	1.4	3335				7191				0.54
	4/14/86	11	1.4	3335	725	10			0.11	0.01		
	4/15/86	14	1.5	4120				6956				0.64
PDZ-140-D	5/13/86	14	0.9	292				423				0.04
	5/14/86	14	0.9	885				1222				0.11
	5/14/86	14	1.1	1392				1081				0.10
	5/14/86	14	0.9	1854				1222				0.11
	5/14/86	14	0.9	1854		17				0.03		
	5/15/86	14	1.0	2362				1927				0.18
	5/15/86	14	0.9	3377		38				0.08		
	5/17/86	14	1.0	5382				3149				0.29
	5/17/86	14	0.9	6412		100				0.20		
	5/18/86	14	0.9	6935				3478				0.32
	5/19/86	14	1.0	8474				4371				0.40
	5/19/86	14	1.2	8935				3901				0.36
	5/19/86	14	1.2	8935		136				0.28		

Table 34. (continued)

Test material	Date	Feed batch	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)				Fractional breakthrough			
					Gross beta	^{137}Cs	^{90}Sr	^{85}Sr	Gross beta	^{137}Cs	^{90}Sr	^{85}Sr
"CH"	5/16/87	14	1.1	331		10				0.02		
	5/17/86	14	1.1	827				940				0.09
	5/17/86	14	1.0	1292		13				0.03		
	5/18/86	14	1.0	2196				1645				0.15
	5/18/86	14	1.0	2669		31				0.06		
	5/19/86	14	1.0	3607				2726				0.25
	5/19/86	14	1.3	4031				2585				0.24
	5/19/86	14	1.3	4031		42				0.09		
	5/19/86	14	1.2	4400				2209				0.20
	5/20/86	14	1.3	4785				3008				0.27
	5/20/86	14	1.3	5154				3055				0.28
	5/20/86	14	1.3	5154		57				0.12		
	5/20/86	14	1.4	5415				2726				0.25

[a]Feed concentrations are given in Table 33.

Table 35. Composition of scavenging-precipitation softened feed produced by batch processing for ion-exchange tests in Table 36

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
12/13/85				14	10	1.13	3.82	
12/13/85	24880	6640		14	10	1.13	3.82	
12/13/85				14	10	1.13	3.82	
12/14/85				16	14	0.63	5.52	
12/14/85				16	14	0.63	5.52	
12/14/85				16	14	0.63	5.52	
12/15/85				13	12	0.28	4.69	
12/15/85				13	12	0.28	4.69	
12/15/85				13	12	0.28	4.69	
12/16/85				17	13	0.81	5.31	
12/16/85			13400	17	13	0.81	5.31	
12/16/85				17	13	0.81	5.31	
12/18/85				19	19		7.62	
12/18/85				19	19		7.62	
12/18/85				19	19		7.62	
12/20/85				18	16	0.42	6.41	
12/20/85				18	16	0.42	6.41	
12/20/85				18	16	0.42	6.41	
12/21/85				18	20		7.68	
12/21/85				18	20		7.68	
12/21/85				18	20		7.68	
12/22/85				20	14	1.47	5.65	
12/22/85				20	14	1.47	5.65	
12/22/85				20	14	1.47	5.65	
12/23/85				22	15	1.68	6.04	

Table 35. (continued)

Date	Gross beta (Bq/L)	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Calcium hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
12/23/85				22	15	1.68	6.04	
12/23/85				22	15	1.68	6.04	
12/24/85				13	22		4.30	
12/24/85				13	22		4.30	
12/24/85				13	22		4.30	
12/27/85								
12/27/85	22947	5820						
12/27/85								
12/30/85				18	13	1.02	5.39	
12/30/85				18	13	1.02	5.39	
12/30/85				18	13	1.02	5.39	
12/31/85				19	13	1.31	5.39	
12/31/85				19	13	1.31	5.39	
12/31/85				19	13	1.31	5.39	
01/02/86				21	15	1.41	6.16	270
01/02/86				21	15	1.41	6.16	270
01/02/86				21	15	1.41	6.16	270
Avgerage composition	23913	6230	13400	18	15	1.00	5.00	270

Table 36. Ion-exchange column test results for feed to the scavenging-precipitation softened water[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
HCR-S	12/12/85	4.0	54	2899	811		0.12	0.13	
	12/13/85	4.0	171	3382	5060		0.14	0.81	
	12/13/85	1.2	453	8696	6300		0.36	1.01	
	12/14/85	1.0	1437	9420	6310	1170	0.39	1.01	0.09
	12/15/85	1.0	2878	8696	6280	3020	0.36	1.01	0.23
	12/16/85	1.1	4335			4670			0.35
CS-100	12/12/85	4.6	48	1932	25		0.08	0.00	
	12/13/85	1.8	234	242	67		0.01	0.01	
	12/13/85	1.3	582			451			0.03
	12/14/85	1.1	1473	4106	1330		0.17	0.21	
	12/14/85	1.2	1894			2390			0.18
	12/15/85	1.2	2668	10145	2070	3820	0.42	0.33	0.29
	12/16/85	1.3	3861	28986	3510		1.21	0.56	
	12/16/85	1.1	4275			7900			0.59
	12/18/85	1.5	6265	37682	3920		1.58	0.63	
	12/19/85	2.5	7215	31402	4790		1.31	0.77	
IRC-84	12/13/85	7.2	107	242	2110		0.01	0.34	
	12/13/85	1.4	331		6200	70		0.96	0.01
	12/13/85	0.9	739		6280			1.01	
	12/14/85	1.1	1182	5073	5980		0.21	0.96	
	12/14/85	1.2	1608			77			0.01
	12/15/85	1.1	2400	12561	7170	120	0.53	1.15	0.01
	12/16/85	2.6	3893			186			0.01
	12/27/85	1.2	16431	18358			0.77		
	01/01/86	1.1	23942	30435			1.27		

Table 36. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
Linde-4A	12/13/85	6.2	99	725	140	170	0.03	0.02	0.01
	12/13/85	1.6	299			230			0.02
	12/13/85	0.9	688			500			0.04
	12/14/85	1.1	1144	3382	1430	830	0.14	0.23	0.06
	12/14/85	1.2	1559			920			0.07
	12/15/85	1.2	2300	4831	1980		0.20	0.32	
	12/15/85	1.3	2682			1330			0.10
	12/16/85	1.4	3443	7730	3140		0.32	0.50	
	12/17/85	1.6	4372	7730	2880		0.32	0.46	
	12/17/85	1.1	4744			1970			0.15
	12/18/85	1.5	5509	11111	3000		0.46	0.48	
	12/22/85	1.1	9105		6860			1.10	
	12/25/85	1.2	13069		4030			0.65	
	12/27/85	1.3	15040	13044	5120		0.55	0.82	
	01/01/86	1.0	21727	23430			0.98		
IE-95	12/13/85	4.3	125	725	10	210	0.03	0.00	0.02
	12/13/85	1.3	382			3170			0.24
	12/13/85	0.7	853			5820			0.43
	12/14/85	0.9	1394	17633	70	8690	0.74	0.01	0.65
	12/14/85	1.0	1905			9140			0.68
	12/15/85	0.9	2841	21981	162		0.92	0.03	
	12/16/85	1.1	4699			9130			0.68
	12/17/85	3.6	5363		915			0.15	
	12/18/85	0.9	7118		1210			0.19	
	12/19/85	1.2	8110	28986	1090		1.21	0.17	
	12/22/85	1.0	11240		3140			0.50	

Table 36. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
IE-95	12/25/85	1.1	16001		3100			0.50	
	12/27/85	1.0	17901		4390			0.70	
	01/01/86	1.0	25166		7210			0.16	

[a]Feed concentrations are given in Table 35.

Table 37. Composition of scavenging-precipitation softened feed produced by batch processing for ion-exchange tests in Table 38

Date	^{137}Cs (Bq/L)	^{90}Sr (Bq/L)	^{85}Sr (Bq/L)	Total hardness (mg/L $CaCO_3$)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)
5/09/86				3	0.06	1.20	330
5/09/86	594	770		3	0.06	1.20	330
5/09/86			13066	3	0.06	1.20	330
5/22/86							
5/22/86							
5/22/86			13113				
5/23/86							
5/23/86	575						
5/23/86							
6/03/86							
6/03/86							
6/03/86			7379				
6/05/86				4	0.04	1.30	280
6/05/86	443		6350	4	0.04	1.30	280
6/05/86			6862	4	0.04	1.30	280
6/07/86							
6/07/86							
6/07/86			6439				

Table 38. Ion-exchange column test results for feed to the scavenging-precipitation softened water[a]

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
IRC-84	5/09/86	1.3	540	529		94	0.91		0.01
	5/10/86	1.3	1645	556		235	0.95		0.02
	5/11/86	1.3	2741	566		188	0.97		0.01
	5/12/86	1.4	3173	555			0.95		
	5/16/86	1.3	7261	543			0.93		
	5/16/86	1.3	8015			141			0.01
	5/17/86	1.3	8392			235			0.02
	5/18/86	1.3	9503			235			0.02
	5/19/86	1.3	10597			329			0.03
	5/19/86	1.3	10969			282			0.02
	5/19/86	1.3	11345			517			0.04
	5/20/86	1.3	11728			564			
	5/21/86	1.4	12852			893			0.07
	5/21/86	1.3	13207			987			0.08
	5/21/86	1.5	13547			1081			0.03
	5/22/86	1.6	13862			1128			[illegible]
	5/23/86	4.6	14492	554			1.0		
	5/23/86	1.3	14702	47		1551	0.08		
	5/23/86	3.8	14917	47		846	0.08		
	5/24/86	9.9	15007			423			0.03
	5/24/86	8.6	15060			376			0.03
	5/27/86	0.7	15182			2491			0.19
"CH"	6/03/86	2.2	75	10		94	0.02		0.01
	6/04/86	1.6	610	10		282	0.02		0.04

Table 38. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
"CH"	6/05/86	1.4	1605	10		282	0.02		0.04
	6/05/86	1.3	1950			235			0.03
	6/05/86	1.3	2320			141			0.02
	6/06/86	1.3	2700			376			0.06
	6/06/86	1.3	2700	27		320	0.06		0.05
	6/07/86	1.2	3819			423			0.06
	6/07/86	1.2	3819	43		386	0.10		0.06
	6/08/86	1.3	4943			564			0.08
	6/08/86	1.4	4943	84		518	0.19		0.08
	6/09/86	1.4	6026			752			0.11
	6/09/86	1.4	6026	107		755	0.24		0.11
	6/10/86	1.4	7101	127			0.29		
	6/11/86	1.3	8183	176			0.40		
PDZ-140-D	6/03/86	1.6	95	10		94	0.02		0.01
	6/04/86	1.3	760			329			0.05
	6/04/86	1.3	760	10		194	0.02		0.04
	6/05/86	1.4	1860			517			0.08
	6/05/86	1.4	1860	10		613	0.02		0.09
	6/05/86	1.3	2200			799			0.12
	6/05/86	1.4	2554			799			0.12
	6/06/86	1.5	2902			893			0.13
	6/06/86	1.5	2902	24		949	0.05		0.14
	6/07/86	1.3	3912			987			0.15
	6/07/86	1.3	3912	38		1190	0.09		0.18

Table 38. (continued)

Test material	Date	Residence time (min)	Total throughput (bv)	Effluent concentration (Bq/L)			Fractional breakthrough		
				Gross beta	^{137}Cs	^{90}Sr	Gross beta	^{137}Cs	^{90}Sr
PDZ-140-D	6/08/86	1.5	4922			1504			0.22
	6/08/86	1.5	4922	51		1570	0.12		0.23
	6/09/86	1.4	5947			2162			0.32
	6/09/86	1.4	5947	70		2010	0.16		0.30
	6/10/86	1.3	7042	90			0.20		
	6/11/86	1.3	8117	126			0.28		

[a]Feed concentrations are given in Table 37.

APPENDIX C

RESULTS OF JAR TESTS

APPENDIX C

LARGE-SCALE RESULTS

The experimental data from full- and pilot-scale tests of the potential flowsheets developed in this report are given in Tables 39-44. Data obtained during startup and initial operation of the strong-acid IX flowsheet are listed in Tables 39-42. Tables 43-45 contain data from operation of the full- and pilot-scale zeolite columns. Table 43 summarizes the operation of two full-scale columns containing Ionsiv IE-95, a synthetic chabazite, operated in series. Table 44 contains information for four pilot-scale columns loaded with PDZ-300, a natural chabazite, also operated in series.

Table 39. Operating data for the full-scale reactor/clarifier
(Based on daily log sheets, i.e., from 0800 to 0800 of the next day)

Date	50% NaOH used (gal)	Total flow PWW for day (gal)	50% NaOH/PWW (gal/1000 gal)	Average pH	Average TH[a]
2/22	397	144,000	2.76	11.8	74
2/23	271	144,000	1.88	11.7	65
2/24		Down			
2/25		Down			
2/26	245	144,000	1.70	11.7	100
2/27	434	144,000	3.01	11.8	88
2/28	406	144,000	2.82	11.8	80
3/01	142	144,000	0.99	11.8	58
3/02	38	48,000	0.79	11.8	46
3/03	140	126,000	1.11	11.8	43
3/04	175	123,000	1.42	11.8	48
3/05	204	192,000	1.06	11.8	41
3/06	191	192,000	0.99	11.8	44
3/07	167	171,000	0.98	11.8	48
3/08	152	153,000	0.99	11.8	41
3/09	185	174,000	1.06	11.8	35
3/10	189	150,000	1.26	11.8	32
3/11	236	150,000	1.57	11.7	19
3/12	258	195,000	1.32	11.7	22
3/13	95	194,400	0.49	11.8	7
3/14	123	206,400	0.60	11.8	9
3/15	90	177,000	0.51	11.8	7
3/16	118	216,000	0.55	11.8	7
3/17	106	192,000	0.55	11.8	6
3/18	92	198,000	0.46	11.7	10
3/19	72	216,000	0.33	11.6	9
3/20	76	202,500	0.38	11.6	10
3/21	56	216,000	0.26	11.6	13
3/22	49	210,000	0.23	11.6	10
3/23	47	198,000	0.24	11.6	8
3/24	82	174,000	0.47	11.6	10
3/25	61	183,000	0.33	11.7	10
3/26	83	210,000	0.40	11.6	14
3/27	105	216,000	0.49	11.5	16
3/28	105	216,000	0.49	11.7	14
3/29	61	138,000	0.44	11.7	20
3/30	81	174,000	0.47	11.7	16
3/31	70	162,000	0.43	11.6	10

Table 39. (continued)

Date	50% NaOH used (gal)	Total flow PWW for day (gal)	50% NaOH/PWW (gal/1000 gal)	Average pH	Average TH[a]
4/01	73	198,000	0.37	11.5	8
4/02	60	125,400	0.48	11.8	10
4/03	66	141,600	0.47	11.7	8
4/04	62	144,000	0.43	11.6	5
4/05	64	144,000	0.44	11.6	5
4/06	63	144,000	0.44	11.6	5
4/07	57	144,000	0.40	11.6	5
4/08	74	204,000	0.36	11.5	8
4/09	Unknown	165,000		11.8	10
4/10	Unknown	144,000		11.7	8
4/11	58	144,000	0.40	11.7	7
4/12	56	138,000	0.41	11.7	6
4/13	125	144,000	0.87	11.6	6
4/14	75	144,000	0.52	11.4	5
4/15	72	144,000	0.50	11.5	5
4/16	87	150,000	0.58	11.4	8
4/17	90	174,000	0.52	11.4	8
4/18[b]	67	180,000	0.37	11.5	8
4/19	49	174,000	0.28	11.4	7
4/20	87	186,000	0.47	11.5	6
4/21	89	216,000	0.41	11.4	9
4/22	59	153,000	0.39	11.4	9
4/23	63	144,000	0.44	11.3	9
4/24	70	123,500	0.57	11.3	7
4/25[c]	152	198,000	0.77	11.4	7
4/26	112	216,000	0.52	11.4	7
4/27	76	168,000	0.45	11.4	7
4/28	72	135,605	0.53	11.6	5
4/29	68	130,530	0.52	11.5	4
4/30	68	122,820	0.55	11.5	4
5/01	60	119,955	0.50	11.6	5
5/02	65	121,070	0.54	11.5	3
5/03[d]	Unknown	120,770		11.7	4
5/04[d]	Unknown	117,525		11.6	5
5/05[d]	Unknown	121,550		11.6	4
5/06[d]	Unknown	121,070		11.5	4
5/07[d]	Unknown	121,430		11.5	4
5/08	88	121,885	0.72	11.3	6
5/09	104	185,565	0.56	11.3	6
5/10	76	193,645	0.39	11.4	6

Table 39. (continued)

Date	50% NaOH used (gal)	Total flow PWW for day (gal)	50% NaOH/PWW (gal/1000 gal)	Average pH	Average TH[a]
5/11	67	194,170	0.35	11.4	6
5/12	85	193,530	0.44	11.4	5
5/13	49	150,950	0.32	11.5	6
5/14	42	120,720	0.35	11.6	7
5/15	43	119,230	0.36	11.6	8
5/16	44	121,555	0.36	11.5	4
5/17	53	121,795	0.44	11.6	6
5/18	59	120,170	0.49	11.7	6
5/19	47	121,805	0.39	11.7	8
5/20	64	131,795	0.49	11.7	8
5/21[e]	70	136,635	0.51	11.8	12
5/22	63	130,050	0.48	11.5	10
5/23	94	216,000	0.44	11.3	15
5/24	101	153,000	0.66	11.5	11
5/25	87	144,000	0.60	11.5	8
5/26	87	144,000	0.60	11.4	8
5/27	110	144,000	0.76	11.4	8
5/28	98	144,000	0.60	11.4	7
5/29	73	144,000	0.51	11.5	7
5/30[f]	77	144,000	0.53	11.4	6
5/31	60	144,000	0.42	11.5	7
6/01	71	144,000	0.49	11.4	5
6/02	79	144,000	0.55	11.5	6
6/03	71	144,000	0.49	11.4	5
6/04[g]	102	120,300	0.85	11.4	9
6/05	166	93,600	1.77	11.4	9
6/06	240	126,000	1.90	11.4	10
6/07	364	144,000	2.53	11.4	10
6/08	345	144,000	2.40	11.5	9
6/09	310	144,000	2.15	11.5	9
6/10	Unknown	144,000		11.4	7
6/11	263	117,600	2.24	11.4	8
6/12	238	115,200	2.07	11.4	9
6/13	233	115,200	2.02	11.5	8
6/14	240	135,600	1.77	11.4	8
6/15	251	144,000	1.74	11.4	7
6/16	180	95,700	1.88	11.5	6
6/17	185	93,600	1.98	11.5	7
6/18	137	93,600	1.46	11.5	9
6/19	Unknown	93,600		11.4	9
6/20	146	104,400	1.40	11.4	8

Table 39. (continued)

Date	50% NaOH used (gal)	Total flow PWW for day (gal)	50% NaOH/PWW (gal/1000 gal)	Average pH	Average TH[a]
6/21	180	115,200	1.56	11.4	7
6/22	220	108,000	2.04	11.5	8
6/23	174	98,400	1.77	11.3	10
6/24[h]	158	144,000	1.10	11.4	10
6/25[h]	134	144,000	0.93	11.4	13
6/26	281	144,000	1.95	11.4	8
6/27	303	144,000	2.10	11.4	11
6/28	330	144,000	2.29	11.4	12
6/29	301	144,000	2.09	11.4	19
6/30	260	144,000	1.81	11.5	18
7/01[i]	175	123,000	1.42	11.4	11
7/02	279	144,000	1.94	11.4	10
7/03	323	144,000	2.24	11.5	9
7/04	271	144,000	1.88	11.5	7
7/05	259	144,000	1.80	11.5	8
7/06	327	144,000	2.27	11.4	13
7/07	267	144,000	1.85	11.4	14
7/08[i]	156	100,000	1.56	11.4	11
7/09	263	144,000	1.83	11.3	10
7/10	Unknown	144,000		11.4	14
7/11	295	144,000	2.05	11.4	16
7/12	322	144,000	2.24	11.4	11
7/13	295	141,000	2.09	11.4	8
7/14	518	216,000	2.40	11.4	15
7/15	Unknown	198,000		11.4	13
7/16j		93,000			144
7/17		144,000		9.0	149
7/18		138,000		9.0	163
7/19		144,000		8.9	168
7/20		144,000		8.9	166
7/21		144,000		8.4	162
7/22		144,000		8.7	154
7/23		135,750		8.5 to 11.5	175 to 20
7/24	150	142,200	1.06	11.4	30
7/25	241	189,000	1.28	11.3	16
7/26	302	216,000	1.40	11.3	18
7/27	391	216,000	1.81	11.3	9
7/28	290	159,000	1.82	11.4	8
7/29	230	144,000	1.60	11.3	8

Table 39. (continued)

Date	50% NaOH used (gal)	Total flow PWW for day (gal)	50% NaOH/PWW (gal/1000 gal)	Average pH	Average TH[a]
7/30	236	144,000	1.64	11.4	7
7/31	244	144,000	1.69	11.4	8
8/01	258	144,000	1.79	11.4	8
8/02	255	144,000	1.77	11.4	8
8/03	257	144,000	1.78	11.3	8
8/04	197	144,000	1.37	11.4	8
8/05	180	144,000	1.25	11.4	8
8/06	163	144,000	1.13	11.3	10
8/07	Unknown	141,000		11.3	10

[a]TH = total hardness.
[b]pH control automated starting 4/18.
[c]Ferrous sulfate no longer added after 4/25.
[d]Sight glass on caustic tank plugged from 5/3 to 5/7.
[e]Ferrous sulfate restarted on 5/21 because of high TH.
[f]Ferrous sulfate stopped on 5/30 at 1600.
[g]Dilute caustic use started on 6/4. Concentrated caustic is diluted by a factor of 5. This procedure should help to control pH.
[h]Concentrated caustic used on 6/24 and 6/25.
[i]Partial cleanups of the clarifier were performed on 7/1 and 7/8.
[j]On 7/16 the clarifier was taken down and cleanup started. It was restarted on 7/23 at 1700.

Table 40. Characteristics of full-scale filter press sludge

Drum No.	Date (1986)	Surface reading (mR/h)	Solids (%)	Gross alpha (Bq/g)	Gross beta (Bq/g)	^{90}Sr (Bq/g)	^{137}Cs (Bq/g)	^{60}Co (Bq/g)	^{152}Eu (Bq/g)
1	3/08	20	25.5	45.2	6,350	1,630	674	56	995
2	3/09	20	20.4	48.0	8,240	2,740	242	113	1,140
3	3/10	20	31.3	32.0	15,600	5,300	150	885	786
4	3/10	20	28.4	95.7	25,700	4,800	225		
5	3/11	20	27.6	65.9	15,000	5,910	210	150	532
6	3/12	20	25.9	61.5	8,570	3,170	160	200	525
7	3/12	20	24.8	40.9	13,800	5,170	80	386	358
8	3/13	20	23.0	65.2	8,710	3,080	237	161	360
9	3/14	15	24.0	87.9	8,370	3,730	428		391
10	3/17	20	26.2	68.3	41,900	20,100	424		
11	3/17	10	34.0	79.2	15,800	6,780	534		349
12	3/18	10	37.2	55.0	21,700	7,740	560		392
13	3/19	10	44.2	23.3	12,700	4,640	250		157
14	3/20	10	46.6	50.6	21,200	7,370	565		394
15	3/20	10	41.9	37.5	21,200	7,140	773		648
16	3/20	10	42.0	40.5	20,800	8,210	668		609
17	3/21	10	37.7	34.2	30,900	11,900	877		897
18	3/22	30	36.8	27.4	28,600	11,200	850		742
19	3/23	30	41.9	41.5	35,600	14,300	1,040		642
20	3/24	20	45.9	72.0	45,600	18,500	232	36	123
21	3/25	15	41.9	39.6	37,900	14,000	509	196	423
22	3/25	20	40.2	51.3	33,200	13,900	2,860	501	2,630
23	3/28	10	40.9	28.6	20,200	8,700	340	30	140
24	3/29	7	42.0	16.8	11,700	4,120	107	<10	69
25	3/29	10	39.5	21.1	20,700	8,990	142	42	<35
26	3/29	8	43.8	45.0	21,100	9,430	173	<10	<17
27	3/30	10	45.2	36.2	12,700	4,650	109	11	73
28	3/31	10	44.3	43.4	22,400	8,610	52	101	139
29	4/01	10	40.6	29.2	23,600	9,120	31	40	153
30	4/02	10	45.3	24.9	18,000	6,740	85	56	135
31	4/02	10	50.4	38.3	20,000	7,340	100	35	114
32	4/04	10	49.4	19.0	15,600	6,883	613	50	226
33	4/05	18	48.8	19.0	21,200	7,260	772	68	418
34	4/06	10	45.8	40.0	23,200	6,720	898	46	431
35	4/06	10	42.6	14.0	11,000	3,973	619	18	232
36	4/07	10	43.6	<16.0	10,800	3,800	536	34	168
37	4/07	10	40.4	<16.0	5,980	2,090	386	<12	<32
38	4/08	16	87.5	<19.0	16,900	6,440	646	29	294
39	4/09	6	29.0	<20.0	14,900	5,300	283	33	150
40	4/12	15	40.2	<19.0	21,500	8,150	226	110	212

Table 40. (continued)

Drum No.	Date (1986)	Surface reading (mR/h)	Solids (%)	Gross alpha (Bq/g)	Gross beta (Bq/g)	^{90}Sr (Bq/g)	^{137}Cs (Bq/g)	^{60}Co (Bq/g)	^{152}Eu (Bq/g)
41	4/12	10	37.0	<19	19,200	760	344	67	215
42	4/13	6	39.5	<19	20,200	7,940	138	38	240
43	4/15	6	42.0	<20	19,500	7,120	131	<20	212
44	4/16	6	39.7	<19	17,900	7,040	148	32	184
90	7/20	8	54.3	14	16,800		125		290
91	7/21	8	50.6	22	14,700	5,230	165		296
92	7/21	7	50.9	18	14,900		182		296
93	7/21	7	54	26	15,100	10,200	179	19	301
94	7/21	6							
95	7/28	5							
96	7/30	5							
97	7/30	5							
98	7/31	5	45.6	29	11,600	5,500	122		100
99	8/01	7							
100	8/01	8							
101	8/03	4							
102	8/05	5							
103	8/05	4	55.8	15	7,400	4,350	135		103
104	8/09	4							
105	8/09	4							
106	8/10	4							
107	8/12	4							
108	8/12	4	37.3	15	5,920	3,450	134		
109	8/13	8							
110	8/13	8							
111	8/14	5							
112	8/15	4	44.9	12	8,210		118	<20	170
113	8/16	4							
114	8/16	4							
115	8/16	5							
116	8/16	5							
117	8/17	4	38.9	24	7,780		105		119
118	8/18	4							
LL919	8/22	4							
LL920	8/22	3							
LL921	8/23	4	38.4	11	8,180		102		89
LL922	8/24	3							
LL923	8/25	3							
LL924	8/25	3							
LL925	8/26	3							
LL926	8/28	3	37.4	50	10,100		160	11	204
LL927	8/29	5							

Table 40. (continued)

Drum No.	Date (1986)	Surface reading (mR/h)	Solids (%)	Gross alpha (Bq/g)	Gross beta (Bq/g)	^{90}Sr (Bq/g)	^{137}Cs (Bq/g)	^{60}Co (Bq/g)	^{152}Eu (Bq/g)
LL928	8/29	5							
LL929	8/31	6	37.6	14	20,600		231		112
LL930	9/01	6							
LL931	9/02	5	40.9	27	12,300		207		51
LL932	9/03	4							
LL933	9/03	4							
LL934	9/05	5							

Table 41. Operating data for full-scale HCR-S columns using feedwater softened by the scavenging-precipitation and caustic processes

Column	Column on		Column off		Resin form[a]	Average feed[b]		Run time (h)	Run volume (gal)
	Date (1986)	Time	Date (1986)	Time		TH	pH[c]		
A	2/14	2200	2/16	1330	H	140	7.8	39.5	237,000
D	2/16	1330	2/18	0300	H	140	8.0	37.5	225,000
A[d]	2/18	0300	2/19	1300	H/Na	140 to 75	7.6 to 11.6	34.0	174,000
D	2/19	1300	2/21	1830	Na	50	11.5	53.5	160,500
A[e]	2/21	1830	2/22	1930	Na	58	11.7	25.0	135,000
D	2/22	1930	2/26	0700	Na	40 to 156	11.8 to 9.0	83.5	416,250
A	2/24	0930	2/26	1700	H	150	8.9	55.5	263,250
D	2/26	1700	2/28	1400	Na	50	11.7	45.0	270,000
A[e]	2/28	1400	3/04	0900	Na	45 to 150	11.8 to 9.3	91.0	546,000
D	3/04	0900	3/06	2300	Na	40	11.8	59.5	288,000
A	3/05	1300							
D	3/07	1800	3/08	0900	Na	45	11.8	15.0	82,500
A	3/08	0400	3/08	2200	Na	45	11.8	18.0	100,500
D	3/08	2030	3/10	0200	Na	35	11.8	29.5	227,500
A	3/09	1600	3/10	1800	Na	30	11.7	26.0	141,000
D	3/10	1700	3/11	1300	Na	30	11.7	20.0	115,500
A	3/11	1100	3/15	1400	Na	20 to 6	11.8	98.0	482,000
D	3/12	0700	3/17	1530	Na	30 to 6	11.8	127.5	583,950
A	3/16	0400	3/18	0130	Na	6	11.8	45.5	219,700
D	3/18	0130	3/24	0030	Na	10	11.6	143.0	659,250
A	3/18	1200	3/24	1030	Na	10	11.6	142.5	654,740
D[f]	3/24	0900	3/25	2200	Na	11	11.7	37.0	186,750
A	3/24	2230	3/29	0700	Na	14	11.7	104.5	447,000
D	3/26	0930	3/30	1000	Na	16	11.6	96.5	473,250
A	3/30	1000	4/12	0800	Na	8	11.6	310.0	1,571,750
D	3/30	2200	4/17	0100	Na	8	11.6	170.5	945,750
A	4/16	2300	4/18	2300	Na	8	11.4	48.0	249,000
D	4/17	2100	4/20	0300	Na	7	11.5	50.0	261,000
A	4/19	1700	5/24	1500	Na	7	11.5	836.5	4,172,000
D	4/20	1630	5/26	1300	Na	8	11.4	223.0	1.234,000
A	5/26	1300	6/23	1930	Na	8	11.4	671.0	3,430,200
D	6/23	1930	7/03	0930	Na	12	11.4	226.0	1,353,000
A	7/03	1230	7/11	0530	Na	11	11.4	182.0	1,093,000
D	7/11	0530	7/15	0300	Na	13	11.4	96.0	576,000
A	7/14	0700	7/17	2330	Na	13 to 150	11.4 to 9	88.5	474,000
D[g]	7/15	1400	7/18	2100	Na	13 to 163	11.4 to 9	38.5	204,000
A	7/18	2100	7/20	0400	H	168	8.9	31.0	186,000
D	7/20	0400	7/21	0600	H	166	8.9	26.0	156,000

Table 41. (continued)

Column	Column on		Column off		Resin form[a]	Average feed[b]		Run time (h)	Run volume (gal)
	Date (1986)	Time	Date (1986)	Time		TH	pH[c]		
A	7/21	0600	7/22	1000	H	158	8.6	28.0	168,000
D	7/22	1000	7/23	1000	H	160	8.6	24.0	144,000
A[h]	7/23	1000	8/05	0900	Na	175 to 8	8.5 to 11.3	309.0	1,750,200
D	7/25	1700	8/07	1100	Na	11	11.3	118.0	606,000

[a]"Resin form" refers to the form of IX (i.e., H means that a hydrogen ion is exchanged for the Ca, Mg, Sr, and Cs ions, etc., whereas Na means that a sodium ion is exchanged).

[b]"Average feed" refers to the average total bardness (TH in mg/L as calcium carbonate) and pH of the feed to the IX columns during the period that each column is on-line. The IX feed, of course, is the filtered clarifier effluent. Thus, these values indicate the efficiency at which the clarifier was operating.

[c]The average feed pH values listed are suspect. On approximately March 12, it was discovered that the pH meter being used for manual control of the clarifier pH was not working correctly. Table 39 shows that the caustic use was quite high until March 13. Thus, the pH and the low sodium level were both high. The high sodium level indicates that the sodium was regenerating the IX resins in place, thus probably explaining the low volumes of water treated by the IX columns (run time and volume).

[d]When A column was on-line from 2/18 to 2/19, the resin started in the hydrogen form on raw equalization basin (EB) water with its natural TH of 140 mg/L and pH of ~8. During the run, the plant began to process partially softened water at a high pH (up to 11.6) so that the resin was converted to the sodium form.

[e]D and A columns (on-line from 2/22 to 2/26 and 2/28 to 3/4, respectively) each ran for over 400,000 gal. These longer periods, during which the columns typically only ran for ~200,000 gal, were apparently caused by natural water (i.e., unsoftened) being fed to the columns during the operation. This situation would have swept the high sodium content out of the column, thus extending the run time.

[f]D column, on-line from 3/24 to 3/25, only treated 186,000 gal of water. This situation appears to be caused by the automatic pH controller malfunctioning and again raising the pH and sodium levels too high.

[g]The clarifier was taken out of service at 1000 on 7/16 for cleaning. Starting at 1630, the plant was restarted with the clarifier bypassed. At that time, the IX columns began processing raw EB water.

[h]The clarifier was restarted at 1700 on 7/23.

Table 42. Effluent concentrations from full-scale HCR-S columns using feed softened by the scavenging-precipitation and caustic processes

Column[a,b]	Date (1986)	Gross beta (Bq/L)	^{90}Sr (Bq/L)	^{137}Cs (Bq/L)
L4-A	2/18	290	1.8	
L4-A	2/19	610	9.3	
L4-D	2/20	130	7.9	<10
L4-D	2/21	420	7.2	371
L4-A	5/06	370	8.2	315
L4-A	5/07	390	8.2	348
L4-A	5/08	350	8.3	321
L4-A	5/09	340	7.7	310
L4-A	5/13		1.7	
L4-A	5/14	440	2.9	397
L4-A	5/15	440	2.4	414
L4-A	5/16	430	2.5	387
L4-A	5/17	460	2.2	345
L4-A	5/18	430	1.7	396
L4-A	5/19	500	2.8	318
L4-A	5/20	340	3.5	340
L4-A	5/21	370	2.0	
L4-A	5/22	410	1.6	364
L4-A	5/23	410	3.9	341
L4-A	5/24	410	10.0	344
L4-A	5/24	770	28.0	
L4-A	5/26	330	0.4	417
L4-A	6/07	490	0.1	387
L4-A	6/08	500	0.1	410
L4-A	6/11	510	0.1	365
L4-A	6/12	620	0.1	489
L4-A	6/14		0.1	554
L4-A	6/15	650	0.1	550
L4-A	6/16	630	3.1	574
L4-A	6/17	660	0.5	
L4-A	6/18	570	0.7	
L4-A	6/19	420	0.7	
L4-A	6/20	860	0.4	826
L4-A	6/21	700	88.0	502
L4-A	6/22	650	86.0	481
L4-A	6/23	720	92.0	620
L4-A	6/30	640	11.0	
L4-A	7/01		120.0	
PWTP feed	5/02	3200	2500	317
PWTP feed	5/13	3400	2300	440
PWTP feed	5/21	2900	1900	

Table 42. (continued)

Column[a,b]	Date (1986)	Gross beta (Bq/L)	^{90}Sr (Bq/L)	^{137}Cs (Bq/L)
PWTP feed	6/06	3100	1800	382
PWTP feed	6/11	3700	2000	462
PWTP feed	6/18		1200	
PWTP feed	6/25	2700	1500	632
PWTP feed	7/02	2000	1200	
PWTP feed	7/09	3000	1700	

[a]12,000 bv processed in Column L-4A from 4/19 to 5/24 and 10,000 bv processed from 5/26 to 6/23. Bed was backwashed.

[b]Samples taken from IX column L-4A and L-4D.

Table 43. Performance data for full-scale Ionsiv IE-95 columns [a,b,c]

Date (1986)	Total throughput (bv)	Z1 influent			Z2 influent			Z3 influent			System effluent		
		Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs
1/23	130	5,400	4,700	420	510	5	100				460	3	85
1/24	268	5,600	4,600	710	390	55	57				310	5	32
2/08	337	8,700	3,600	341	2,400	84	38	1,700	53	28			
2/09	449	6,500	3,600	318	2,000	91	24	1,400	5	26			
2/10	558	6,300	3,700	382	1,400	160	21	1,100	11	18			
2/11	658	7,000	3,000	423	1,700	220	39	1,200	16	30	1,100	9	29
2/12	757	5,100	3,200	384	1,200	350	28	710	21	28	700	11	26
2/13	848	4,100	2,700	376	880	360	19	340	15	17	400	6	12
2/14	940	3,600	2,600	554	750	350	15	220	9	14	240	5	10
2/15	1,023	3,100	2,400	519	610	370		150	13		140	12	
2/16	1,106	4,200	2,500	467	1,600	930		170	20		200	7	
2/17	1,192	8,500	5,500	720	2,900	2,100		200	26		220	17	
2/18	1,277	9,200	7,100	574	1,300	950	54	390	28	52	390	13	35
2/19	1,351	7,500	6,100	442	2,700	2,400		160	65		130	42	26
2/20	1,442	8,800	6,200	640	2,700	2,100	33	430	130	23	350	64	23
2/21	1,545	7,800	4,700	549	2,200	1,500	16	410	150		250	90	11
2/21	1,627	9,500	4,800	588	2,600	1,300	18	480	143	11	350	89	
2/22	1,684	8,400	5,000	553	4,200	2,800		400	230		350	150	
2/23	1,799	8,400	5,000	540	3,400	2,600		460	310		380	220	
2/23	1,816	9,000	5,900	526	3,300	2,200		480	310		380	230	

[a]Z1 and Z2 contain ~130 ft^3 (970 gal) of Ionsiv IE-95 zeolite; Z3 contains 15 ft^3 (110 gal) of IE-95.

[b]All concentrations are in Bq/L.

[c]The units are in series. The effluent from Z1 feeds Z2, and the effluent from Z2 feeds Z3.

Table 44. Performance data for pilot-scale PDZ-300 columns [a,b,c,d]

Date (1986)	Z1 influent			Z2 influent			Z3 influent			Z4 influent			System effluent		
	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs
4/29[c]	1,200	1,000	<10	200	26	<10	70	2	11	280	60	22	45	2	<10
4/30[c]	910	730	<10	38	1	<10	57	2	<10	120	20	10	42	4	<10
5/01	850	750	<10	42	3	<10	42	1	<10	50	1	<10	34	1	<10
5/02[f]	780	730	<10	56	1	<10	52	1	19	54	1	<10	46	1	<10
5/03	1,000	700	g	41	1	--	46	1	--	47	1	--	42	1	--
5/04	1,200	800	<10	100	1	<10	150	5	48	93	1	<10	110	1	<10
5/05	1,200	1,000	47	110	2	17	120	1	<10	100	1	<10	85	1	<10
5/06	1,200	1,100	<10	83	10	<10	210	7	11	65	1	<10	75	3	<10
5/07	1,200	1,000	<10	76	17	<10	58	1	<10	85	8	<10	52	1	<10
5/08	1,100	1,100	<10	68	26	<10	43	1	<10	44	1	<10	38	1	<10
5/09	1,100	1,100	<10	88	34	<10	39	1	<10	36	1	<10	32	1	<10
5/10	1,200	680	<10	110	34	<10	46	7	<10	30	1	<10	75	6	<10
5/11[h]	1,100	790	<10	120	52	<10	120	47	<10	24	1	<10	22	1	<10
5/12	960	690	<10	130	52	<10	24	1	<10	25	1	<10	27	1	<10
5/13[i]	920	820	<10	190	73	<10	75	1	<10	65	1	<10	64	1	<10
5/14	920	780	<10	180	98	<10	48	1	<10	40	1	<10	39	1	<10
5/15	880	740	<10	230	110	<10	87	1	<10	74	1	<10	86	1	<10
5/16	870	750	<10	260	120	<10	72	1	<10	75	1	<10	63	1	<10
5/17	1,000	710	<10	320	110	<10	110	1	<10	120	1	<10	130	1	<10
5/18	1,100	790	<10	310	110	<10	110	1	<10	100	1	<10	120	1	<10
5/19	910	690	<10	320	130	<10	98	1	<10	88	1	<10	82	1	<10
5/20	880	690	<10	270	130	<10	53	1	<10	67	1	<10	59	1	<10
5/21[j]	870	820	<10	300	160	<10	62	1	<10	65	1	<10	68	5	<10
5/22	900	810	<10	360	170	<10	62	1	<10	54	1	<10	61	1	<10

Table 44. (continued)

Date (1986)	Z1 influent			Z2 influent			Z3 influent			Z4 influent			System effluent		
	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs
5/23	900	830	<10	380	190	<10	61	2	<10	45	1	<10	48	1	<10
5/24	1,400	830	<10	470	190	<10	50	1	<10	53	1	<10	51	1	<10
5/25	1,600	1,100	--	610	250	--	40	2	--	37	1	--	38	1	--
5/26	1,500	1,200	<10	570	300	<10	43	3	<10	46	1	<10	27	1	<10
5/27	1,100	930	<10	510	280	<10	52	4	<10	31	1	<10	25	1	<10
5/28	1,400	1,200	<10	640	380	<10	52	6	<10	37	1	<10	30	1	<10
5/29	1,500	1,400	<10	690	420	<10	86	10	<10	39	1	<10	36	1	<10
5/30	1,300	1,100	<10	750	440	<10	80	12	<10	45	1	<10	49	1	<10
5/31	1,800	1,200	<10	910	420	<10	70	16	<10	40	1	<10	33	1	<10
6/01	1,300	1,000	<10	760	380	<10	76	17	<10	35	1	<10	25	1	<10
6/02[k]	1,300	1,000	<10	900	330	<10	360	22	<10	300	1	<10	290	1	<10
6/03	1,400	870	<10	1,100	400	<10	480	21	<10	450	1	<10	440	1	<10
6/04	1,200	1,100	<10	740	480	<10	190	19	<10	150	1	<10	140	1	<10
6/05	1,100	950	<10	790	450	<10	230	29	<10	150	1	<10	150	1	<10
6/06[l]	1,300	890	<10	1,000	370	<10	440	29	<10	360	1	<10	330	1	<10
6/07	1,300	790	<10	830	410	<10	240	29	<10	130	1	<10	140	1	<10
6/08	1,200	730	<10	830	340	<10	300	32	<10	230	1	<10	200	1	<10
6/09	1,100	950	<10	710	430	<10	210	29	<10	120	1	<10	100	1	<10
6/10	1,200	880	<10	790	390	<10	240	27	<10	140	1	<10	130	1	<10
6/11[m]	1,300	1,100	<10	860	500	<10	290	48	<10	190	1	<10	190	1	<10
6/12	2,700	2,100	<10	1,500	1,100	<10	280	130	<10	88	1	<10	87	1	<10
6/13	2,100	2,000	<10	1,200	900	<10	320	110	<10	160	1	<10	140	1	<10
6/14	2,400	1,400	<10	1,400	690	<10	360	92	<10	160	1	<10	140	1	<10
6/15	1,400	870	<10	900	470	<10	260	69	<10	120	7	<10	130	1	<10
6/16	1,100	940	<10	1,100	970	<10	220	62	<10	84	6	<10	77	1	<10

Table 44. (continued)

Date (1986)	Z1 influent			Z2 influent			Z3 influent			Z4 influent			System effluent		
	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs	Gross beta	^{90}Sr	^{137}Cs
6/17	1,300	1,100	<10	850	610	<10	250	84	<10	110	11	<10	80	1	<10
6/18[n]	1,300	1,000	<10	930	520	<10	270	84	<10	89	5	<10	70	1	<10
6/19	1,400	1,200	<10	810	590	<10	250	100	<10	99	5	<10	83	1	<10
6/20[o]	2,200	2,000	--	890	760	--	200	85	--	88	4	--	67	1	--

[a]Each vessel contains ~20 ft^3 (150 gal) of PDZ-300 zeolites.

[b]All concentrations are in Bq/L.

[c]Samples are taken at 0630 each day.

[d]The units are in series. In the original configuration, the effluent of Z1 feeds Z2, the effluent of Z2 feeds Z3, and the effluent of Z3 feeds Z4. This configuration will change as columns are taken off-line and the spent zeolite is replaced with fresh resin.

[e]The high values for Z4 on 4/29 and 4/30 probably reflect some initial contamination present in the Z3 vessel that was subsequently washed out.

[f]On 5/2, the influent to the filter (i.e., the PWTP feed) contained 3200 Bq/L gross beta and 2500 Bq/L ^{90}Sr. The filter being used before the four zeolite vessels is one of the 6-ft-diam Chem-Nuclear units previously purchased. It contains 130 ft^3 of IE-95, a synthetic zeolite resin. From the previous test in January and February, it was loaded to >50% capacity. It should soon stop adsorbing strontium.

[g]Means the results have not yet been obtained.

[h]On 5/11/87, the columns were restarted using the following configuration. PWTP feed was prefiltered using a sand filter and now feeds Z3. The Z3 effluent feeds Z4, Z4 effluent feeds Z1, Z1 effluent feeds Z2, and Z2 discharges to L5.

[i]On 5/13, the PWTP feed contained 3400 Bq/L gross beta, 2300 Bq/L ^{90}Sr, and 440 Bq/L ^{137}Cs.

[j]On 5/21, the PWTP feed contained 2900 Bq/L gross beta and 1900 Bq/L ^{90}Sr.

[k]The high gross beta values observed starting on 6/2 are apparently caused by the decay of ^{90}Sr to ^{90}Y and the subsequent wash-through of the yttrium.

[l]On 6/06, the PWTP feed contained 3100 Bq/L gross beta, 1800 Bq/L ^{90}Sr, and 382 Bq/L ^{137}Cs.

[m]On 6/11, the PWTP feed contained 3700 Bq/L gross beta, 2000 Bq/L ^{90}Sr, 462 Bq/L ^{137}Cs, 27 Bq/L ^{152}Eu, and 15 Bq/L of ^{60}Co.

[n]On 6/18, the PWTP feed contained 1200 Bq/L ^{90}Sr.

[o]The system was shut down at 2030 on 6/20/86 because of a high pressure drop across Z1 (probably caused by high levels of algae in the EB). The zeolite was replaced, all columns were backwashed, and Z1 moved to the back of the train of columns. The system sat idle until May 1987. A high pressure drop across Z2 at startup caused us to replace the zeolite and move Z2 to the end of the train. The pressure drop was later attributed to plugging of the distributor.

Table 45. Volume of process wastewater treated as of 0630 on the the indicated dates (total gallons of water divided by 150)

Date	No. bv	Date	No. bv	Date	No. bv	Date	No. bv
4/29	152	5/14	2475	5/29	4783	6/13	7119
4/30	338	5/15	2630	5/30	4946	6/14	7278
5/01	479	5/16	2795	5/31	5102	6/15	7435
5/02	639	5/17	2945	6/01	5254	6/16	7587
5/03	792	5/18	3093	6/02	5406	6/17	7743
5/04	947	5/19	3252	6/03	5564	6/18	7901
5/05	1124	5/20	3403	6/04	5724	6/19	8054
5/06	1273	5/21	3556	6/05	5882	6/20	8205
5/07	1426	5/22	3709	6/06	6037	Shutdown	8288
5/08	1577	5/23	3862	6/07	6196		
5/09	1724	5/24	4016	6/08	6346		
5/10	1877	5/25	4168	6/09	6498		
5/11	2026	5/26	4321	6/10	6655		
5/12	2171	5/27	4473	6/11	6813		
5/13	2321	5/28	4627	6/12	6966		