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**MARTIN MARIETTA**

## **Treatability Studies in Support of the Nonradiological Wastewater Treatment Project**

J. M. Begovich  
C. H. Brown, Jr.  
J. F. Villiers-Fisher  
V. L. Fowler

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Chemical Technology Division

NUCLEAR AND CHEMICAL WASTE PROGRAMS  
Environmental Restoration and Facilities Upgrade Program  
(Activity No. KG 02 00 00 0, KGO 2300)

TREATABILITY STUDIES IN SUPPORT OF THE NONRADIOLOGICAL  
WASTEWATER TREATMENT PROJECT

J. M. Begovich  
C. H. Brown, Jr.  
J. F. Villiers-Fisher  
V. L. Fowler

Environmental Control Technology Group

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## CONTENTS

	<u>Page</u>
LIST OF FIGURES . . . . .	vii
LIST OF TABLES . . . . .	ix
GLOSSARY . . . . .	xi
ABSTRACT . . . . .	1
1. INTRODUCTION . . . . .	2
2. CHARACTERIZATION OF FEED STREAMS . . . . .	4
3. SIMPLIFIED FLOWSHEET . . . . .	9
4. PHASE I RESULTS . . . . .	11
4.1 BACKGROUND . . . . .	11
4.2 METALS REMOVAL VIA PRECIPITATION . . . . .	16
4.3 REMOVAL OF ORGANIC CONTAMINATION VIA AIR STRIPPING . . . . .	18
4.4 ALTERNATIVE METHODS FOR METALS REMOVAL . . . . .	23
4.4.1 Batch Adsorption Tests with Amberlite IRC-718 Resin . . . . .	23
4.4.2 Heavy-Metals Removal with Cellulose Xanthate. . . . .	27
4.5 SCREENING OF MERCURY REMOVAL FROM MH-190 WATERS BY GAC . . . . .	29
5. PHASE II RESULTS . . . . .	31
5.1 CHARACTERIZATION OF 190 WEIR BOX WATER . . . . .	31
5.2 PRECIPITATE SETTLING TESTS . . . . .	31
5.3 SLUDGE DEWATERING TESTS . . . . .	35
5.4 JAR TESTS . . . . .	35
5.5 REACTOR/CLARIFIER-DUAL-MEDIA FILTER . . . . .	37
5.6 AIR STRIPPING OF TRACE ORGANICS - BEAKER TESTS . . . . .	43
5.7 CARBON ISOTHERMS - MERCURY, DBP, AND NAPHTHALENE . . . . .	45
5.8 ION EXCHANGE FOR METALS REMOVAL . . . . .	50
6. FLOWSHEET AND DESCRIPTION OF THE MINI-PILOT PLANT EQUIPMENT . . . . .	52
6.1 API SEPARATOR . . . . .	52
6.2 REACTOR/CLARIFIER . . . . .	58
6.3 DUAL-MEDIA FILTERS . . . . .	61
6.4 AIR STRIPPER . . . . .	61
6.5 ACTIVATED-CARBON COLUMNS . . . . .	61
6.6 ION-EXCHANGE COLUMN. . . . .	64

CONTENTS (continued)

	<u>Page</u>
7. OPERATION OF THE MINI-PILOT PLANT SYSTEM . . . . .	64
7.1 ACQUISITION OF FEED STREAMS . . . . .	64
7.2 SPIKING OF FEED STREAMS . . . . .	67
7.3 DETAILED FLOWSHEET . . . . .	70
7.4 ACTUAL OPERATING CONDITIONS . . . . .	75
8. MINI-PILOT PLANT RESULTS AND DISCUSSION . . . . .	77
8.1 API SEPARATOR . . . . .	77
8.2 REACTOR/CLARIFIER . . . . .	77
8.2.1 Lime-Soda Softening . . . . .	77
8.2.2 Caustic Precipitation . . . . .	79
8.3 DUAL-MEDIA FILTERS . . . . .	79
8.4 ADJUSTMENT OF pH . . . . .	84
8.5 AIR STRIPPER . . . . .	85
8.6 CARBON COLUMNS . . . . .	88
8.6.1 Toxic Trace Elements . . . . .	88
8.6.2 Mercury Removal . . . . .	89
8.6.3 Organics Spiking . . . . .	89
8.6.4 Chloroform Removal . . . . .	91
8.6.5 Naphthalene and DBP Removal . . . . .	91
8.6.6 Biogrowth in Granular Activated-Carbon Columns . . . . .	91
8.6.7 Radionuclide Accumulation . . . . .	94
8.7 THE ION-EXCHANGE SYSTEM . . . . .	98
8.7.1 Hydraulic Life . . . . .	98
8.7.2 Ion-Exchange Column Performance . . . . .	99
8.8 PRECIPITATOR SLUDGE . . . . .	99
8.9 MISCELLANEOUS RESULTS . . . . .	101
8.9.1 Arsenic and Selenium . . . . .	101
8.9.2 Total Suspended Solids (TSS) . . . . .	101
8.9.3 Total Dissolved Solids (TDS) . . . . .	105
8.9.4 Total Organic Carbon (TOC) . . . . .	105
8.9.5 Biological Oxygen Demand (BOD) . . . . .	105
8.9.6 Biototoxicity Test . . . . .	105
9. CONCLUSIONS . . . . .	106
ACKNOWLEDGMENTS . . . . .	111
10. REFERENCES . . . . .	113

CONTENTS (continued)

	<u>Page</u>
APPENDIX A. RESULTS OF JAR TESTS. . . . .	115
APPENDIX B. SUMMARY OF MPP OPERATIONS . . . . .	133
APPENDIX C. MPP DATA SUMMARY. . . . .	143



LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	A simplified flowsheet of the Nonradiological Wastewater Treatment Project . . . . .	10
2	Titration of MH-190 weir box water . . . . .	32
3	Settling column data: lime and 0.5 mg/L polymer (Percol 727) . . . . .	33
4	Settling column data: caustic and 2 mg/L polymer (Percol 728) . . . . .	34
5	Trace element precipitation/filtration system. . . . .	39
6	Carbon isotherm for mercury at pH 10 . . . . .	51
7	Layout of mini-pilot plant . . . . .	55
8	API separator . . . . .	56
9	Sludge-blanket type of reactor/clarifier . . . . .	57
10	Rapid mixer for precipitator . . . . .	59
11	Precipitator/clarifier for caustic campaign . . . . .	60
12	Dual-media filter . . . . .	62
13	Air stripper . . . . .	63
14	Granular activated-carbon column . . . . .	65
15	Ion-exchange column . . . . .	66
16	Mini-pilot plant piping and instrumentation diagram . . . . .	71
17	Simplified block flow diagram of the mini-pilot plant . . . . .	76
18	Metals removal in the mini-pilot plant using lime precipitation . . . . .	107
19	Metals removal in the mini-pilot plant using caustic precipitation with metal spikes . . . . .	108
20	Metals removal in the mini-pilot plant using caustic precipitation without metal spikes . . . . .	109



LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	NPDES effluent limitations for the Nonradiological Wastewater Treatment plant . . . . .	5
2	Source characterization of influent wastewaters of the NRWT plant . . . . .	6
3	Flow rates of wastewater sources of the NRWT plant . . . . .	8
4	Volumetric proportions of the NRWT raw water composite . . . . .	12
5	Raw water assays (mg/L) . . . . .	13
6	Radionuclide assays (Bq/L) . . . . .	15
7	Precipitation test sequence . . . . .	17
8	Trace element precipitation . . . . .	19
9	Total organic carbon of the emulsion during air stripping . . . . .	21
10	IRC-718 capacities for batch-loading tests of trace elements . . . . .	25
11	Control of criteria trace elements with cellulose xanthate . . . . .	28
12	Phase I – granular activated-carbon results . . . . .	30
13	Effective trace element removal conditions during the jar tests . . . . .	38
14	Feed stock tests . . . . .	41
15	Softening/filtration process effluents . . . . .	42
16	Air stripping beaker tests . . . . .	44
17	Carbon isotherm contact-time study . . . . .	46
18	Zero carbon-loading assays . . . . .	46
19	DBP and mercury carbon isotherm tests . . . . .	47
20	Phase II bench-scale resin column tests . . . . .	53

LIST OF TABLES (continued)

<u>Table</u>		<u>Page</u>
21	Decrease of nitrate concentration in the Equalization Basin . . . . .	68
22	Proportions of the various wastewaters collected . . . . .	68
23	Relative stream contributions to the precipitator loop in the MPP . . . . .	69
24	Pressure drops across dual-media filters during lime-soda campaign . . . . .	81
25	Pressure drops across dual-media filters during caustic campaign . . . . .	82
26	Chloroform levels at various sample points in the MPP . . . . .	86
27	Pressure drops across GAC columns during lime-soda campaign . . . . .	93
28	Pressure drops across 33%-full GAC columns during caustic campaign . . . . .	95
29	Pressure drops across empty and 33%-full GAC columns . . . . .	96
30	Radionuclide analyses on spent GAC . . . . .	97
31	ICP results from the MPP around the IX column . . . . .	100
32	Centrifuged precipitator sludge from the lime-soda campaign . . . . .	102
33	Centrifuged precipitator sludge from the caustic campaign with metal spikes . . . . .	103
34	Dewatered precipitator sludge from the caustic campaign with no metal spikes . . . . .	104

## GLOSSARY

AA	atomic absorption
ACD	Analytical Chemistry Division
A/E	architect/engineer
A/S	air stripper
API	American Petroleum Institute
BAT	best available technology
BOD	biological oxygen demand
CDR	Conceptual Design Report
COD	chemical oxygen demand
DBP	dibutyl phthalate
ECT	Environmental Control Technology
EPA	Environmental Protection Agency
GAC	granular activated carbon
gpd	gallons per day
gpm	gallons per minute
HFIR	High Flux Isotope Reactor
ICP	inductively coupled plasma
IX	ion exchange
MH	manhole
MPP	mini-pilot plant
NPDES	National Pollutant Discharge Elimination System
NRWT	nonradiological wastewater treatment
NRWTP	Nonradiological Wastewater Treatment Project
ORNL	Oak Ridge National Laboratory
ppb	parts per billion
ppm	parts per million
PWTP	Process Waste Treatment Plant
R/C	reactor/clarifier
TDS	total dissolved solids
TOC	total organic carbon
TRU	Transuranium Processing Plant
TSS	total suspended solids
TURF	Thorium Uranium Recycle Facility



TREATABILITY STUDIES IN SUPPORT OF THE  
NONRADIOLOGICAL WASTEWATER TREATMENT PROJECT

J. M. Begovich  
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V. L. Fowler

ABSTRACT

The Nonradiological Wastewater Treatment Project (NRWTP) will treat nonradiological wastewaters generated at the Oak Ridge National Laboratory (ORNL) to pollutant levels acceptable under restrictions imposed by the effluent limits of best available technology (BAT) regulations of the U.S. Environmental Protection Agency (EPA), according to the goals established by the Clean Water Act.

A three-phase treatability study was conducted to resolve many of the uncertainties facing the NRWTP. The first phase consisted of batch simulation of the proposed NRWTP flowsheet in the laboratory. The Phase I results revealed no major problems with the proposed flowsheet. Phase II consisted of more-detailed parametric studies of the flowsheet processes at a bench-scale level in the laboratory. The Phase II results were used to guide the planning and design of the Phase III study, which consisted of flowsheet simulation on a continuous basis using a mini-pilot plant (MPP) facility. This facility is contained within two connected semitrailer vans and an analytical trailer.

The purpose of this effort was to simulate the treatment the ORNL nonradiological wastewaters will receive in the NRWT plant. These tests provided the detailed design data needed by the architect/engineer (A/E) in designing the NRWT plant, served as a performance check to determine plant removal efficiencies and water effluent quality, and identified potential improvements in the proposed flowsheet.

The influent to the NRWT plant will come from several sources and will typically contain occasional surges of the heavy metals (ppm levels or less), lasting up to a few hours, and a wide variety of criteria organics at the ppb level. Sources of feed to the plant include: (1) drainage from various laboratories (chemical, physics, electronics, biological, environmental, and metallurgical); (2) process wastewater pretreated for radionuclides removal; (3) boiler blowdown from the steam plant; and (4) aqueous streams from several radiochemical processing plants and reactor operations.

The handling of this wastewater is not a typical treatment problem due to its dilute nature, widely varying composition, and high flow rate - 350 gpm nominal up to 560 gpm maximum.

The following bench-scale treatability studies were performed: titration curves, jar tests to determine the optimum precipitation chemistry, polymer selection, column settling tests, filterability tests, air stripping experiments, carbon isotherm studies, and heavy-metal-selective, ion-exchange resin tests.

In the MPP, all wastewaters, with the exception of those not containing heavy metals, flowed through an API-type separator. The criteria metals (except for mercury) were removed in the reactor/clarifier as hydroxide precipitates. Overflow from the precipitator was then treated by dual-media filters. Wastewaters that had been pretreated by ion exchange for radionuclide removal bypassed the first three unit operations and were combined with the other wastewaters prior to air stripping. Volatile organics were removed by the air stripper, while heavy (nonvolatile) organics and mercury were removed in the granular activated-carbon columns.

In general, results of the bench-scale treatability studies correlated well with those of the MPP studies. Biogrowth proved to be a major operational consideration in the MPP despite the low available level of total organic carbon ( $\approx 8$  ppm); it prohibited the continuous operation of the ion-exchange column and dictated special design features for both the air stripper and the carbon columns. The necessary design data were provided to the A/E, and operation of the MPP demonstrated that BAT guidelines are achievable for the ORNL nonradiological wastewaters using the selected unit processes.

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## 1. INTRODUCTION

The Nonradiological Wastewater Treatment Project (NRWTP) will treat nonradiological wastewaters, generated at the Oak Ridge National Laboratory (ORNL), to pollutant levels acceptable under restrictions imposed by the effluent limits of best available technology (BAT) regulations of the U.S. Environmental Protection Agency (EPA), according to the goals established by the Clean Water Act.

Martin Marietta Energy Systems, Inc., Engineering has issued a Conceptual Design Report (CDR)<sup>1</sup> and a Design Criteria Document<sup>2</sup> concerning the NRWTP. To resolve many of the uncertainties facing the NRWTP, the Environmental Control Technology (ECT) group of the Chemical Technology Division (Chem Tech) engaged in a three-phase treatability

study of the NRWTP. Initial scouting work was done in which granular activated-carbon (GAC) adsorption and reverse osmosis were operated on two of the major feed streams to the NRWTP plant<sup>3</sup>. The first phase of the main study consisted of batch simulation of the proposed NRWTP flowsheet in the laboratory. Phase II consisted of more detailed parametric studies of the flowsheet processes at a bench-scale level in the laboratory. The Phase II results were used to guide the planning and design of the Phase III study, which consisted of flowsheet simulation on a continuous basis using a mini-pilot-plant (MPP) facility. This facility is contained within three semitrailer vans located next to Building 3544 at ORNL and bounded by Building 3544 on the west, Building 3518 on the north, and the 3513 settling basin on the east.

The purpose of the MPP was to simulate the treatment the ORNL nonradiological wastewaters will receive in the NRWTP plant. The results from these tests provided the detailed design data needed by the architect/engineer (A/E) in designing the NRWTP facility. The tests also served as a performance check to determine plant removal efficiencies and effluent water quality and helped to identify potential improvements in the proposed flowsheet.

The MPP was run in essentially two campaigns over a 5-month period. In the first, heavy metals (i.e., Ag, Cd, Cr, Cu, Fe, Ni, Pb, and Zn) were precipitated using calcium hydroxide (lime) and sodium carbonate (soda ash) in a reactor/clarifier operating with a sludge blanket. In the second campaign, the metals were precipitated using sodium hydroxide (caustic) in a reactor, with the subsequent removal of the floc that formed in a separate clarifier.

Following the precipitation step, the water was treated in a dual-media (sand and anthracite) filter. Next, the pH of the water was adjusted to 7, and the volatile organics were removed by air stripping in a packed tower. Finally, the water was passed through three columns in series filled with granular, activated carbon in which the nonvolatile organics and mercury were removed. In both campaigns, the concentrations of criteria metals were reduced to well below the likely

discharge limits of the National Pollutant Discharge Elimination System (NPDES) permit.

The remainder of this document details: (1) the typical influent streams the NRWT plant will receive; (2) the simplified flowsheet and results of the Phase I and II studies; (3) the flowsheet and specific unit operations to be used to treat the feed streams; (4) the system operation, including procedures by which these streams were acquired for MPP treatability studies and spiked to detectable levels in metals and organics; (5) the results from the two campaigns; and finally, (6) the conclusions formulated by this treatability work.

## 2. CHARACTERIZATION OF FEED STREAMS

The influent to the NRWT plant will come from several sources and will typically contain varying amounts of heavy metals, volatile and nonvolatile organics, and other pollutants. As ORNL encompasses a wide variety of disciplines, the process wastewater will come from a number of different sources, including chemical, physics, electronic, biological, environmental, and metallurgical laboratories. The effluent standards that have been listed on the NPDES permit<sup>4</sup> are shown in Table 1.

Sources of feed to the plant include: (1) drainage from the 4500 complex (usually referred to as 190 pond water and marked as Ponds 3539 and 3540); (2) treated process wastewater from the Process Waste Treatment Plant (PWTP) in Building 3544; (3) boiler blowdown and demineralizer regeneration wastes from the steam plant (referred to as 3518 water); (4) waters from the High Flux Isotope Reactor (HFIR), Transuranium Processing Plant (TRU), and Thorium Uranium Recycle Facility (TURF); (5) drainage from the Building 2000 and Building 1505 areas; and (6) miscellaneous streams accessible through manholes (MH) 229, 149, 25, 240, 235, and 189. The characteristics of these streams, as taken from the Design Criteria Document<sup>2</sup>, are shown in Table 2, and typical flow rates of these streams, also taken from ref. 2, with the exception of the HFIR and 3544 flow rates, are shown in Table 3. As part of the detailed design effort by the A/E for the NRWTP, a thorough

Table 1. NPDES effluent limitations for the  
Nonradiological Wastewater Treatment plant<sup>a</sup>

Parameter	Monthly average (mg/L)	Daily maximum (mg/L)
Total suspended solids	31	60
Oil and grease	10	15
Total toxic organics	--	2.13
Cyanide	0.65	1.20
Cadmium	0.26	0.69
Chromium	1.71	2.77
Copper	2.07	3.38
Lead	0.43	0.69
Nickel	2.38	3.98
Silver	0.24	0.43
Zinc	1.48	2.61

<sup>a</sup>Standards listed on the National Pollutant Discharge Elimination System (NPDES) Permit No. TN 0002941 for the NRWT plant at the Oak Ridge National Laboratory.

Table 2. Source characterization of influent wastewaters of the NRWT plant<sup>a</sup>

Parameter	190 Ponds	2000	1505	3544	HFIR	TRU	TURF	3518
Flow, gpm	125	10	6	110	25	10	1	28
pH	6.8	7.5	6.6	8.2	6.9	7.3	7.7	6.3
<u>(mg/L)</u>								
BOD	5	5	30	5	5	5	5	5
COD	8	17	6	6	5	7	5	16
TOC	8	2	9	3	4	3	2	8
TSS	5	5	8	5	5	10	5	9
TDS	180	186	178	793	350	228	166	1550
Ammonia	0.8	0	0.2	0.2	0	0.2	0	0
Nitrate	5	5	5	287	190	9	5	20
Phosphate	5	5	5	5	5	31	5	5
Oil & grease	2	2	2	2	2	2	2	2
<u>(<math>\mu\text{g/L}</math>)<sup>b</sup></u>								
Cd	660	11	140	9	1100	17	9	52
Cr	450	10	120	14	25	440	17	45
Cu	280	30	30	20	360	200	39	40
Fe	210	58	390	140	100	220	140	560
Hg	6	0.5	0.6	0.4	0.3	1	0.1	0.1
Ni	10	12	39	10	10	120	10	27
Pb	55	4	4	37	46	22	9	70
Zn	220	140	160	50	200	470	250	730
Ag	0	0	0	0	0	0	0	0
Sr	100	100	95	5	120	100	100	500
CN	4	5	21	8	2	26	5	2
Phenols	3	2	4	1	25	9	2	1
PCB	0.1	0.1	0.1	0.1	0.1	0.1	0.6	0.1
Chloroform	18	10	8	5	5	3	4	19
Chlorobenzene	94	74	20	20	33	20	22	25
Methylene chloride	530	2	2	510	2	5	5	12
Trichloroethylene	74	100	45	62	39	41	61	54
1,1,1-trichloroethane	27	16	16	19	17	16	16	16

Table 2 (continued)

Parameter	190 Ponds	2000	1505	3544	HFIR	TRU	TURF	3518
<u>(mg/L)</u>								
Ca	30	30	30	0.5	40	30	34	200
Mg	10	10	10	0.1	12	10	10	65
Na	7	7	8	70	12	8	8	540
K	2	2	2	0.5	3	3	2	100

<sup>a</sup>Taken from Design Criteria for Nonradiological Wastewater Treatment Project, Document No. X-OE-299, Martin Marietta Energy Systems, Inc., Engineering, July 15, 1985.

<sup>b</sup>The trace metal values listed are the maximum values reported for each element. The average values are often much lower. Some values were not confirmed by alternate assay procedures.

Table 3. Flow rates of wastewater sources of the NRWT plant<sup>a</sup>

Source	Flow rate	
	(gpm)	(%)
4500 Area (190 ponds)	125	35
2000 Area	10	3
1505 Area	5	1
Miscellaneous	40	11
3518	30	8
HFIR <sup>b</sup>	10	3
TRU	10	3
TURF	1	1
3544 <sup>b</sup>	<u>125</u>	<u>35</u>
Total	356	100

<sup>a</sup>Taken from Design Criteria for Nonradiological Wastewater Treatment Project, Martin Marietta Energy Systems, Inc., Engineering, Document No. X-OE-299, July 15, 1985.

<sup>b</sup>Denotes change from Table 2.3, as given in above document, to reflect more likely average flow rates.

evaluation of existing hydraulic data will be performed and the flow rates adjusted accordingly.

The ORNL nonradiological wastewaters consist primarily of Oak Ridge city water contaminated with the products of ion-exchange demineralization of the water and with what appear to be spills or washdowns of small quantities of criteria trace elements and organics. The available data suggest that most criteria contamination occurs randomly at less than the 1-ppm level for any component. Mercury is always found at just above the allowable limits in the 4500 complex wastes. This may reflect mercury accumulations in the traps, joints, etc., of this system. Traces of radionuclides are also found in the wastewaters. In addition, there may be groundwater leakage into the plant drainage system.

About 70% of the wastewater has a nearly constant composition. The 190 pond water has occasional 1-ppm spikes of criteria elements and organics. The 3544 water averages <20 Bq/L of radionuclides and contains essentially no multivalent elements. The 3518 water is city water enriched with the products of its demineralization together with the demineralization resin regenerants. It enters as a daily batch discharge (40,000 gpd)<sup>a</sup> and may be strongly basic or acidic. The HFIR and TRU wastewaters are also a mix of city water and demineralization regenerant water. The 2000 and 1505 area waters are essentially city waters with traces of contaminants similar to the 190 pond waters.

### 3. SIMPLIFIED FLOWSHEET

The first phase of treatability studies consisted of a cursory evaluation of the proposed flowsheet for the NRWT plant via batch simulation in the laboratory. A block representation of this flowsheet is presented in Fig. 1. The plant consists of an equalization capacity on the front end into which flows all of the Melton and Bethel Valley

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<sup>a</sup> 40,000 gpd may be an error in a previous report. It represents the maximum winter value. According to steam plant records for the period September 1983 to August 1984, the average value was 20,700 gpd, or 14.4 gpm.

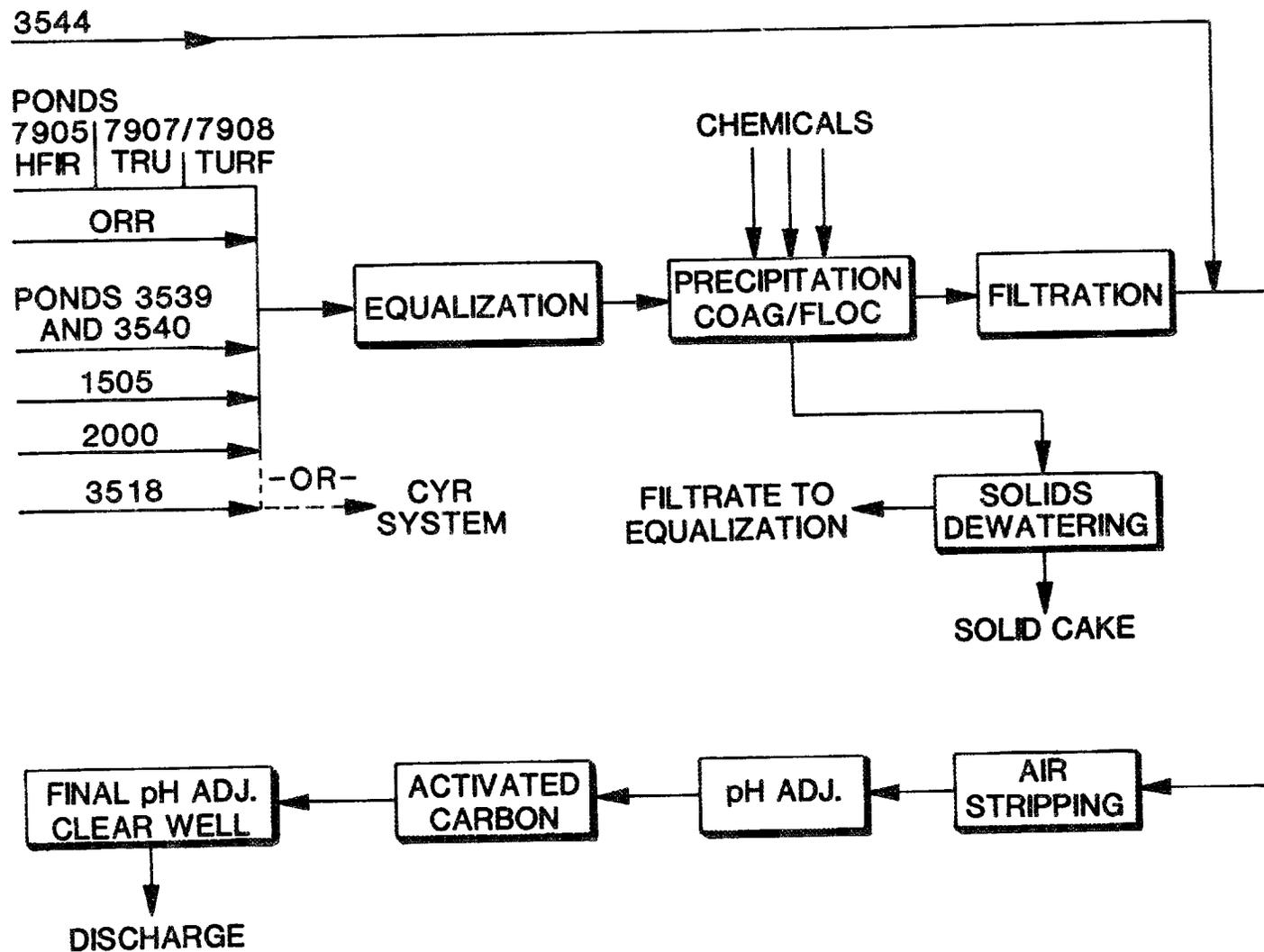


Fig. 1. A simplified flowsheet of the Nonradiological Wastewater Treatment Project.

streams except the effluent from the PWTP. From the Equalization Basin, the water is processed first through a reactor/clarifier to remove heavy metal contamination via precipitation. The sludge from the reactor/clarifier is dewatered and stored in an undetermined location, while the aqueous effluent is processed through a filter for total suspended solids (TSS) reduction. This stream is then combined with the PWTP effluent and processed sequentially through air stripping (for volatile organic reduction), pH adjustment, activated carbon (for nonvolatile organic reduction), and final pH adjustment before being discharged to the environment.

#### 4. PHASE I RESULTS

##### 4.1 BACKGROUND

Utilizing wastewater collected in the field and composited to simulate the actual feed to the NRWT plant, the following treatment steps were tested in the laboratory: (1) metals removal by precipitation, (2) volatile organic removal via air stripping, and (3) metals removal via cellulose xanthate and chelating ion-exchange resin. The tests performed and results achieved are summarized in this section.

To most closely simulate the NRWT plant feed stream, 48-h composite samples of each of the contributing waste sources were collected. The composites were blended in proportion to their expected flow rates as shown in Table 4. Assays of the blended composite and two other streams of interest, the steam plant wastewater discharge (Bldg. 3518) and the process waste treatment effluent (Bldg. 3544), are shown in Tables 5 and 6. The alkali metals, sulfate, and chloride levels in the composite are higher than that projected from the mix of process water and the steam plant effluent, suggesting that another major source had contributed water softener regeneration waste. This phenomenon had not been noticed during a sampling program conducted December 12 to 19, 1984.

Table 4. Volumetric proportions of  
the NRWT raw water composite

Source	Vol %
HFIR	21.5
TRU	11.4
190 Pond	42.1
1505	2.5
2000	2.5
MH-240	1.7
MH-25	1.7
MH-149	2.7
MH-235	0.7
MH-229	3.5
MH-189	0.5
TURF	2.2
3518	6.9

Table 5. Raw water assays (mg/L)

	Composite	3518 <sup>a</sup>	3544 <sup>b</sup>
Ag	<0.07	<0.07	<0.07
Al	0.32	0.49	0.29
As	<0.2	<0.2	<0.2
B	0.11	0.14	0.16
Ba	0.056	0.18	<0.02
Be	<0.001	<0.001	<0.001
Ca	57	200	0.22
Cd	<0.009	<0.009	<0.009
Co	<0.02	<0.02	<0.02
Cr	0.0084	0.051 <sup>c</sup>	<0.008
Cu	0.029	0.023	<0.02
Fe	<0.03	0.14	<0.03
Hf	0.065	0.13	0.065
K	4	12.8	1.3
Li	<0.02	0.38	<0.2
Mg	21	51	0.054
Mn	0.0036	0.039	<0.003
Mo	<0.02	0.037	<0.02
Na	80	620	280
Ni	<0.06	<0.06	<0.06
P	0.68	5	<0.3
Pb	<0.2	<0.2	<0.2
Sb	<0.3	<0.3	<0.3
Se	<0.4	<0.4	<0.4
Si	1.5	11	1.6
Sr	1.9	0.57	<0.005
Ti	<0.02	0.02	<0.02
V	<0.03	<0.03	<0.03
Zn	0.084	0.59	<0.02
Zr	<0.06	<0.06	<0.06
SO <sub>4</sub>	80	790	40
NO <sub>3</sub>	14	<50	220
F	1	8	1
Cl	130	940	38
Br	<5	<50	<5
PO <sub>4</sub>	<5	<50	<5
Total N	<5	<5	54
NH <sub>3</sub>	<0.2	<0.2	<0.2
NO <sub>2</sub>	<5	<50	39
CN	<0.01	<0.01	<0.01
Phenols	<0.01	<0.01	<0.01
Oil and grease	5	3	<2

Table 5 (continued)

	Composite	3518 <sup>a</sup>	3544 <sup>b</sup>
<u>Assays by atomic absorption (AA)</u>			
Cd	0.00044	0.0017	0.00004
Cr	0.0005	0.0032	0.0008
Cu	0.035	0.017	0.004
Pb	0.0009	0.0038	0.0025
Ni	<0.005	<0.005	<0.005
Zn	0.13	0.66	0.01

<sup>a</sup>Steam plant wastewater discharge.

<sup>b</sup>Process wastewater treatment plant.

<sup>c</sup>Believed to be in error. Assays by AA showed <10% of this value. The failure of ICP with this water was never explained.

Table 6. Radionuclide assays (Bq/L)

	Composite	3518 <sup>a</sup>	3544 <sup>b</sup>
Gross $\alpha$	4.5 $\pm$ 4.5	<3	16 $\pm$ 7
Gross $\beta$	42 $\pm$ 8	1.5 $\pm$ 3.8	140 $\pm$ 10
<sup>141</sup> Ce	0.46 $\pm$ 0.08		
<sup>137</sup> Cs	1.7 $\pm$ 0.2	0.29 $\pm$ 0.11	110 $\pm$ 10
<sup>60</sup> Co	25 $\pm$ 2	<0.1	16 $\pm$ 1
<sup>51</sup> Cr	9 $\pm$ 1.6		
<sup>90</sup> Sr	12 $\pm$ 1	<0.1	0.33 $\pm$ 0.22
<sup>134</sup> Cs			2.8 $\pm$ 0.5
<sup>106</sup> Ru			11 $\pm$ 3
<sup>46</sup> Sc	0.32 $\pm$ 0.21		

<sup>a</sup>Steam plant wastewater discharge.

<sup>b</sup>Process wastewater treatment plant (PWTP).

The composite sample (Table 5) assayed far below the likely allowable limits for all the criteria trace elements (Ag, Cd, Cr, Cu, Fe, Ni, Pb, and Zn) and, in most cases, was below inductively coupled plasma (ICP) detection limits. The data in Table 6 indicate the presence of some radioactivity in the composite sample (predominantly  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{51}\text{Cr}$ ). The Building 3544 effluent contains levels up to 140 Bq/L of gross  $\beta$ . As expected, the Building 3518 water was free of radioactivity.

#### 4.2 METALS REMOVAL VIA PRECIPITATION

Metals removal utilizing lime [ $\text{Ca}(\text{OH})_2$ ] and soda ash ( $\text{Na}_2\text{CO}_3$ ) as the reagents was tested in laboratory jar tests with the composite NRWT feed water.

A water-softening sludge was prepared by treating 100 gal of process water with 60 g  $\text{Ca}(\text{OH})_2$  and 42.4 g  $\text{Na}_2\text{CO}_3$  at pH 11. Trace element seed was prepared by spiking 1 L of tap water with 5 ppm (parts per million; also mg/L) of each of the trace elements and precipitating by raising the pH to 10 using 0.01 N NaOH. The  $\text{Fe}^{3+}$  was added 1.5 h after the others so that its gel would sweep out any suspended particles. This precipitate was admixed with 130 mL of water-softening sludge and the mix split into four parts. These parts provided the "sludge blankets" for the precipitation tests.

Five precipitators were placed in parallel, forming the test sequence shown in Table 7, described below. Beaker Nos. 2 through 5 had  $\approx 20$  mL sludge in each. In cases 2 through 4, 1 L of composite wastewater was spiked with 1 ppm of the trace elements, except iron, and added to the sludge. No trace elements were added in case 1. Five ppm of  $\text{Cr}^{6+}$  was added to No. 5 along with 5 ppm  $\text{Fe}^{2+}$  to reduce the  $\text{Cr}^{6+}$  to  $\text{Cr}^{3+}$ . This should have reduced the residual  $\text{Cr}^{6+}$  to 3.4 ppm.

All waters were partially softened by adding 0.2 g  $\text{Ca}(\text{OH})_2$  and 20 mL of 0.1 N  $\text{Na}_2\text{CO}_3$  to yield a pH between 10.5 and 10.8. One ppm of  $\text{S}^{2-}$  was added to beakers No. 3 and No. 4. After 1.5 h of gentle stirring, 1 ppm of the  $\text{Fe}^{3+}$  was added to Nos. 2 through 5, and the stirring was reduced to the point at which the sludge was just

Table 7. Precipitation test sequence

Beaker No.	Initial sludge <sup>a</sup>	Aqueous phase <sup>b</sup>	Iron addition <sup>c</sup>	
1	No	None	None	Sludge separated in cone, supernate filtered and analyzed, sludge recycled for second cycle. <sup>d</sup>
2	Yes	A = [1 ppm trace metals except Fe <sup>3+</sup> ]	B = [1 ppm Fe <sup>3+</sup> ]	
3	Yes	A + 1 ppm sulfide	B	
4	Yes	A + 1 ppm sulfide	B	
5	Yes	5 ppm Cr <sup>6+</sup> and 5 ppm Fe <sup>2+</sup>	B	

<sup>a</sup>40 mL softening sludge seeded with trace metals.

<sup>b</sup>In addition to 1 L of composite wastewater; mixture gently agitated for 1.5 h after addition of 0.2 g Ca(OH)<sub>2</sub> and 20 mL of 0.1 N Na<sub>2</sub>CO<sub>3</sub> resulting in pH 10.5-10.8.

<sup>c</sup>Iron added to 2-5 after 1.5 h agitation; very gentle agitation continued for 0.5 h.

<sup>d</sup>Analysis performed after second cycle; filtered and unfiltered analysis performed after third cycle on No. 3.

suspended and held at this rate for 0.5 h. The reactor contents were then transferred to settling cones and held for 2 h. The sludge was drawn off and returned to the reactor. The procedure described in Table 7 was repeated for a second cycle.

Assays of all filtered (1- $\mu$ m paper) supernatants were run after the second cycle, and a third cycle was run for case 3 - normal spike plus 1 ppm  $S^{2-}$  for both the filtered and unfiltered supernatant. These assays are presented in Table 8. In the chromate test, the observed chromium was slightly above the spike of 5.2 ppm, whereas, it should have been  $\approx 3.5$  if the reduction had occurred. All filtered supernatants were at or below ICP detection limits, confirming the expected low solubilities. However, the unfiltered supernatant from No. 3 showed high levels of all but lead, with the  $Cr^{3+}$  being above the allowable limit. Evidently, the precipitation technique did not increase the size of the particles of the trace elements to the size range where they would settle readily.

Hexavalent chromium could enter the NRWT plant feedwater from unauthorized dumping of glassware cleaning solutions into laboratory drains. The traditional reduction of  $Cr^{6+}$  to  $Cr^{3+}$  with  $Na_2SO_3$  was tested but found to be nonreproducible. It was successful at pH < 3 using 100% excess  $Na_2SO_3$  and seed liquor from a strong acid chromium reduction run. No further study occurred, as it was decided to eliminate  $Cr^{6+}$  via administrative controls.

#### 4.3 REMOVAL OF ORGANIC CONTAMINATION VIA AIR STRIPPING

Fifty grams of an organic present in a 440-gpm stream produces 0.02 ppm of solution. While the organic may be soluble at this concentration, it is very difficult to get into solution. Bench tests indicate that chlorinated hydrocarbons may not form a stable emulsion even during passage through a centrifugal pump. However, material such as the relatively soluble toluene may form a stable emulsion in a pump, but not during passage along a drain. Most of a spill is expected to either float on the water or move in a thin layer along the drain floor.

Table 8. Trace element precipitation

Test	Trace elements in supernatant liquid (ppm)										Filtered (1 $\mu$ m)	
	Ca	Mg	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn		
Raw composite	57	21	<0.07	<0.01	<0.01	0.03	<0.03	<0.06	<0.2	0.08		
<u>Beaker No.<sup>a</sup></u>	<u>Description<sup>b</sup></u>											
1	No trace elements	57	1	<0.07	<0.01	<0.01	<0.02	<0.03	<0.06	<0.2	<0.02	Yes
2	No sulfide	62	1	<0.07	<0.01	<0.01	<0.02	<0.03	<0.06	<0.2	<0.02	Yes
5	Chromate	55	0.2	<0.07	<0.01	5.2	<0.02	0.04	<0.06	<0.2	<0.02	Yes
3	Trace sulfide 2 cycle	56	1	<0.07	<0.01	<0.01	<0.02	<0.03	<0.06	<0.2	<0.02	Yes
4	Trace sulfide 2 cycle	23	7	<0.07	0.02	0.008	<0.02	<0.03	<0.06	<0.2	<0.02	Yes
3	Trace sulfide 3 cycle	62	1	<0.07	<0.01	0.014	<0.02	<0.03	<0.06	<0.2	<0.02	Yes
3	Trace sulfide	69	4	0.09	0.15	0.19	0.26	0.44	0.15	<0.2	0.36	No

<sup>a</sup>As noted in Table 7.

<sup>b</sup>The pH values of the filtrates ranged from 10.5 to 11.

Small spills of those organics heavier than water will be trapped in irregularities along the drain, while larger spills will be trapped in the weir boxes, etc. These devices should be kept clean and provided with bottom weep holes.

It was felt that a significant fraction of the organic contaminant load could enter the NRWT plant as an emulsion, which would be the most difficult case to treat via stripping. For these reasons, air stripping of organic emulsions was examined for three systems: water-toluene, water-trichloroethane, and water-dichlorobenzene. These compounds represent a wide range in volatility from relatively high (toluene) to low (dichlorobenzene) levels. In the tests, 3 mL of the organic was violently agitated with 1600 mL of water in a covered baffled beaker for 1 h. The emulsion was then settled for 20 min, and the residual bulk-organic phase was either blotted off of the surface or the water decanted from the bottom layer. The emulsion was then stripped with air at a flow rate of 1 L/min. The air entered through a 6-mm-ID tube having an opening  $\approx 3$  cm above the base of the beaker. The liquid height above the opening was  $\approx 12$  cm. Using TOC analysis, the organic concentration in the aqueous phase was measured as a function of time, resulting in the data summarized in Table 9.

Neither the toluene nor the trichloroethane segregated during air stripping, and no organic phase was visible at the end of the stripping step. Conversely, the dichlorobenzene emulsion broke during decanting, and a layer of droplets accumulated at the base of the container. The air bubbler did not disturb this layer, and, consequently, this material was not stripped. The concept that the decrease in the dichlorobenzene concentration could have been an artifact of the settling process rather than the air stripping is supported by the fact that after settling for 75 min, the supernate TOC was 27 mg/L; upon agitation and mixing of the two-phase mixture, the TOC was 613 mg/L. The data indicate that air stripping will be effective for volatile organics in an emulsion form, since toluene was reduced from 474 mg/L to 4 mg/L via stripping with 100 volumes of air. Whether it would be effective for volatile organics flowing as films down the surfaces of the packing in a tower is not known.

Table 9. Total organic carbon of the emulsion during air stripping

Time (min)	Air volume (L)	Toluene (ppm)	Trichloroethane (ppm)	Dichlorobenzene (ppm)
0	0	474	82	200
10	10	358	54	180
20	20	183	44	100
40	40	96	31	46
60	60	24	0	27
80	80	8	0	Heavy layer on bottom <sup>a</sup>
100	100	4	0	
120	120	0	0	
		clear, no oils	clear, no oils	

<sup>a</sup>The dichlorobenzene was reagitated at 75 min, and the suspension measured 613 ppm.

Emulsion stripping depends greatly on the degree of dispersion. The component must dissolve, migrate through the water, and vaporize into the gas. While toluene dispersed very well, trichloroethane was stable for the test period but the dispersion was not very fine. Dichlorobenzene did not form a stable emulsion.

As a rough check, the vapor pressure in the gas was assumed to be proportional to the mole fraction in the liquid phase, assuming everything is in solution. The calculated gas volumes are compared with the actual volume used at a few points:

Component	Vapor pressure at 20°C	Gas volume used	Liquid concentration after A/S, ppm	Calc. req. gas volume
Toluene	30 mm Hg	40	96	16
		80	8	40
Trichloroethane	100 mm Hg	40	31	3
		60	≈2	11

Air stripping of an emulsion approaches the theoretical for a highly dispersed emulsion of reasonably soluble (200—1000 ppm) organic but falls off rapidly as the ease of dispersion and solubility decreases.

If emulsions enter the NRWT plant, it is likely that they will contact softening sludges and materials such as ion-exchange resin and the activated carbon used for heavy organic removal. It was found that material which is difficult to emulsify may form stable emulsions in the presence of sludge precipitates. A stable emulsion of dichlorobenzene could not be prepared in the available laboratory equipment. However, 2 mL of dichlorobenzene was readily emulsified with the sludge produced by lime softening of 1600 mL of tap water. The oil and solids did not segregate into discrete phases after standing for 3 d.

An emulsion of 10 mL toluene in 50 mL water was drained through 30 mL of ion-exchange resin in a 15-mm-ID tube at 6 mL/min. The resin broke the emulsion and retained 50% of the toluene. An identical test

with GAC showed complete toluene retention and even the removal of the toluene odor. Based on this test, other experience, and GAC performance published in the literature, GAC columns appear to be capable of handling many organic emulsions.

#### 4.4 ALTERNATIVE METHODS FOR METALS REMOVAL

As part of the Phase I study, methods for metals removal, other than precipitation, were investigated. Since the wastewater sources are only occasionally contaminated with toxic trace elements, and then at low levels (i.e., <2 ppm and generally <0.5 ppm), these wastewaters are logical candidates for treatment with ion-selective resins, such as IRC-718, or with cellulose zanthate. Ideally, an ion-selective resin having a large preferential adsorption for the trace metals over calcium and magnesium could operate for months before it approaches saturation. An insoluble zanthate, which bonds the trace metals in a manner analogous to sulfide precipitation, could be dumped into a holding reservoir whenever an exceedence is noted and then filtered out together with the  $S^{2-}$ -bonded metals. The cellulose backbone of cellulose zanthate acts like a sulfide crystal blanket by providing a point of adherence for the metal sulfides that tend to be present in colloidal form. The potential for use of the IRC-718 and cellulose zanthate in the NRWT application was evaluated via batch adsorption tests.

##### 4.4.1 Batch Adsorption Tests with Amberlite IRC-718 Resin

Three 10-mL lots of resin were repeatedly slurried in 2 L of tap water. The calcium and magnesium in the supernatant water approached raw water levels after the fourth batch of water. By material balances, the loadings on the resin were 0.58 g of calcium and 0.08 g of magnesium per liter of resin, in apparent equilibrium with 22 ppm of calcium and 13 ppm of magnesium in the tap water. This preload corresponds to the expected column condition at the time a spike of heavy metals might be encountered in the NRWT plant.

Wastewater assays indicate that these spikes will be somewhat <0.5 ppm, averaged over a 24-h period, and will occur at 7- to 20-d intervals.

The alkali metal-loaded resins were then reslurried in 2 L of tap water. The pH levels were adjusted with  $\text{HNO}_3$  to 4 for batch No. 1, to 5.5 for batch No. 2, and to 7 for batch No. 3. Each batch was spiked with 0.01 g-equiv of Co, Cu, and Zn, which is equivalent to 5 ppm of each element in the supernatant liquid. The batches were agitated for 2 h and settled. The supernate was sampled and assayed. The 100-mL sample volume was replaced with 100 mL of tap water, and the spikes were repeated three more times without changing the supernatant liquid. After settling, the supernatants were assayed, resulting in the data presented in Table 10. The total added metal was 0.04 g per 10 mL of resin for each element and the sum of four spikes. The loadings on the resin batches quoted in Table 10 were derived from material balances.

At the low pH, the resin dumped most of the calcium and magnesium, presumably by  $\text{H}^+$  replacement. Only copper was effectively held on the resin. However, at pH 7, the calcium and magnesium displacement is small and appears to be by replacement with the adsorbed heavy metals. The dump, 0.25 g equiv/L of resin, is less than adsorption of the spike elements, which is  $\approx 0.38$  g equiv/L of resin.

To simulate extended contact of the metal-laden resin with clean water, the resin batches were reslurried with 2 L of tap water acidified to the previously noted pH levels. Significant quantities of cobalt and zinc transferred to the fresh water at pH 4, but very little was released from the resin at pH 7. The supernatant assays are the lines denoted as tap water in Table 10.

The limiting capacity for the heavy elements is not known. It appears to be  $>0.4$  g equiv/L resin at concentrations in the wastewater  $<0.1$  ppm. The sales brochure quotes 1 g equiv/L at an unidentified concentration.

Table 10. IRC-718 capacities for batch-loading tests of trace elements

	Water phase (ICP assay) (ppm)					Resin phase (material balance) (g-equiv/L resin)					pH
	Ca	Mg	Co	Cu	Zn	Ca	Mg	Co	Cu	Zn	
	Saturated with tap water	22	13				0.58	0.08			
<u>Batch 1</u>											
Spike 1	89	19	0.5	0.2	0.5	0.0	0.0	0.034	0.031	0.031	4
2	91	19	1.7	0.2	1.4	0.0	0.0	0.065	0.062	0.058	
3	93	19	4.0	0.05	3.3	0.0	0.0	0.074	0.093	0.070	
4	94	19	7.4	0.07	6.2	0.0	0.0	0.105	0.124	0.107	
Tap water	27	8	0.5	0.07	0.5	0.0	0.0	0.105	0.124	0.107	4
5	28	8.2	0.46	0.02	0.46	0.07	0.0	0.108	0.154	0.14	
6	32	8.8	1.9	0.09	1.7	0.07	0.0	0.128	0.183	0.167	
7	36	9.5	4.2	0.14	3.6	0.04	0.0	0.133	0.212	0.181	
8	39	9.9	6.9	0.14	6.1	0.0	0.0	0.120	0.241	0.180	
after 20 h	39	9.8	8.9	0.10	7.8						
Trace elements 0.54 g-equiv/L											
<u>Batch 2</u>											
Spike 1	62	17	0.2	0.2	0.3	0.2	0.03	0.034	0.031	0.031	5.5
2	64	16	0.04	0.04	0.05	0.2	0.03	0.068	0.062	0.062	
3	72	17	0.07	0.06	0.08	0.1	0.03	0.101	0.093	0.093	
4	75	17	0.4	0.07	0.4	0.1	0.03	0.132	0.124	0.119	
Tap water	30	9	0.05	0.14	0.05	0.1	0.04	0.132	0.124	0.119	5.5
5	28	8.3	0.29	0.71	0.42	0.1	0.05	0.162	0.150	0.153	
6	34	9.2	0.23	0.2	0.27	0.17	0.04	0.193	0.180	0.187	
7	41	10	0.67	0.09	0.61	0.1	0.00	0.220	0.21	0.219	
8	45	11	2.4	0.49	2.2	0.00	0.00	0.237	0.237	0.242	
after 29 h	47	10	3.7	0.16	3.3						
Trace elements 0.72 g-equiv/L											

Table 10 (continued)

	Water phase (ICP assay) (ppm)					Resin phase (material balance) (g-equiv/L resin)					pH
	Ca	Mg	Co	Cu	Zn	Ca	Mg	Co	Cu	Zn	
<u>Batch 3</u>											
Spike 1	38	14	0.1	0.19	0.2	0.4	0.08	0.034	0.031	0.031	7.0
2	38	14	<0.02	0.06	<0.02	0.4	0.08	0.068	0.062	0.062	
3	44	15	0.03	0.08	0.05	0.33	0.08	0.101	0.093	0.093	
4	49	15	0.04	0.09	0.05	0.33	0.08	0.132	0.124	0.122	
Tap water	33	10	0.05	0.09	0.06	0.03	0.08	0.132	0.124	0.122	7.0
5	35	9.9	<0.02	0.03	0.04	0.33	0.08	0.164	0.154	0.159	7.7
6	41	10	0.12	0.23	0.16	0.27	0.08	0.196	0.183	0.194	
7	45	10	0.10	0.18	0.11	0.23	0.07	0.228	0.212	0.229	
8	50	11	0.58	0.21	0.56	0.20	0.07	0.257	0.240	0.263	
after 20 h	58	12	0.35	0.18	0.35						
								Trace elements 1.03 g-equiv/L			

Selectivities quoted, with respect to calcium, are:

Hg <sup>2+</sup>	2800
Cu <sup>2+</sup>	2300
Pb <sup>2+</sup>	1200
Ni <sup>2+</sup>	57
Cd <sup>2+</sup>	15
Co <sup>2+</sup>	7
Ca <sup>2+</sup>	1

#### 4.4.2 Heavy-Metals Removal with Cellulose Xanthate

Fibrous cellulose xanthate was screened as an adsorbent for the criteria heavy elements that may contaminate the NRWT plant feedwater. Cellulose xanthate does not appear to be a practical adsorbent for controlling these elements at concentrations below a few parts per million.

The instability of the material dictates its use on demand in a batch-agitated mode followed by removal by filtration. The xanthate material was evaluated at two concentrations, 0.05 g and 0.2 g in 2 L of water (see Table 11). Both tap water and a synthetic tap water (containing only nitrate anions) were employed. Trace elements, in their nitrate forms, were added at several concentration levels prior to the introduction of the xanthate and its subsequent agitation for preset time periods. The pH was controlled, in cases C and D, by the addition of either nitric acid or sodium hydroxide. The effects of a chelating agent, ethylenediaminetetraacetic acid (EDTA), were also screened.

The data are summarized in Table 11, which shows the filtrate assays as functions of xanthate addition level, stirring time, pH, and the presence of EDTA. Some of the apparent efficiency may be the result of precipitation as the hydroxide at the chosen pH level; Cr(OH)<sub>3</sub> solubility is <1 ppm at pH 7, and Cu(OH)<sub>2</sub> solubility may be near 1 ppm at pH 7. According to the available data,<sup>5,6,7</sup> the other elements have solubilities >1 ppm at pH 7. The exact values are uncertain due to variations in the published data. Results from case A, in which a 5-ppm spike was added to tap water at pH 7, suggest that

Table 11. Control of criteria trace elements with cellulose xanthate

Xanthate addition (g/L)	Agitation time (min)	Final pH	Elemental assay of filtrate (ppm)									
			Ca	Mg	Na	Cd	Cr	Cu	Co	Ni	Pb	Zn
(A) Tap water spiked with 5 ppm each of Co, Cu, Zn												
0.05	20		33	9.5	6.5			3.9	4.5			5.4
	40	≈7	33	10	7.3			1.7	4.6			5.3
	240		32	9.6	11			0.7	4.4			4.1
0.2	20	7	32	9.6	12			2.8	4.4			5
	40		32	9.4	11			2.3	4.3			5
	240	7.4	32	9.6	11			1.7	4.5			5
(B) Synthetic tap water spiked with 0.2 ppm each of Cd, Cr, Cu, Co, Ni, Pb, Zn												
0.05	240	8.7	28	11	6	0.012	<0.02	<0.02	0.1	0.09	<0.2	0.04
0.2	20		28	10	6	0.028	<0.02	0.04	0.26	0.13	<0.2	0.12
	240	9.2	29	9.6	6.5	<0.009	<0.02	<0.02	0.04	<0.06	<0.2	<0.02
(C) Synthetic tap water spiked with 2 ppm each of Cd, Cr, Cu, Co, Ni, Pb, Zn												
0.2	20	6		11		1.4	<0.02	<0.02	1.2	1.6	<0.2	0.52
	240	6		11		1.6	0.02	0.04	1.3	1.0	<0.2	0.54
0.2	20	7		11		0.4	<0.02	<0.02	0.24	0.44	<0.2	0.03
	240	7		11		1.0	<0.02	0.03	0.5	0.75	<0.2	0.09
(D) Synthetic tap water spiked with 1 ppm each of Cu, Ni, Zn, and 0.03 g EDTA/L												
0.2	240	7	28	9.6	9			1		1.1		1.1

either copper solubility exceeds 3 ppm or the rate of  $\text{Cu}(\text{OH})_2$  precipitation is very slow.

The very poor xanthate performance in case A could be the result of xanthate quality. The product is under development by the manufacturer, and the first test run was made with a different xanthate batch than the last three runs. The data do not rule out the use of xanthate, but its performance was not sufficiently promising to justify further development.

#### 4.5 SCREENING OF MERCURY REMOVAL FROM MH-190 WATERS BY GAC

The behaviors of two activated-carbon columns, one filled with coconut char and one filled with coal-based char (Filtrisorb 300), were followed for a 30-d period. The inlet mercury levels ranged between 1.1 and 1.9 ppb (parts per billion or  $\mu\text{g}/\text{L}$ ). The effluent levels (see Table 12) ranged between 0.5 and 1.1 ppb from the coconut char and 0.1 and 0.8 ppb for the Filtrisorb. The Filtrisorb effluents of May 30 and June 7 exceeded the goal of 0.5 ppb. The reason for these poor performances is unknown.

Assays performed during the first week of the test showed 8 to 15 ppm of TOC. The level of organics was sufficient to permit biogrowth on the adsorption media. With time, a gelatinous mass built up throughout the beds, resulting in back-pressures that made flow control of the very simple flow circuits quite difficult. Simple backwashing did not remove the sludge. The beds were kept open by wire rodding while in the backwash mode, which caused some carbon mixing in the beds. This cleaning procedure was ineffective by the end of the 30-d period.

Since column lives should exceed several months, it may prove necessary to operate with a number of beds in series, each having provision for air scouring. The design will have to recognize that air scouring yields a back-mixed carbon bed. Periodic sterilization of the beds might be of value. However, a safe sterilization technique must be demonstrated; for example, discharge of an effluent containing biocides is likely to be unacceptable.

Table 12. Phase I - granular activated-carbon results<sup>a</sup>

Date	MH-190 water inlet mercury (ppb)	Coconut effluent mercury (ppb)	Filtrisorb 300 effluent mercury (ppb)
5/23/85	1.9	0.3	0.1
5/24/85	1.8	0.4	0.2
5/25/85	1.2	0.4	0.2
5/26/85	0.8	0.7	0.1
5/27/85	0.6	0.6	0.2
5/28/85	1.5	1.1	0.4
5/29/85	2.1	0.9	0.4
5/30/85	1.1	0.8	0.6
6/07/85	1.4	1.1	0.8
6/10/85	1.8	0.4	0.2
6/21/85	1.5	0.6	0.2

<sup>a</sup>Bed depths 30 in., column diameter 1-in. ID, column height 48 in., carbon charge Filtrasorb 300 - 198.8 g, coconut 171.5 g. Nominal flow rate 250 mL/min through each column.

## 5. PHASE II RESULTS

### 5.1 CHARACTERIZATION OF 190 WEIR BOX WATER

Figure 2 shows the titration curves for a sample of 190 water. The results are expressed in milliequivalents of acid or base per liter of raw water and are combined into a single curve.

### 5.2 PRECIPITATE SETTLING TESTS

Rough estimates of the clarifier throughput were made for two recipes for trace metal removal. The lime-based and caustic-based recipes selected from early jar tests were: (1) pH 11 using lime and 0.5 ppm Percol 727, and (2) pH 11 using caustic and 2 ppm Percol 728. Four- to 5-gal batches of 190 water were spiked to 1 ppm each of the trace elements. The water in the 5-gal buckets was stirred with a rod and adjusted with the appropriate base to pH 11. The polymer was then added and stirred in gently using a stirring rod.

The mix was dumped into a plastic settling tube having a 6-in. ID and a 6-ft length. The slurry was agitated and sampled over the column depth. The system was allowed to stagnate, and profile samples were taken at 10, 20, 30, 45, 60, and 90 min and assayed for TSS. Figures 3 and 4, prepared by the A/E, Engineering-Science, show the percentage decrease in the solids concentration with time at various column depths.

If the feed were distributed continuously and evenly across the clarifier and the rise time set equal to the time required to obtain 99% removal at a depth of 4 ft, then  $\approx 1\%$  residual solids would be found in the rising water at the 4-ft depth. The overflow would have a much lower concentration. The projected surface area is, at best, a crude guide. The convection currents induced by the entry of the feed, by small temperature changes in the feed with time, and even the action of the sludge rake can dictate major increases in the required surface area. Further, the results are only applicable to the specific feed employed and to such factors as agitation during precipitation and flocculation.

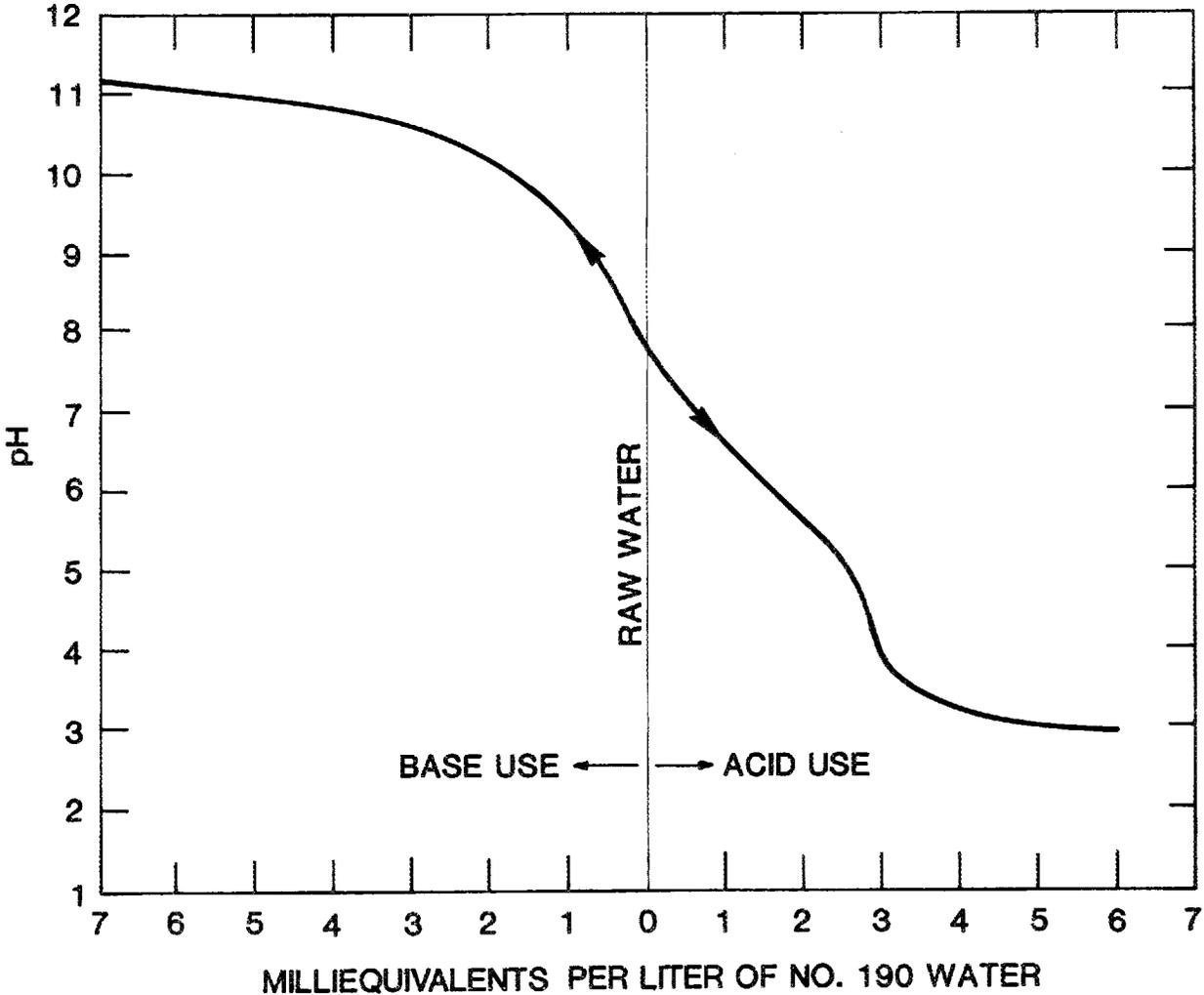


Fig. 2. Titration of MH-190 weir box water.

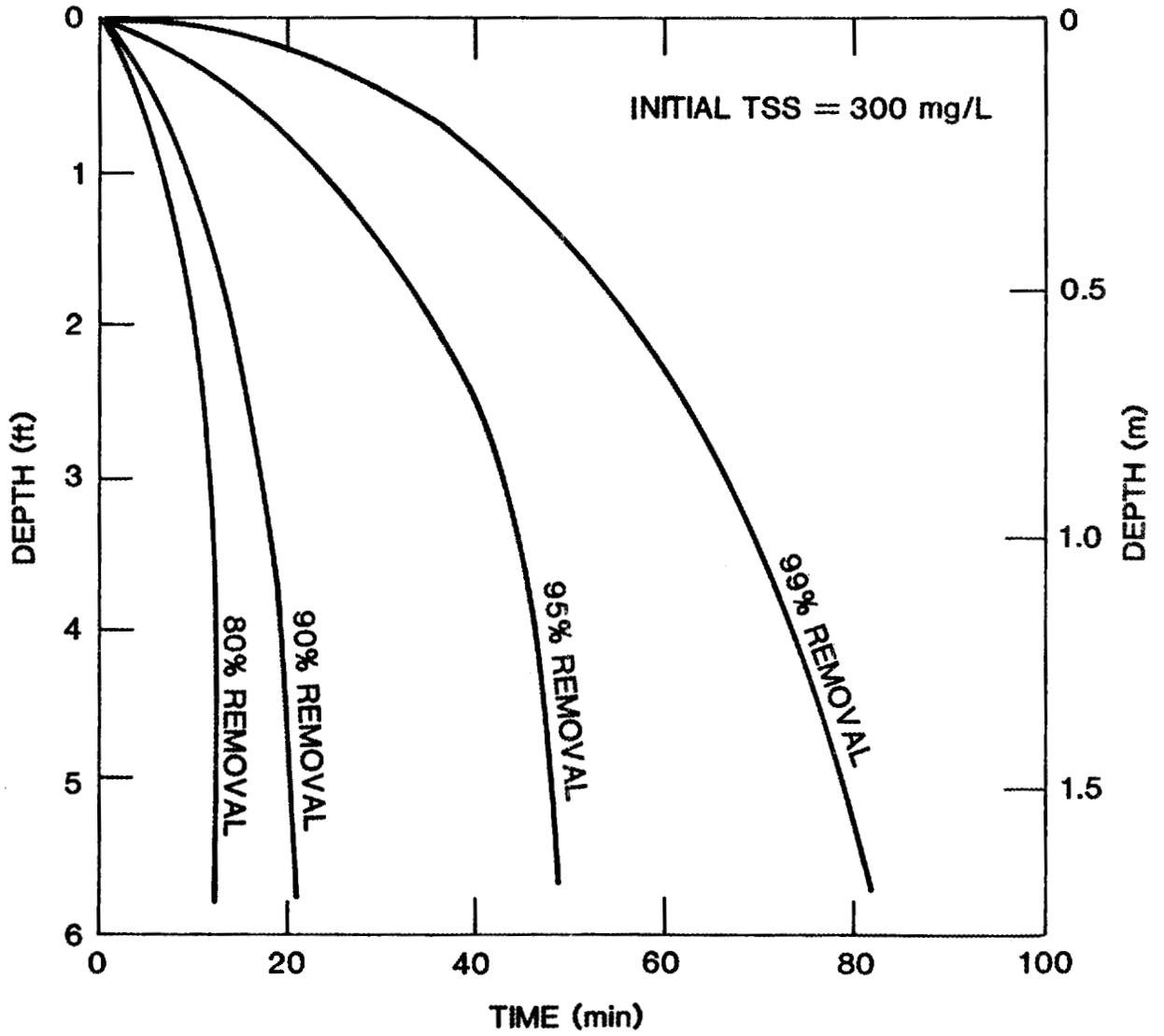


Fig. 3. Settling column data: lime and 0.5 mg/L polymer (Percol 727).

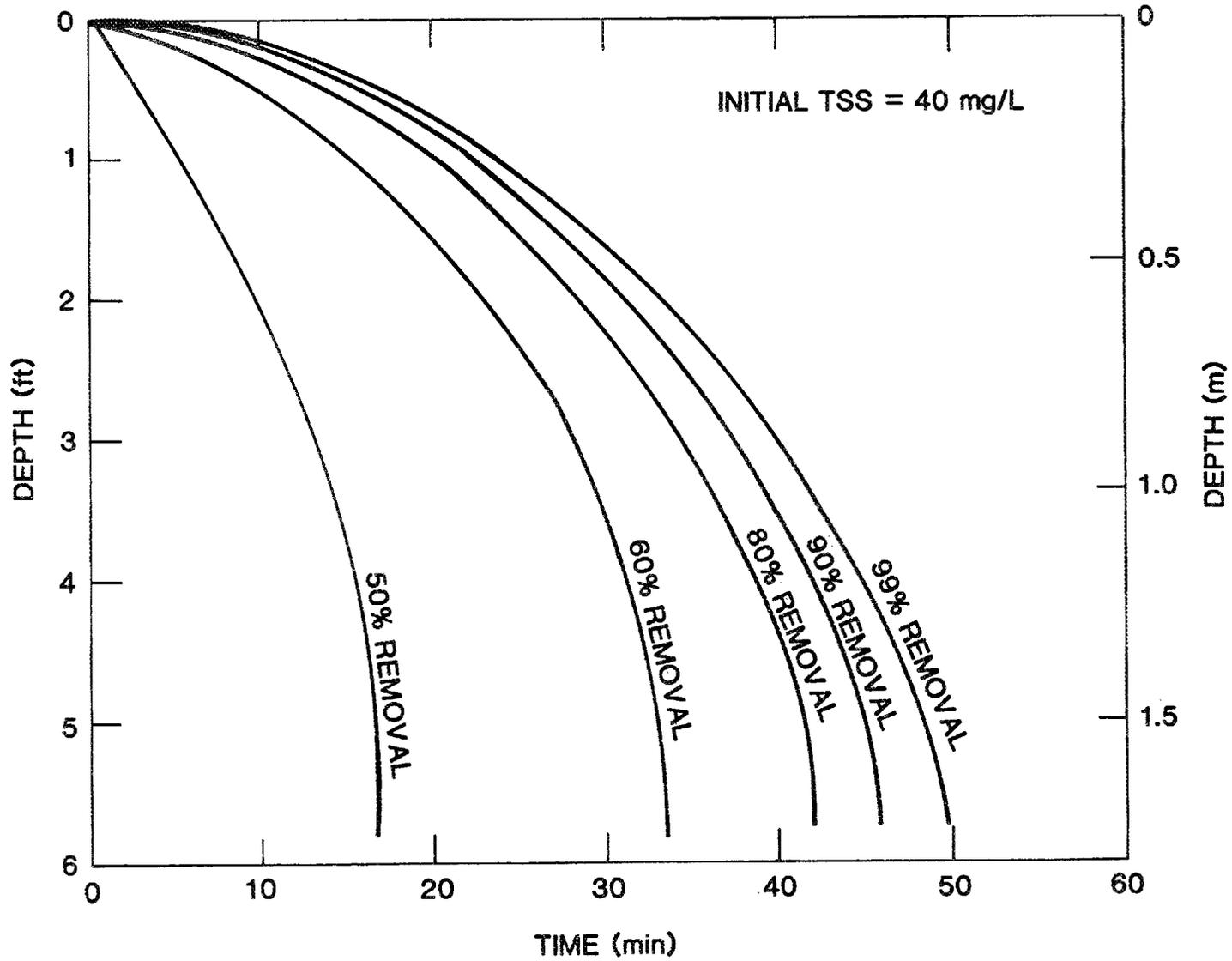


Fig. 4. Settling column data: caustic and 2 mg/L polymer (Percol 728).

### 5.3 SLUDGE DEWATERING TESTS

Five 200-L batches of 190 water were treated serially in a stirred and baffled 55-gal drum. Each batch was spiked to 10 ppm in each of the eight criteria trace elements. The pH was raised to 11 by alkali addition while stirring rapidly for 5 min. The agitator speed was then reduced to gentle action, polymer was added, and stirring continued for 15 min. The liquor was settled for 30 min, and the sludge was drained into a 5-gal carboy. The precipitation recipes were the same as those employed in the settling tests (i.e., one sludge employed lime plus 0.5 ppm Percol 727 while the other employed caustic plus 2 ppm Percol 728).

The sludge was processed in the Engineering-Science test system, which consisted of a 60-psi gas-pressurized sludge receiver connected by an underflow line to a small plate and frame filter. The plate used was 1.9 cm thick and had a diameter of 10.8 cm to give a cross-sectional area of 92 cm<sup>2</sup>. A typical run charged the receiver with 7 L of lime slurry. Upon pressurization, 0.75 L of solids-laden solution was followed by 2.75 L of clear filtrate. Pressure was maintained until the flow decreased to a very slow trickle (1 to 2 h). There was 3.25 L left in the receiver, while 171 g of wet cake filled the press. The cake initially assayed 40% solids, while a repeat test assayed 43% solids. The sludge produced by caustic treatment could not be contained by clean cloth. However, 3 to 7 g of filter aid (diatomaceous earth) applied as a precoat contained the sludge in the filter. The 155 g of wet cake assayed ≈45% solids when dried the next day.

### 5.4 JAR TESTS

The proposed removal of the criteria trace elements (Ag, Cd, Cr<sup>3+</sup>, Cu<sup>2+</sup>, Fe<sup>3+</sup>, Ni, Pb, and Zn) by precipitation at an elevated pH followed by filtration was screened for the optimum operating conditions by means of a series of jar tests. The jar tests model precipitation

followed by clarification. The more efficient sludge-blanket R/C cannot be modeled effectively on a very small scale.

The proposed process system removes the trace elements as their hydroxides in the sludge blanket, while carryover is removed in a downstream dual-media filter. Incidentally, silver is likely to precipitate as the chloride, and lead may come down as a basic carbonate in the wastewaters of concern. Precipitation as the sulfide is a potential alternate to hydroxide precipitation, as the solubilities of many sulfides are extremely low. Sulfide precipitation would remove mercury and has been reported to be effective for  $\text{Cr}^{6+}$  removal and the removal of chelated metals.<sup>8</sup>

Removal of the trace elements by the precipitation-settling-filtration process sequence depends on adequate crystal growth, particulate agglomeration, flocculation, and sedimentation rates. Only a small fraction of the crystals should carry over into the filter. Further, these crystals must be large enough to be removed in the granular filter bed. The best results are achieved by flash mixing in the presence of recirculating precipitate to minimize nuclei formation and maximize crystal growth. Crystal agglomeration and flocculation are best achieved in a slowly mixed suspension.

The jar tests, six of 1-L beakers in parallel, employ a 5-min rapid-mix period, a 15-min slow-mix period, and finally, a 30-min settling period. Reagents such as alkali and sulfide are added during the rapid mix period. Flocculants such as alum and polymer are added during the slow-mix period. Filtration in these tests was through a 0.45- $\mu\text{m}$  membrane.

The results of the jar tests provide a guide to the optimum process conditions, although the jar does not duplicate the concentration and sludge profiles in a commercial unit. Many impurities in wastewaters hinder crystal growth. The plant water contains traces of many impurities, and their concentrations are continually changing. Storage of large quantities of composite water is not a solution because of the biological processes occurring in the wastewaters. A reproducible, generally low level of each trace element in the effluent may be a better guide to the optimum than a very low-

level spot value. The optimum conditions for the MH-190 weir box water were pH 10.5 to 11.5 using lime, lime and soda, or caustic. The clarification step could be improved by the use of appropriate organic polymers in the range of 0.5 to 2 ppm. Table 13 provides a quick reference to the jar test data for these optima. The detailed results of the jar tests are presented in Tables A.1 to A.16 in Appendix A.

The additions of  $\text{Na}_2\text{S}$ ,  $\text{NaBH}_4$ , and  $\text{Na}_2\text{SO}_3$  were screened under several conditions. Sodium borohydride improved trace element removal in some cases, although the improvement was relatively small, while sodium sulfite addition was deleterious. There is no clear evidence that  $\text{Na}_2\text{S}$  enhanced the removal of the trace elements despite the lower solubilities of the sulfides, which may indicate that the crystals were not growing to capture size. In the electroplating industry, the sulfide sludge blanket is the key to the success of the sulfide precipitation step;<sup>9</sup> however, the jar tests did not model a sludge blanket.

#### 5.5 REACTOR/CLARIFIER — DUAL-MEDIA FILTER

Bench-scale operation of a sludge blanket lime softener followed by a dual-media (anthracite and coal) filter was attempted (see Fig. 5). The reactor/clarifier had a residence time of 1.5 h at 70 mL/min. An even distribution of liquid through the blanket was unattainable. Most of the particulates in the overflow were trapped in the 3- to 6-mm anthracite layer at the top of the dual-media bed. The mechanism of the sheet formation, which would choke off flow within 24 h, is not clear. Bridging of the voids by large flocs, which occasionally came over from the precipitator, appears to initiate the process. Postprecipitation of  $\text{CaCO}_3$  may then strengthen the bridges to the point where they resist the available driving force of 5 to 10 psi on the liquid.

Iron addition at 6 ppm and Purifloc (a polyelectrolyte) additions between 0.3 and 3 ppm did not impede the growth of the layer. This layer appeared to be weaker during Purifloc additions between 0.3 and 1 ppm, but this is a very subjective judgment. In the complete absence

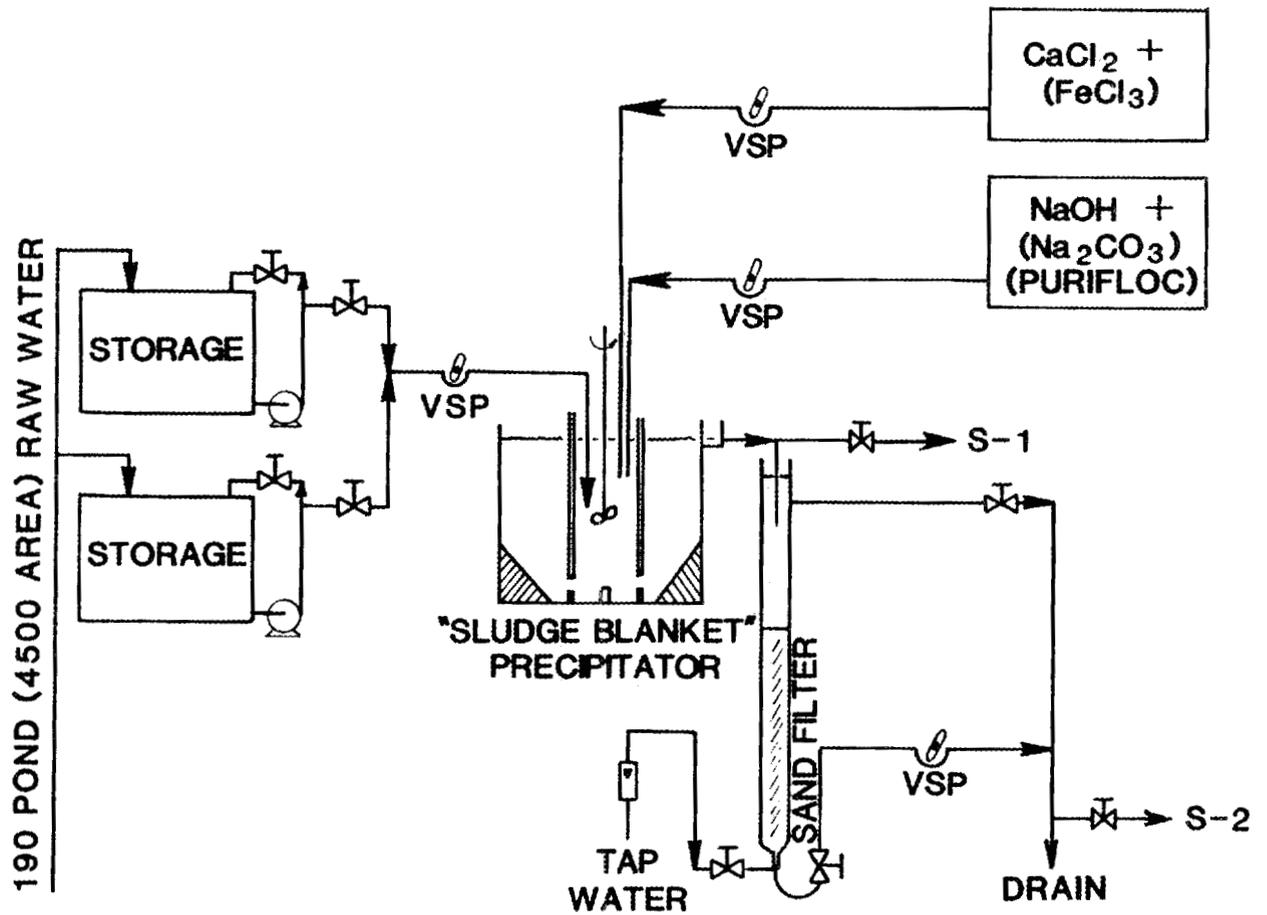
Table 13. Effective trace element removal conditions during the jar tests

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Set 1	pH 11	with NaOH
	11.5	with $\text{Ca(OH)}_2$
	11.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3$
7 <sup>a</sup>	11	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 + \text{polymer}$
8	11	with NaOH
	11.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3$
	10.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 + \text{NaBH}_4$
	11	with NaOH + polymer
9	11.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3$
	10.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 + \text{NaBH}_4$
10	10.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 + \text{NaBH}_4$
	11	with NaOH + polymer
15	11.5	with $\text{Ca(OH)}_2 + \text{Na}_2\text{S}$
16	11.5	with NaOH + $\text{Na}_2\text{S}$

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<sup>a</sup>Set 7 illustrates improvement in the settling rate attainable with the choice of the correct polymer.



VSP INDICATES VARIABLE SPEED PERISTALTIC PUMP

Fig. 5. Trace element precipitation/filtration system.

of polymer, a thin brittle sheet was formed that frequently had to be broken up by rodding.

Filter backwashing might have to be very frequent if floc floaters and supersaturation cannot be controlled. This problem can only be resolved in much larger-scale equipment. Only tap water spiked with 1 ppm each of the trace elements Cd, Co, Cr, Cu, Ni, Pb, and Zn was employed in the tests. The water was charged to 55-gal drums and spiked with the trace elements. A weak agitation level was maintained by recirculating the water with 2-gpm pumps. The trace elements remained in suspension or solution. Assays (see Table 14) showed that most of the chromium and copper was filterable from the feed stock with 1- $\mu$ m filters. Some precipitation of lead occurred as well as unexpected precipitation of zinc.

The  $\text{Ca}(\text{OH})_2$  for the softening reaction was formed in the precipitator by the reaction of feed solutions of NaOH and  $\text{CaCl}_2$ . At the flow rates employed,  $\approx 6$  mL/min of mixed reagents, lime slurry pumping was too unreliable. The added lime and 30 to 50% of the calcium in the tap water precipitated in the pH range of 9.4 to 10, while 85% of the calcium precipitated at pH 10.6.

The assays showed that the trace elements were effectively precipitated at pH values  $>9.5$ . However, only those initially in solution were effectively removed by the precipitation and filtration process. Chromium was a consistent offender, showing 0.1 to 0.2 ppm in the product, whether filtered or unfiltered through 1- $\mu$ m paper. The extremely insoluble  $\text{Cr}(\text{OH})_3$  probably approached colloidal dimensions and was not agglomerated by the reagents employed. These conclusions are derived from the limited data base presented in Table 15, showing the process effluents as functions of process and additives employed. The last two sets show unfiltered and filtered effluent samples after 20 h of dual-media filter use (partially plugged) and after 4 h of filter use (free flowing). The partially plugged condition is effective for all materials but chromium.

Table 14. Feed stock tests<sup>a</sup>

	Ca	Mg	Cd	Co	Cr	Cu	Ni	Pb	Zn
Unfiltered	35	10	1	1	1	1	1.1	1	1-2
Filtered	35	10	1	1	0.1-0.2	0.05-0.1	1.1	0.4-0.6	0.6-0.7
Unfiltered	36	10	1.1	1.0	0.96	1.0	1.2	0.92	1.3
Filtered	36	10	0.91	0.74	0.10	0.05	0.97	0.35	0.11

<sup>a</sup>All results are given in parts per million (ppm).

Table 15. Softening/filtration process effluents

Softening process	Purifloc addition	Fe <sup>3+</sup>	pH	Sample preparation	Assay (ppm)								
					Ca	Mg	Cd	Co	Cr	Cu	Ni	Pb	Zn
Lime/soda	-	-	10.6	Unfiltered	7	4	<0.01	<0.02	0.2	<0.02	<0.06	<0.2	0.1
Lime	-	6 ppm	9.8	Unfiltered	18	6	0.01	<0.02	0.08	<0.02	<0.06	<0.2	0.03
Lime	0.6 ppm	-	9.7	Unfiltered	24	8	0.02	<0.02	0.2	<0.02	<0.06	<0.2	0.04
Lime	0.6 ppm	-	9.7	Unfiltered	14	8	0.04	0.04	0.2	<0.02	<0.06	<0.2	0.05
Lime	1.0 ppm (after 20 h through dual-media)	-	9.5-10	Unfiltered	15	7	0.02	0.03	0.08	<0.02	<0.06	<0.2	0.03
				Filtered	14	7	<0.01	<0.02	0.07	<0.02	<0.06	<0.2	0.02
Lime	1.0 ppm (after 4 h through dual-media)	-	9.5-10	Unfiltered	23	7	0.04	0.11	0.12	0.05	0.13	<0.2	0.12
				Filtered	22	7	<0.01	<0.02	0.07	<0.02	<0.06	<0.2	<0.02

## 5.6 AIR STRIPPING OF TRACE ORGANICS - BEAKER TESTS

A 20-L sample of MH-190 water was collected in a polyethylene carboy and spiked with 200 ppb of  $\text{CHCl}_3$  (chloroform), 100 ppb of  $\text{C}_8\text{H}_{10}$  (naphthalene), 25 ppb of dibutyl phthalate (DBP), and 5000 ppb of  $\text{NH}_3$  (ammonia). The mix was sampled immediately and assayed 176 ppb  $\text{CHCl}_3$ , 45 ppb  $\text{C}_8\text{H}_{10}$ , 65 ppb DBP, and 210 ppb  $\text{NH}_3$ . The water was transferred to 1-gal glass jugs, adjusted to several pH levels, and air stripped, using an open tube immersed in the water in 4-L glass beakers.

The accuracies of the assays are uncertain. Based on the residuals noted in waters treated in the MPP system through the three carbon columns, the lower detection limit is 2 to 8 ppb. If we assume an accuracy of 10%, then the  $\text{CHCl}_3$  inlet may be 200 ppb and the outlet  $\approx 10$  ppb (for 95% removal) after 30 gas volumes per volume of liquid (see Table 16).

Superficially,  $\text{CHCl}_3$  stripping is efficient. However, naphthalene stripped to very similar levels, but its vapor pressure is  $<0.001$  times the chloroform vapor pressure. The change in concentration of naphthalene should be undetectable. While ammonia simply disappeared from the system before stripping commenced (according to the feed analysis), the DBP assay more than doubled. In view of these anomalies, the possibility that the chloroform data are also untrustworthy must be kept in mind. Indeed, the validity of much of our organic collecting and sample-preparation procedures may be in question.

Assuming that the measured feed concentration for chloroform is correct and ignoring the 433-ppb value measured at pH 5, the stripping data show  $>90\%$  removal at all five pH levels tested. Similarly, assuming that the ammonia feed concentration had been accurately made up to the 5-ppm level, the stripping data show  $>85\%$  removal for pH levels  $>5.5$ .

Table 16. Air stripping beaker tests

pH	T °C	Gas/liquid (L air/ L water)	Chloroform (ppb)	Naphthalene (ppb)	Dibutyl phthalate (ppb)	Ammonia (ppm)
4	21	30	7	17	48	0.64
4	21	100	1	12	69	2.34
5.5	21	30	433	9	100	0.35
5.5	24	100	4	11	94	0.24
7	23	30	18	9	86	0.16
7	23	100	4	8	63	0.16
8.5	23	30	14	37	95	0.60
8.5	23	100	4	21	91	0.18
10	24	30	8	31	70	0.40
10	23	100	3	14	72	0.41
Desired feed concentration			200	100	25	5
Measured feed concentration			176	45	65	0.21
Detection limit			1	7	9	

## 5.7 CARBON ISOTHERMS - MERCURY, DBP, AND NAPHTHALENE

Before performing the carbon isotherm tests, a contact-time study was made to determine the amount of time that each isotherm test should keep the carbon in contact with the liquid. The MH-190 water was spiked with 25 ppb DBP; 350 mL of this water was then contacted with 50 mg of the two carbons tested - Filtrasorb 300 and Hydrodarco 4000. Four tests were run in parallel, with the contact time varied from 0.5 to 4 h. As can be seen in Table 17, a contact time of 0.5 h was sufficient to reach equilibrium for both carbons tested.

Fresh MH-190 water was then collected and separated into three lots, each  $\approx$ 5 L. The containers were adjusted to pH 4, pH 7, and pH 10 and then spiked with 25 ppb of DBP. The water normally contains 1 to 2 ppb of mercury. Shake tests were performed with two carbon types at carbon levels between 0 and 100 mg in fixed liquid volumes of 350 mL.

Assays of the product filtrates for mercury, DBP, and naphthalene showed that there were major unknowns in the system, the assay reliability, or both. The zero carbon samples should show the initial liquid composition corrected for any adsorption on the container walls. The zero carbon compositions are shown in Table 18.

Taking a simplistic view, at pH 4, mercury is strongly adsorbed on the container walls; but at pH 7 and above, the mercury remains in solution or suspension. At pH 4, the DBP is not adsorbed; however, the analytical system is reading twice the level of the spike. Above pH 4, the phthalate is strongly adsorbed onto the container walls. Although naphthalene was not added to the wastewater, values of 3 to 12 ppb were reported. These results may reflect trace inputs of naphthalene in the wastewater, noise from other unknown compounds, or analytical error.

The observed liquid concentrations are shown as functions of added carbon levels and pH in Table 19. Mercury sensitivity levels are 0.1 to 0.2 ppb; consequently, the quantities adsorbed from the liquid at pH 4 cannot be estimated. At pH 7,  $\approx$ 50% is removed, irrespective of carbon loading up to 40 mg. The sudden drop to 0.1 ppb for the 100 mg loading is contrary to adsorption behavior, suggesting that an unknown mechanism or an error in procedure is involved. The mercury data at

Table 17. Carbon isotherm contact-time study<sup>a</sup>

Carbon type	Contact time (h)	Mercury concentration (ppb)	DBP concentration <sup>b</sup> (ppb)	% remaining in liquid	
				Hg	DBP
Feedwater	-	1.3	2500	100	100
F-300	0.5	0.3	15	23	0.6
HD-4000	0.5	0.3	14	23	0.6
F-300	1	0.3	17	23	0.7
HD-4000	1	0.2	11	15	0.4
F-300	2	0.3	14	23	0.6
HD-4000	2	0.3	10	23	0.4
F-300	4	0.1	12	8	0.5
HD-4000	4	0.2	12	15	0.5

<sup>a</sup>Study conducted with 50 mg carbon plus 350 mL of water at 23°C.

<sup>b</sup>DBP concentration given with range of  $\pm 5$  ppb.

Table 18. Zero carbon-loading assays

pH	Carbon type <sup>a</sup>	Mercury	Dibutyl phthalate	Naphthalene
4	F-300	0.2	48	7
4	HD-4000	0.2	48	7
7	F-300	1.5	1	4
7	HD-4000	1.5	1	4
10	F-300	1.3	0	3
10	HD-4000	1.3	0	3

<sup>a</sup>F-300 is Filtrasorb 300, while HD-4000 is Hydrodarco 4000.

Table 19. Dibutyl phthalate and mercury carbon isotherm tests

Sample No.	Weight of carbon (mg)	Volume of liquid (mL)	Liquid concentration ( $\mu\text{g/L}$ )	Amount adsorbed ( $\mu\text{g/mL}$ )	Adsorbate adsorbed per unit wt of C (mg ads/g C)
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Test conditions: Carbon type F-300, pH = 4, T = 23°C

Mercury

A-0949	0	350	0.2	-	-
A-0951	1	350	0.1	0.1	0.0350
A-0955	4	350	0.2	0	0
A-0959	10	350	0.1	0.1	0.0035
A-0963	40	350	0.1	0.1	0.0009
A-0967	100	350	0.1	0.1	0.0004

Dibutyl phthalate

A-0948	0	350	48	-	-
A-0950	1	350	42	6	
A-0954	4	350	45	3	
A-0958	10	350	55	0	
A-0962	40	350	31	17	
A-0966	100	350	21	27	

Test conditions: Carbon type HD-4000, pH = 4, T = 23°C

Mercury

A-0949	0	350	0.2	-	-Hg
A-0953	1	350	0.1	0.1	0.0350
A-0957	4	350	0.1	0.1	0.0088
A-0961	10	350	0.1	0.1	0.0035
A-0965	40	350	0.1	0.1	0.0009
A-0969	100	350	0.1	0.1	0.0004

Dibutyl phthalate

A-0948	0	350	48	-	-
A-0952	1	350	33	15	
A-0956	4	350	40	8	
A-0960	10	350	24	24	
A-0964	40	350	30	18	
A-0968	100	350	18	30	

Table 19 (continued)

Sample No.	Weight of carbon (mg)	Volume of liquid (mL)	Liquid concentration ( $\mu\text{g/L}$ )	Amount adsorbed ( $\mu\text{g/mL}$ )	Adsorbate adsorbed per unit wt of C (mg ads/g C)
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Test conditions: Carbon type F-300, pH = 7, T = 23°C

Mercury

A-0971	0	350	1.5	-	-
A-0973	1	350	0.8	0.7	0.2450
A-0993	4	350	0.6	0.9	0.0788
A-0997	10	350	0.7	0.8	0.0280
2182	40	350	0.6	0.9	0.0079
2186	100	350	0.1	1.4	0.0049

Dibutyl phthalate

A-0970	0	350	1	-	-
A-0972	1	350	12	0	
A-0992	4	350	19	0	
A-0996	10	350	0	1	
A-1000	40	350	12	0	
2185	100	350	0	1	

Test conditions: Carbon type HD-4000, pH = 7, T = 23°C

Mercury

A-0971	0	350	1.5	-	-
A-0975	1	350	0.9	0.6	0.2100
A-0995	4	350	0.6	0.9	0.0788
A-0999	10	350	0.9	0.6	0.0210
2184	40	350	0.7	0.8	0.0070
2188	100	350	0.1	1.4	0.0049

Dibutyl phthalate

A-0970	0	350	1	-	-
A-0974	1	350	13	0	
A-0994	4	350	5	0	
A-0998	10	350	0	1	
2183	40	350	0	1	
2187	100	350	0	1	

Table 19 (continued)

Sample No.	Weight of carbon (mg)	Volume of liquid (mL)	Liquid concentration ( $\mu\text{g/L}$ )	Amount adsorbed ( $\mu\text{g/mL}$ )	Adsorbate adsorbed per unit wt of C (mg ads/g C)
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Test conditions: Carbon type F-300, pH = 10, T = 25°C

Mercury

2190	0	350	1.3	-	-
2192	1	350	0.7	0.6	0.2100
2196	4	350	0.5	0.8	0.0700
2200	10	350	0.4	0.9	0.0315
2204	40	350	0.2	1.1	0.0096
2208	100	350	0.2	1.1	0.0039

Dibutyl phthalate

2189	0	350	0	-	-
2191	1	350	9	0	
2195	4	350	12	0	
2199	10	350	31	0	
2203	40	350	127	0	

Test conditions: Carbon type HD-4000, pH = 10, T = 25°C

Mercury

2190	0	350	1.3	-	-
2194	1	350	0.5	0.8	0.2800
2198	4	350	0.4	0.9	0.0788
2202	10	350	0.5	0.8	0.0280
2206	40	350	0.3	1.0	0.0088
2210	100	350	0.2	1.1	0.0039

Dibutyl phthalate

2189	0	350	0	-	-
2193	1	350	2	0	
2197	4	350	13	0	
2201	10	350	15	0	
2205	40	350	70	0	
2209	100	350	9	0	

pH 10 produce reasonably normal types of adsorption isotherms, as can be seen in Fig. 6. Based on these isotherms, there is little difference to choose between the carbons.

The scatter of the DBP data at pH 7 and pH 10 suggests that the assays are not valid at readings <20 ppb and that the system is sensitive to unknown interferences. Assuming an uncertainty of  $\pm 15$  ppb at levels >25 ppb, the pH 4 data may imply very little adsorption at carbon loadings up to 10 and possibly 40 mg, although DBP should be strongly adsorbed by activated carbon.

Although little can be learned about carbon performance from these isotherm tests, two important observations emerge: (1) uncertainties exist in the analytical procedures for the <100 ppb region, and (2) possibilities occur for component loss by adsorption during sample collection. In addition, the observations that efficient mercury adsorption at pH 4 and phthalate adsorption above pH 4 occur are entirely unexpected.

#### 5.8 ION EXCHANGE FOR METALS REMOVAL

A large batch of IRC-718 resin was presaturated with calcium and magnesium by passing tap water through the bed until the influent and effluent hardnesses were equal. The waters for the subsequent, controlled-pH column tests were distilled-water stripped of  $\text{CO}_2$  by  $\text{N}_2$  sparging and spiked with 30 ppm Ca and 10 ppm Mg as nitrates. The water was then spiked with 1 ppm each of Cd, Co,  $\text{Cr}^{3+}$ , Cu, Ni, Pb, and Zn as their nitrates. Nitric acid addition was used to control the pH. The liquid residence time in the resin beds was 0.7 to 0.8 min, about a third of the IX column residences of the PWT. Batches of resin were run using pH 6.8, 5.8, 5.5, and 5 feed stocks. The pH rose between 0.5 and 1.0 units during passage of the spiked feed through the beds. This rise is believed to be associated with the displacement of the more alkaline calcium and magnesium by the heavy trace elements.

The trace elements in the feed stock partially precipitated when the pH was held at levels >5.8. These precipitates stayed in suspension and did not dissolve during passage through the resin. As

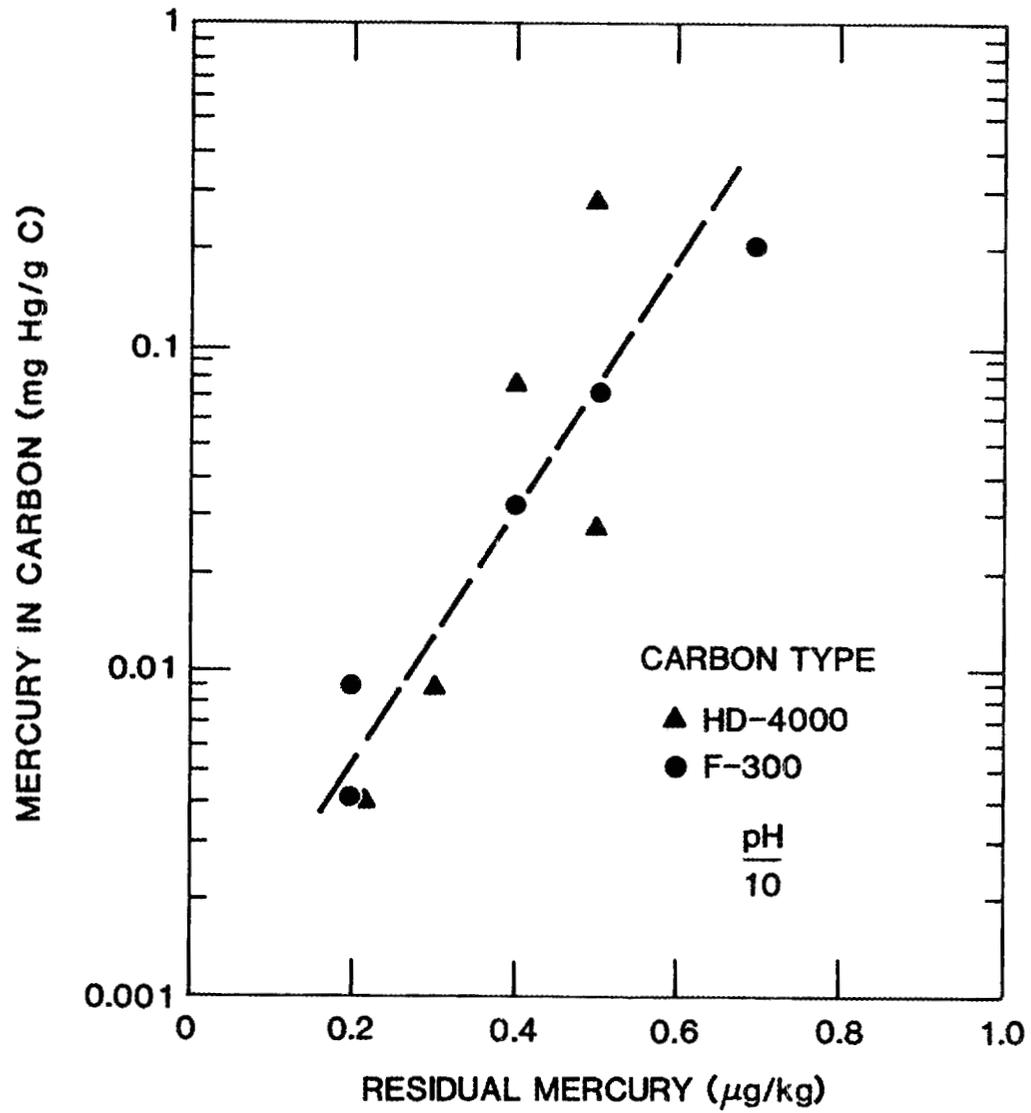


Fig. 6. Carbon isotherm for mercury at pH 10.

seen in a comparison of filtered and unfiltered samples of run 10 with those of runs 9 and 11 (Table 20), the feed stock did not precipitate at pH 5.2, but some precipitation occurred in passage through the bed. No precipitation occurred in the system at an inlet pH of 5 (run 12).

Column performance appears to have improved with decreasing pH despite the  $H^+$  competition. This may, however, be an artifact of precipitate dissolution processes. Precipitation of the trace elements at the 1-ppm level is borderline at pH 5 under ideal conditions. The practical operating pH of the feed is likely to be  $\approx 4.5$  at the column inlet.

The resin cannot break up EDTA complexes with the trace elements, as shown in runs 5 and 6. Thus, the control of trace elements in the presence of strong complexing agents is an unresolved problem.

## 6. FLOWSHEET AND DESCRIPTION OF THE MINI-PILOT PLANT EQUIPMENT

The physical layout of the mini-pilot plant in the two semitrailer vans is presented in Fig. 7. The trailers contain three feed tanks, three dual-media filters, an air stripper, an ion-exchange column, a reactor/clarifier, a phase separator, three GAC columns, an ozonation unit, and a reverse osmosis unit. (The latter two units were not used in this study). A chemical addition rack for the precipitator and various panels for the automatic process control of the equipment were also included.

### 6.1 API SEPARATOR

The API separator, illustrated schematically in Fig. 8, acts as a phase separator. Light, insoluble organics (e.g., oil) float to the top of the center section, while any solids (e.g., dirt) settle to the bottom. The unit was sized to give a residence time of  $\approx 1$  h at a flow rate of 2 gpm.

Table 20. Phase II bench-scale resin column tests<sup>a</sup>

Starting conditions: 7.4 mL IRC-718, ≈ 10 mL/min of tap water spiked with 1 ppm each of Cd, Co, Cr, Cu, Ni, Pb, and Zn; Ca ≈ 30 ppm, Mg ≈ 10 ppm.

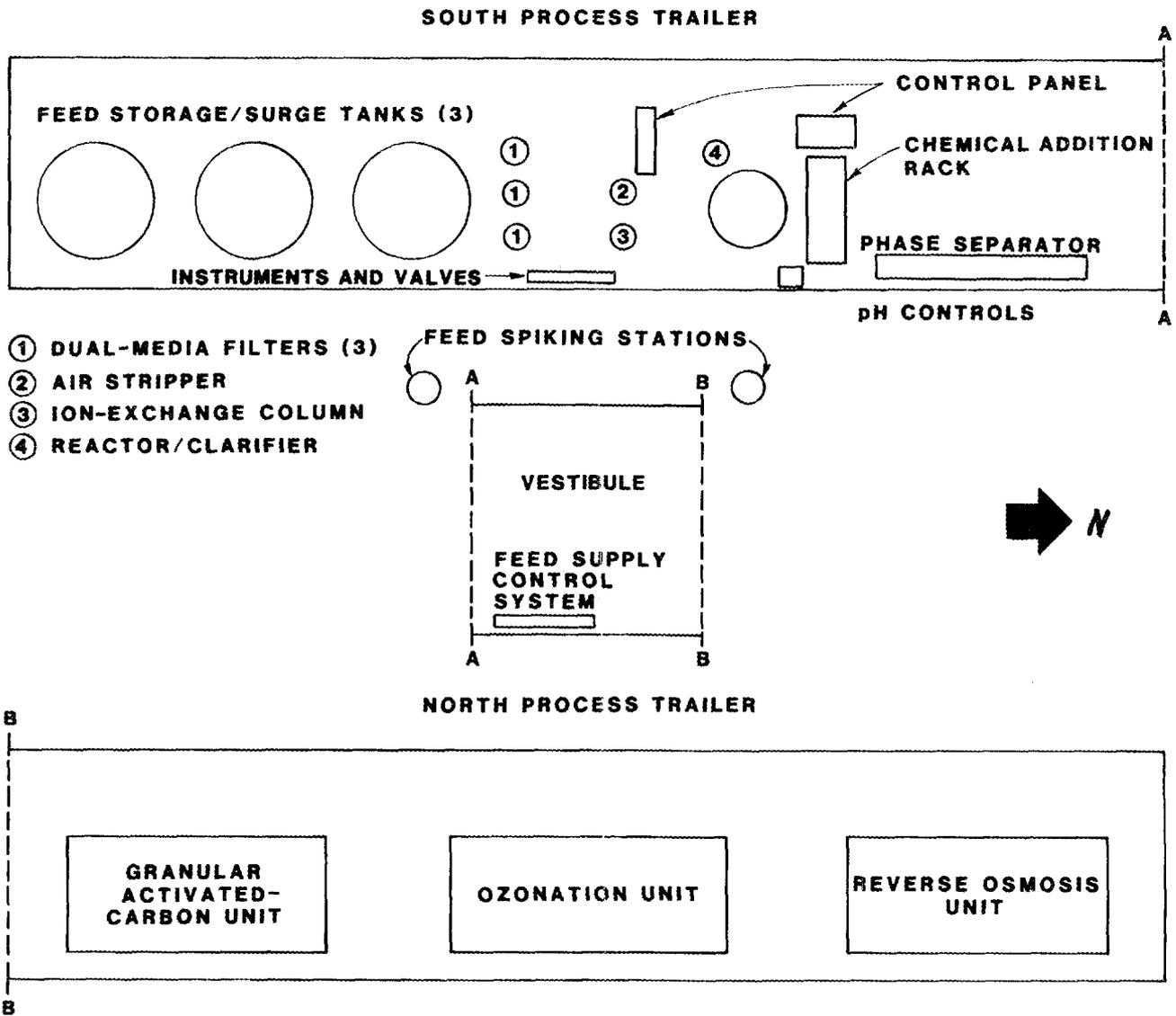
Effluent volume (L)	Feed								Effluent								Run No.	
	pH	Cd	Co	Cr	Cu	Ni	Pb	Zn	pH	Cd	Co	Cr	Cu	Ni	Pb	Zn		
8.7	6.8	0.99 0.98	1.0 0.92	1.0 <0.02	1.1 0.096	1.0 0.93	1.1 0.26	1.2 0.95	7.4	0.12 0.08	0.19 0.09	0.58 0.04	0.56 0.07	0.14 0.07	<0.2 <0.2	0.28 0.13	unfiltered filtered <sup>b</sup>	9
6.5	6.2								6.5	0.05 0.09	0.11 0.11	0.55 0.03	0.45 0.05	0.09 0.08	<0.2 <0.2	0.38 0.16	unfiltered filtered	11
10.9	5.6	1.0 1.0	1.0 0.95	0.9 0.04	1.0 0.34	1.1 1.0	1.0 0.64	1.1 1.2	6.3								unfiltered filtered	
6.3	5.5								6.0	0.05 0.09	0.66 0.09	0.12 0.05	0.07 0.05	<0.06 <0.06	<0.2 <0.2	0.17 0.13	unfiltered filtered	10
11.5	5								6.4	0.15 0.17	0.17 0.17	0.18 0.02	0.1 0.04	0.13 0.13	<0.2 <0.2	0.23 0.21	unfiltered filtered	
21.9	5.4	0.93 0.94	0.91 0.94	0.86 0.84	0.97 0.97	0.98 0.99	0.97 0.97	1.0 1.0									filtered unfiltered	
24.4	5.0								6.1	0.38	0.40	0.33	0.22	0.33	<0.2	0.45	unfiltered	
3.5	4.9								6.6	0.01	0.01	0.05	<0.02	<0.06	<0.2	0.07	unfiltered	12
5.7	4.9								5.7	0.02 0.03	0.03 0.04	0.08 0.07	<0.02 0.02	<0.06 <0.06	<0.2 <0.2	0.09 0.18	unfiltered filtered	
flow rate reduced to 5 mL/min																		
8.5	5								6.3	0.01	0.02	0.06	<0.02	<0.06	<0.2	0.14	unfiltered	
11									6.2	0.01	0.02	0.07	<0.02	<0.06	<0.2	0.09	unfiltered	
12	5	0.93 0.92	<0.93 0.91	0.90 0.88	1.0 0.97	0.98 0.98	1.1 1.0	1.2 1.1	6.2								unfiltered filtered	

Table 20 (continued)

Starting conditions: 7.4 mL IRC-718 plus $\approx$ 10 mL/min of distilled water																					
Effluent volume (L)	Feed								Effluent							Run No.					
	pH	Cd	Co	Cr	Cu	Ni	Pb	Zn	pH	Cd	Co	Cr	Cu	Ni	Pb		Zn				
11.3		nominal 1 ppm Ni <sup>2+</sup> , 1 ppm Zn <sup>2+</sup> ,										1.0						1.0	filtered	5	
16.0		29 ppm Ca <sup>2+</sup> , 10 ppm Mg <sup>2+</sup> as nitrates,										1.0						1.1	unfiltered		
31.2		20 ppm Na <sub>2</sub> EDTA, distilled water										0.98						1.2	unfiltered		
48.8												1.0						1.2	unfiltered		
51.1																		1.1	filtered		
10.4		nominal 1 ppm Cu <sup>2+</sup> , 29 ppm Ca <sup>2+</sup> ,													1.0				0.06	filtered	6
14.6		10 ppm Mg <sup>2+</sup> as nitrates, 10 ppm													1.0				0.45	unfiltered	
28.5		Na <sub>2</sub> EDTA, distilled water. Source													1.8				0.5	unfiltered	
47.3		of Zn <sup>2+</sup> unknown													1.1				0.26	unfiltered	
															1.1				0.44	filtered	

<sup>a</sup>Test results expressed in parts per million (ppm).

<sup>b</sup>Filtered through 0.45- $\mu$ m paper.



**NOTE: TRAILERS JOIN VESTIBULE AT A--A AND B--B LINES SHOWN ABOVE.**

Fig. 7. Layout of mini-pilot plant.

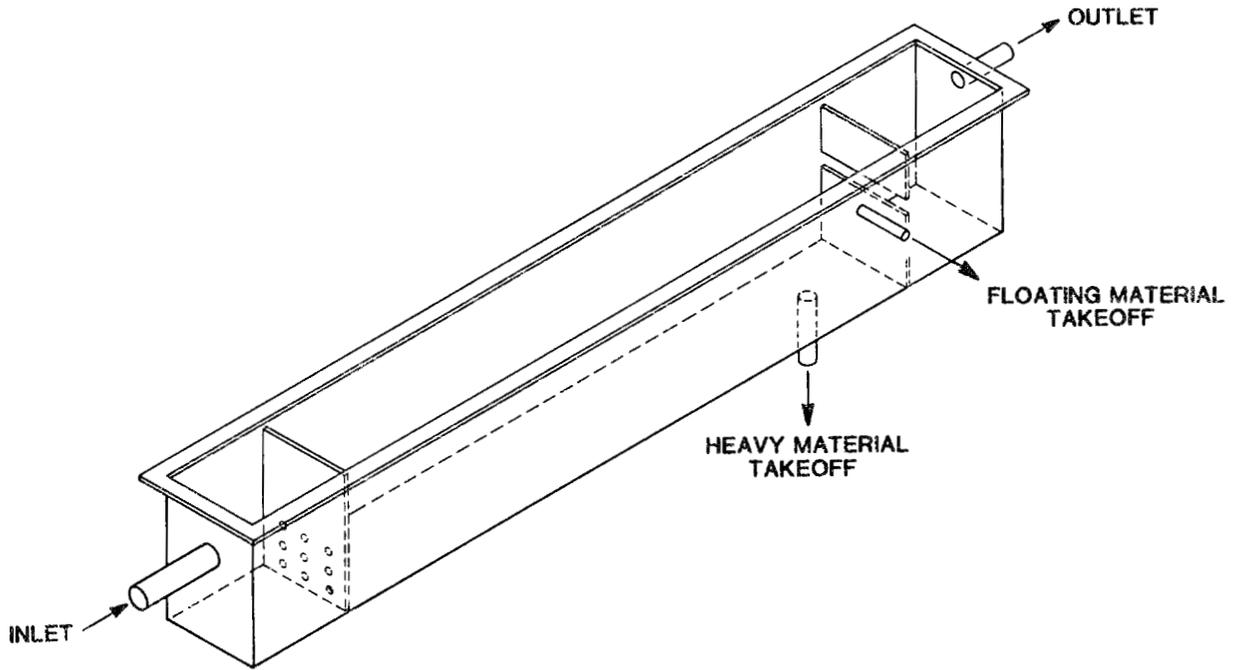


Fig. 8. API separator.

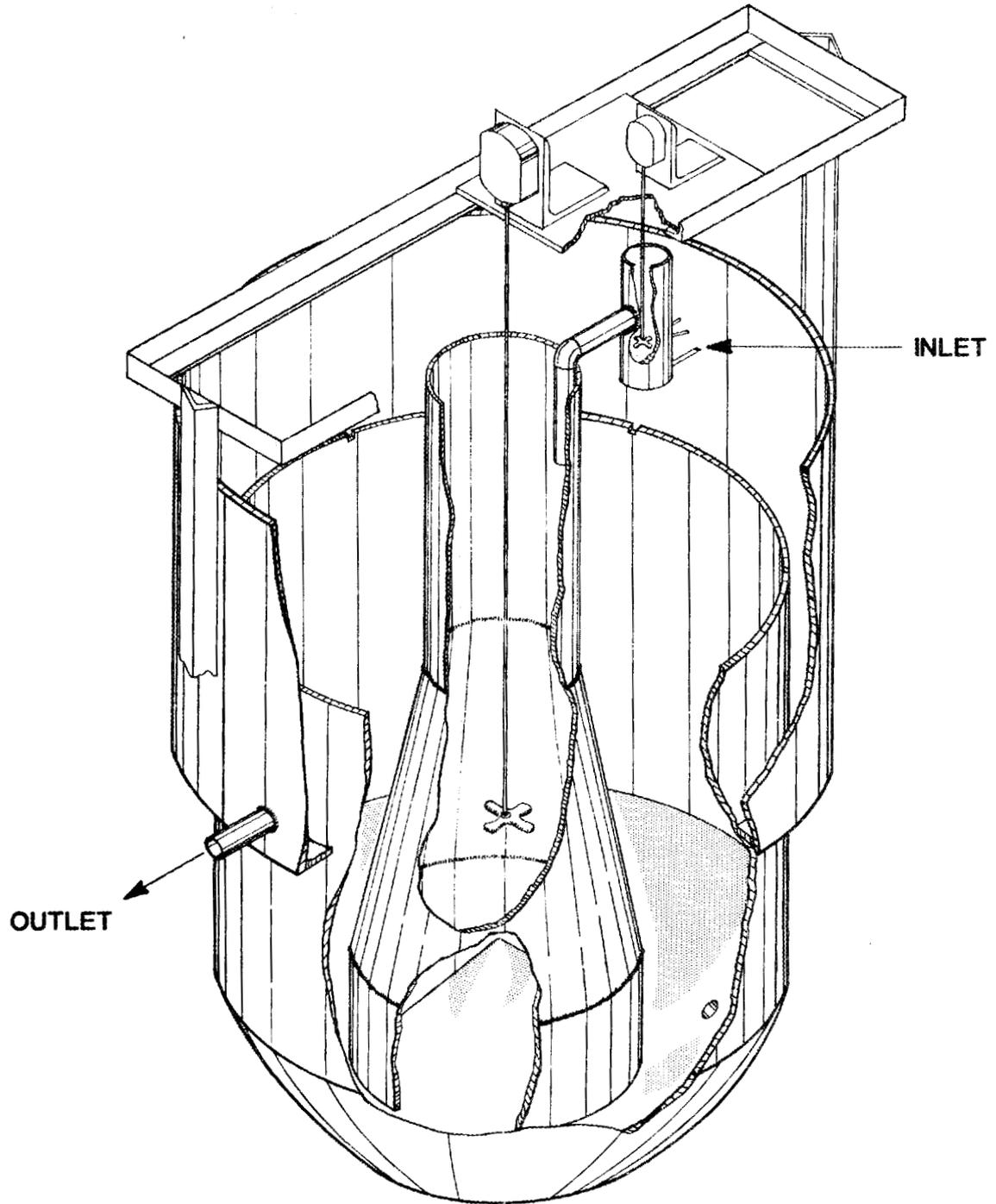


Fig. 9. Sludge-blanket type of reactor/clarifier.

## 6.2 REACTOR/CLARIFIER

Criteria trace-element precipitation is the method that was used for removing metals from the feed water in this study. In the first MPP campaign, most of the criteria metals were removed by the reactor/clarifier (R/C), shown in Fig. 9, using lime and soda ash. The critical aspect of this approach is the growth of the trace-element particulates and other precipitates to sufficiently large sizes to settle out.

The R/C is a device that allows introduction of the feed water below the surface of a developed blanket of sludge containing heavy-metal hydroxides in addition to the calcium carbonate/hydroxide-magnesium hydroxide mixture which comprises the bulk of the solid phase.

A rapid mixer (Fig. 10) blends lime and sodium carbonate to form insoluble calcium carbonate and increases the pH to  $\approx 9.5$ . The criteria elements then precipitate either as hydroxides or as carbonates. After 20 to 30 s of intense mixing, the slurry is dumped into a slow-mix zone in the R/C (i.e., center of the unit) where the particles grow within a blanket of existing sludge. A flocculant (polyelectrolyte) is added to this zone for the purpose of bonding gel particles together. The addition of this agent also serves to enhance system operation by minimizing the sludge volume.

The liquid in the R/C passes successively into the outer section, up through a sludge blanket, and into the settling zone. Although the effluent from the settling zone is typically rather clear, it must be filtered in order to remove suspended criteria trace-element particulates.

In the second MPP campaign, in which caustic was used to precipitate the criteria trace metals, the R/C was modified as shown in Fig. 11. The rapid mixer was used to blend the incoming process wastewater with caustic and the polymer. The overflow was collected in a 15-gal tank which was used as a reactor with a slow mixer. The overflow from the reactor was subsequently piped to the bottom of the

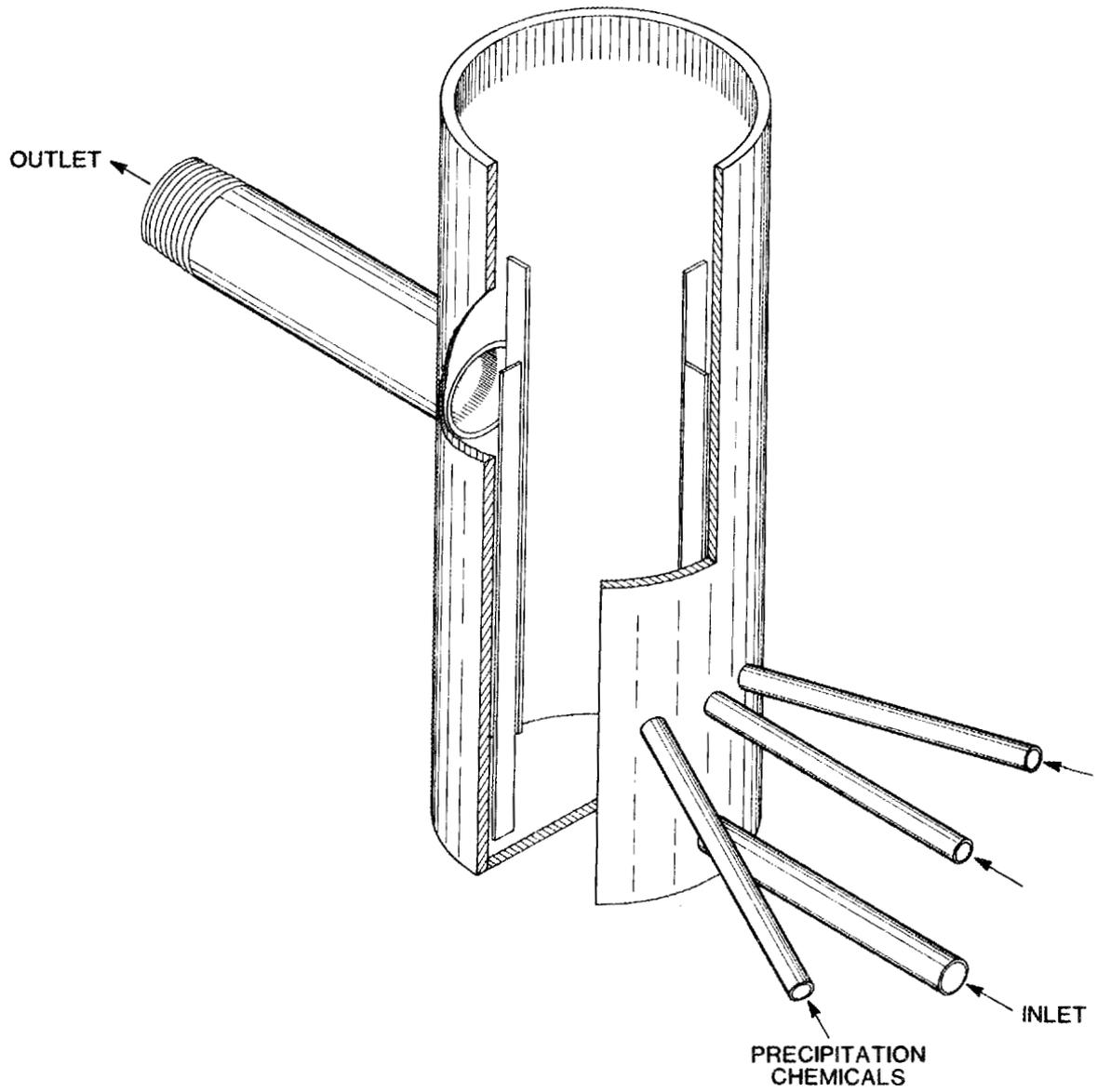


Fig. 10. Rapid mixer for precipitator.

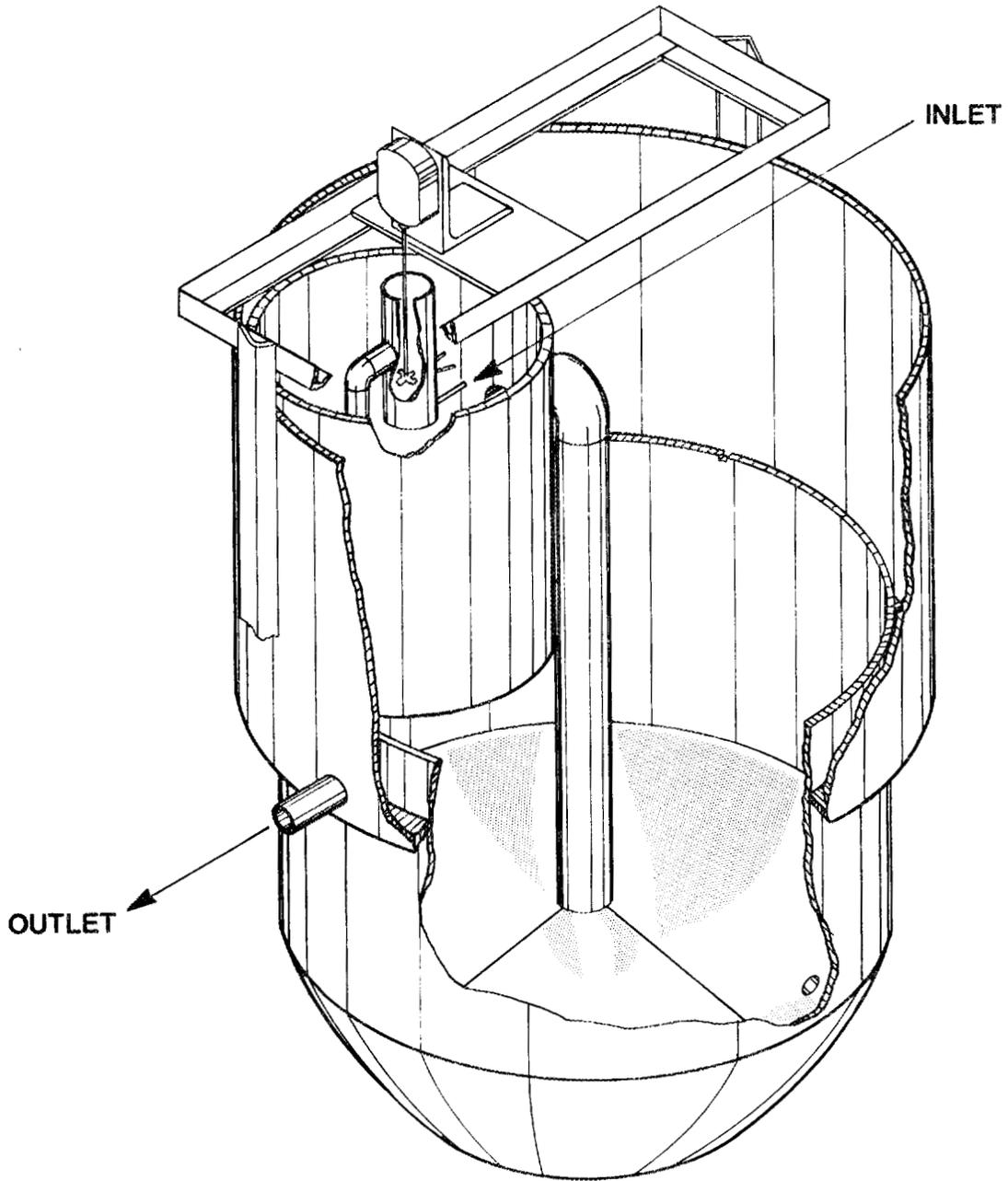


Fig. 11. Precipitator/clarifier for caustic campaign.

former R/C in which the slow-mix zone had been removed; at this point, the vessel simply served as a clarifier.

### 6.3 DUAL-MEDIA FILTERS

Two, identical dual-media filters, capable of removing >1- to 5- $\mu$ m particulates, were installed in parallel for treating the effluent from the R/C. A schematic of one of these filters is shown in Fig. 12. Approximately 12 in. of 1.7- to 1.9-mm anthracite coal was placed in the 8-in.-diam by 5-ft-long unit on top of another 12-in. layer of 0.6- to 0.8-mm sand particles. Coarse particulates were trapped on the bed and in the voids between the particles as the influent flowed downward through the column.

While one of the units was in operation, the other unit was being regenerated by backwashing in upflow with process water. Polyelectrolyte could have been added to the latter stages of the backwash solution so that it could be adsorbed onto the filter particles. Such treatment would probably improve the capability of the filters for trapping very small particulates but was not done in this study.

### 6.4 AIR STRIPPER

A schematic of the air-stripping column is presented in Fig. 13. The column packing (5/8- by 5/8-in. stainless steel Pall rings) allows for a large interfacial area between the downflowing liquid and the upflowing air and, thus, ensures equilibrium between the two phases. The liquid stream is stripped with 50 to 150 volumes of air per volume of water. The volatile organics and emulsions are typically well removed in this type of unit.

### 6.5 ACTIVATED-CARBON COLUMNS

Activated carbon is a very effective medium for removing organics in solution as well as organics that exist as emulsion phases. Nonvolatile organics and mercury were removed by a series of three

ORNL DWG 86-346R

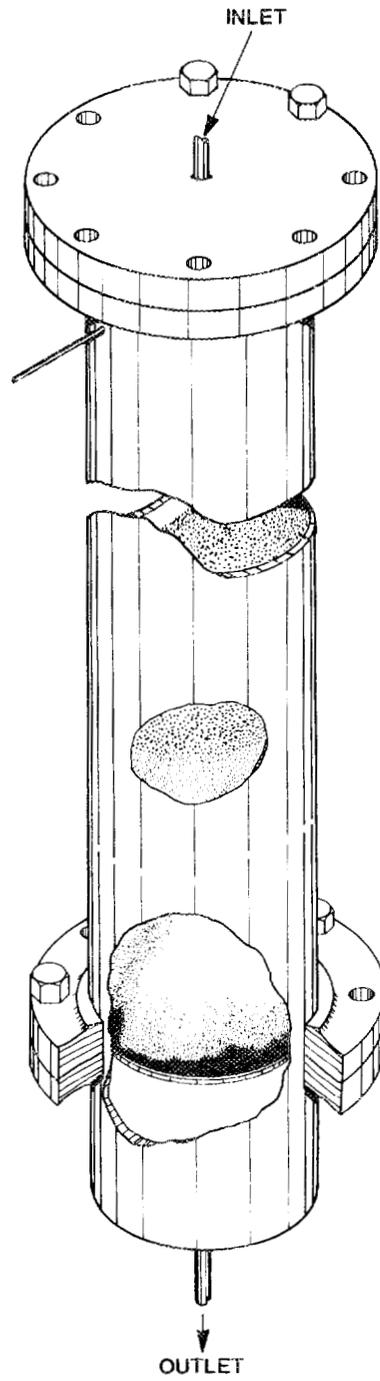


Fig. 12. Dual-media filter.

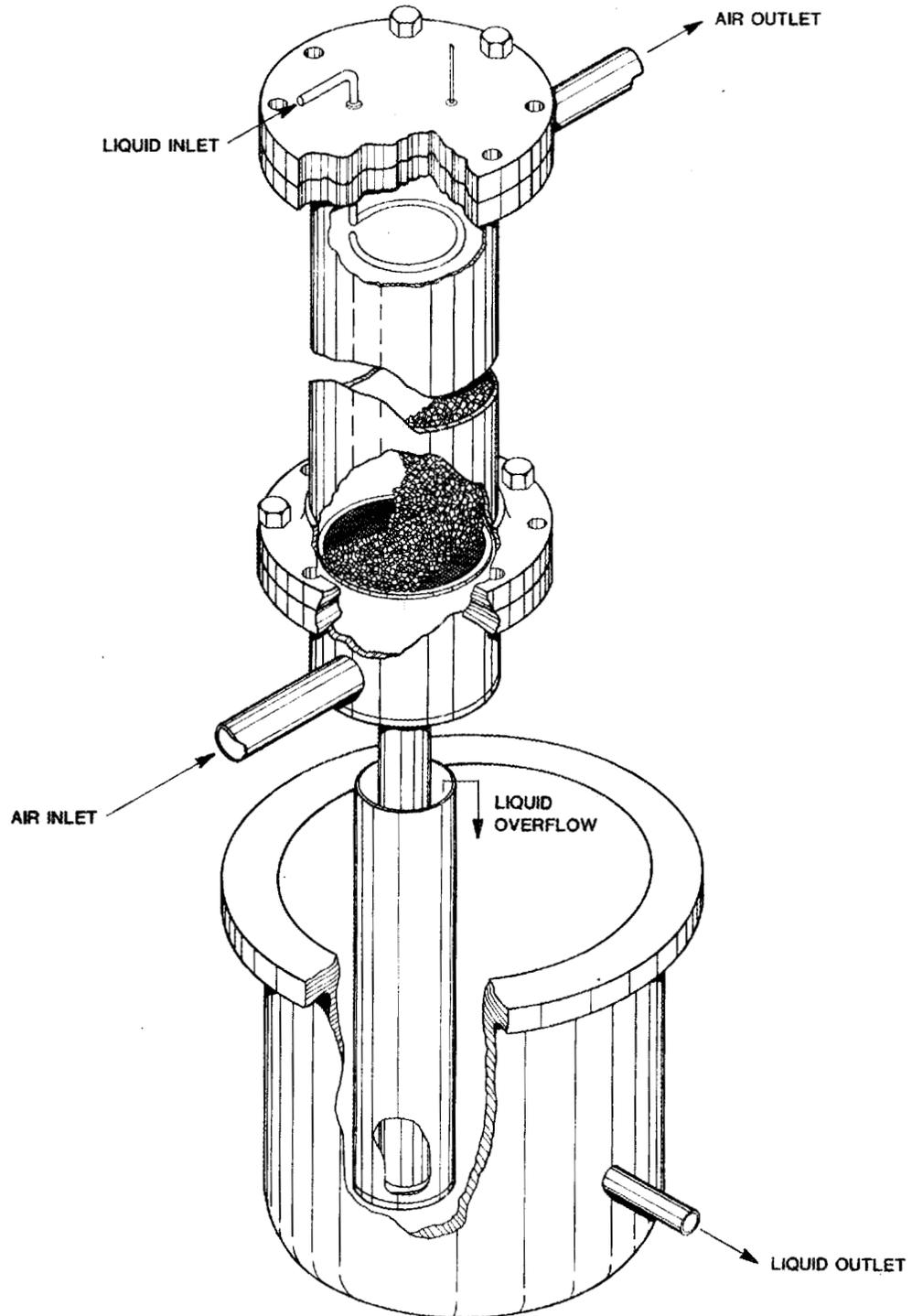


Fig. 13. Air stripper.

10-in.-diam GAC columns filled with 8 x 30 mesh Calgon F-300 activated carbon. In the first MPP campaign, ~90 lb of carbon was loaded into each column, resulting in a packed depth of 5 ft; in the second MPP campaign, the loading was reduced to 30 lb. A schematic of a typical column is shown in Fig. 14. The effluent from the GAC columns is the simulated aqueous discharge from the NRWT plant.

## 6.6 ION-EXCHANGE COLUMN

An ion-exchange (IX) column was operated in parallel with the R/C in the MPP in order to evaluate the long-term performance of Amberlite IRC-718, a chelating, heavy-metal-selective resin. The column used (see Fig. 15) was 8 in. in diameter and contained 1 ft<sup>3</sup> of resin.

# 7. OPERATION OF THE MINI-PILOT PLANT SYSTEM

## 7.1 ACQUISITION OF FEED STREAMS

The 190 pond and Building 3544 waters, which flow at nearly steady-state conditions and are readily available, provided the base feed to the MPP. The 190 pond water was pumped continuously from the weir box at MH-190 to the trailers. A special mixing chamber was added below the weir to permit collection of samples representative of both floating and dissolved organics in the wastewaters. Unfortunately, the froth generated by the fall over the weir into the chamber did not allow enough clear liquid to be pumped to the trailers. To circumvent this problem, the area above the weir was used for water collection. The liquid collected in this way was generally free of coarse particulates and oil droplets. The neutralized PWTP effluent was also continuously pumped from the clearwell below the Building 3544 effluent weir. To avoid the introduction of nitrates, the Building 3544 effluent was not pumped to the MPP until its nitrate concentration had been reduced. This step was accomplished by routing the nitric acid rinse water to the 3518 basin instead of returning it to the 3524 Equalization Basin. The decrease in nitrate concentration as a

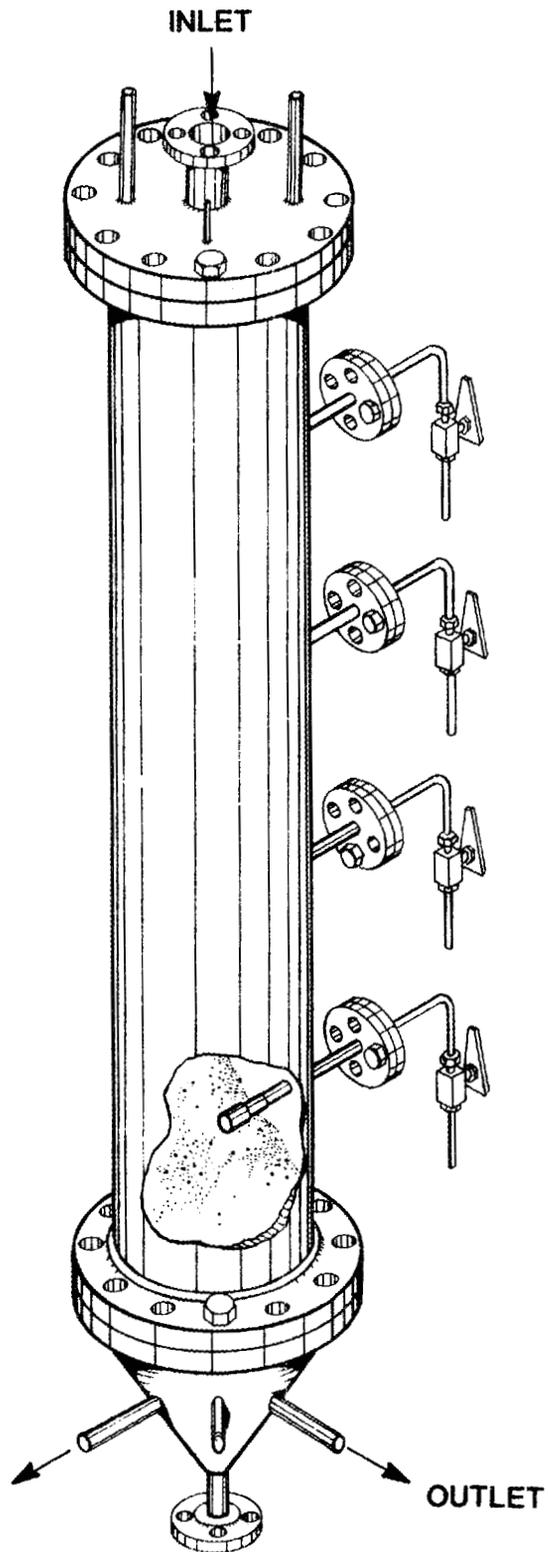


Fig. 14. Granular activated-carbon column.

ORNL DWG 86-348R

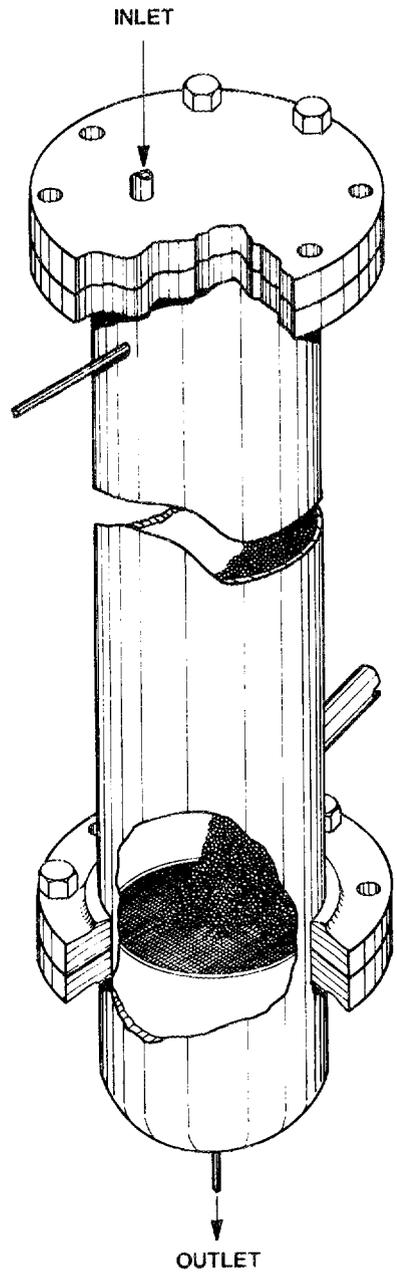


Fig. 15. Ion-exchange column.

function of time is summarized in Table 21. The feed of Building 3544 effluent to the MPP was started on August 5.

After an initial period of operation with only the 190 pond and Building 3544 waters, the remaining significant wastewaters were also fed to the MPP. Water from MH-229, which was located nearby, was pumped directly to the MPP. The remainder of the sources (i.e., HFIR, TRU, TURF, Building 1505, and MH-149, MH-235, and MH-240) were collected via truck on a routine basis and held in storage at the MPP. These streams were then introduced into the system at rates proportional to their generated rates. Based on the information in Table 3, these wastewaters were collected as indicated in Table 22 and were metered into the system in proportion to the 190 pond water (see Table 23).

## 7.2 SPIKING OF FEED STREAMS

Since the presence of contaminants in the ORNL wastewaters is fairly rare, except for mercury and some volatile organics, it was necessary to spike these wastewaters with the appropriate criteria metals (i.e., Ag, Cd, Cr, Cu, Fe, Pb, Ni, and Zn) and organics. The criteria metals were solubilized as nitrate salts and were metered into the main wastewater flow so that the stream that was fed to the API separator contained  $\approx 1$  mg/L (1 ppm) of each metal except for Ag and Fe, which were each fed at a concentration of only  $\approx 0.1$  ppm. In order to simulate the expected pulse nature of contaminants in the 190 pond water, the MPP feed was typically spiked with the solution of metals for 24 h twice per week.

Spiking of the influent streams with organics was done on a schedule similar to that described for the metals. Three organics were chosen, with the help of the ACD, to cover a wide range of volatility. These organics - chloroform, naphthalene, and dibutyl phthalate (DBP) - could also be more easily analyzed, which would reduce the required analytical costs substantially. The 190 feed water was spiked with naphthalene to a level of 100 to 200 ppb, while the Building 3544 water (which enters the MPP just prior to the air stripper and the

Table 21. Decrease of nitrate concentration in the Equalization Basin

Date	Time	Nitrate concentration (ppm)
8/1/85	0830	427
8/2/85 <sup>a</sup>	0830	106
8/3/85	0830	60
8/4/85	0830	32
8/5/85	0830	15
8/6/85	0830	8
8/7/85	0830	11

<sup>a</sup>The IX column rinse was switched from the Equalization Basin to the 3518 basin on 8/2/85 at 1630.

Table 22. Proportions of the various wastewaters collected

Source	% of total
HFIR	24
TRU	20
TURF	4
Building 1505	18
MH-149	8
MH-229	14
MH-235	5
MH-240	7
Total	100

Table 23. Relative stream contributions to the precipitator loop in the MPP

Source	% of total
190 pond	56.1
HFIR	10.3
TRU	9.0
TURF	1.8
Building 1505	7.6
MH-149	3.6
MH-229	6.3
MH-235	2.2
MH-240	<u>3.1</u>
Total	100.0

activated-carbon columns) was spiked with chloroform to a level of 200 ppb and with DBP to levels of 25 to 100 ppb. Of course, any contaminants present in the raw wastewaters were also present in the feed to the MPP. Thus, the proposed discharge limits were probably exceeded on several occasions during the 5-month period of MPP operation.

### 7.3 DETAILED FLOWSHEET

The piping and instrumentation diagram for the MPP is shown in Fig. 16. The basic connectivities are described in the paragraphs below.

Wastewater from the 190 pond entered the MPP at the API separator. After phase separation, it was divided into two fractions. One fraction went first to tank T-301, where the pH was adjusted to 4.7, then to the dual-media filter, and finally, to the IX column. The effluent from the IX column was removed from the system. The other fraction went to the R/C. After treatment in the R/C, the stream was routed first to the filtrate equalization tank and then through one of the two dual-media filters. After pH adjustment to 7 in tank T-201, the wastewater flowed downward through the air stripper and was subsequently pumped through the GAC columns.

Since the Building 3544 wastewater had already been treated for metals removal, it bypassed that step in the MPP and entered the process directly at the air stripper for removal of volatile organics. The removal of heavy organics and mercury was achieved in the GAC columns, along with the remainder of the process wastewaters.

One of the 725-gal tanks (T-401) was used as a supplemental feed tank. Wastewaters from HFIR, TRU, TURF, and Building 1505, etc., were trucked to the MPP and pumped into tank T-401. From there, they were transferred to the head of the process (i.e., the API separator) and were subjected to the same steps as was the 190 pond water.

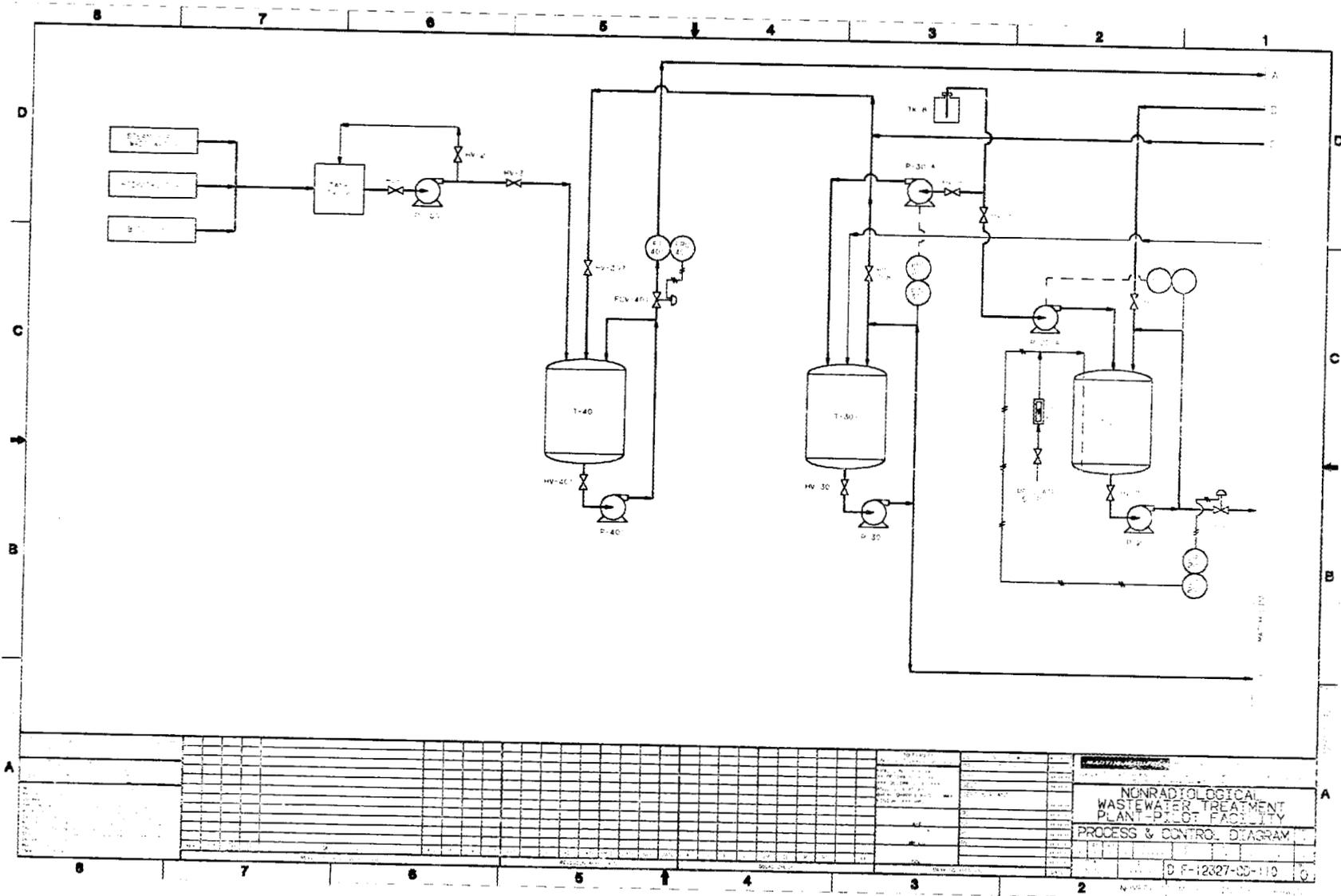


Fig. 16. Mini-pilot plant piping and instrumentation diagram.

NONRADIOLOGICAL  
WASTEWATER TREATMENT  
PLANT - PILOT FACILITY  
PROCESS & CONTROL DIAGRAM  
D F-12327-00-110







#### 7.4 ACTUAL OPERATING CONDITIONS

Typical flow rates at various points in the flowsheet are shown in Fig. 17, along with the numbered sample points (e.g., S-1). The total flow of 2 gpm from the API separator was divided so that 1 gpm went to the IX column and 1 gpm went successively to the R/C and the dual-media filter. The effluent from the filter was combined with 0.5 gpm of Building 3544 wastewater before entering the air stripper. Thus, the air stripper and the GAC columns processed feed at the rate of  $\approx 1.5$  gpm.

In the first MPP campaign, the pH of the entering water was adjusted to  $\approx 9.5$  by using lime and soda ash. Typical flow rates used were as follows: 17.4 mL/min of 2% lime solution (500 g in 25 L of water), 10 mL/min of 1.3% soda ash solution (i.e., 35 ppm in soda ash after mixing with the 1-gpm stream), and 20 mL/min of a 0.01% polymer solution (for a concentration of 1 ppm). Although Purifloc A-23 was initially used as the polyelectrolyte, subsequent jar tests indicated that Betz 1100 was superior in flocculating the precipitates. Thus, Betz 1100 was used throughout most of the MPP operation. During this campaign, only the 190 pond and Building 3544 waters were used, and spiking with metals and organics was done one to three times per week.

In the second MPP campaign, the pH was adjusted to  $\approx 10.5$  by using caustic alone. The following typical flow rates were used: 12 mL/min of 1 N caustic and 5 mL/min of polymer (at a concentration of 15 g/20 L, this resulted in a polymer dosage of 1 ppm). During this campaign, all of the significant process wastewaters were fed to the MPP. The IX column was not operated because of biogrowth and pressure drop problems, thereby decreasing the flow rates through the API separator by 50%. In the first half of this campaign, the waters were spiked with metals and organics as before. During the last 2 weeks of operation, however, the metal-spiking step was omitted. This course of action allowed the system to simulate actual NRWT plant operation.

A summary of the entries into the logbooks detailing the operations in the MPP is presented in Appendix B.

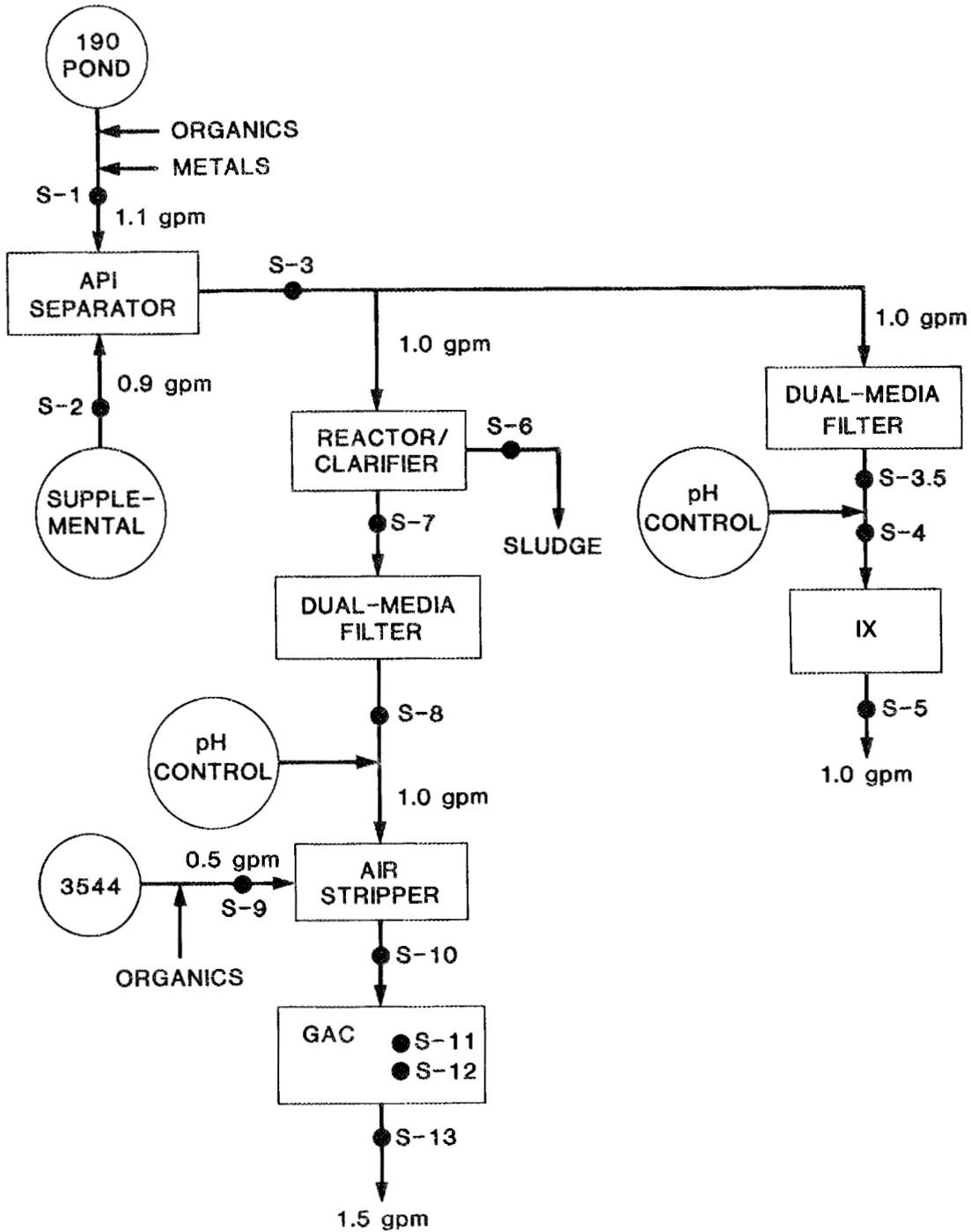


Fig. 17. Simplified block flow diagram of the mini-pilot plant.

## 8. MINI-PILOT PLANT RESULTS AND DISCUSSION

### 8.1 API SEPARATOR

The API separator never accumulated light or heavy oil phases that were identifiable; however, a layer of biomass built up on the walls and the floor, and the surface became covered with a greasy-looking scum which had a distinct rigidity. This layer of scum did not thicken significantly. Agitation of the scum caused it to settle to the bottom. When some of the scum was collected and acidified to a pH <2, the resulting ICP analysis showed that the scum contained considerable amounts of metals as shown below (the values given are in ppm):

Ag - 1	Al - 8	Ca - 120	Cd - 46
Cr - 190	Cu - 140	Fe - 12	Mg - 24
Mo - 3	Na - 36	Ni - 53	P - 210
Pb - 16	Sb - 6	Si - 4	Zn - 180

It appears that the scum did an excellent job of concentrating the above metals.

The need for an oil-water separator is based on observations at the 190 weir, where large globs of black sludge entered the pool and settled out. Droplets of light oil rose from these globs. The generally clean operation of the API separator is probably the result of the location of the collection pump in the pool. The practical pilot-plant feed-pump location was such that neither phase was likely to be collected. Further, it is doubtful that the pump could have handled the larger globs.

### 8.2 REACTOR/CLARIFIER

#### 8.2.1 Lime-Soda Softening

The API separator overflow was pumped to the rapid-mixer vessel above the R/C. A lime slurry and a sodium carbonate solution were metered into this vessel. The lime feed was adjusted to maintain the pH level at  $\approx 9.5$ ; however, the lime feed was difficult to control, and the pH fluctuated between 9 and 10. Lime addition was typically

≈100 ppm, and soda ash addition was ≈35 ppm. The calcium carbonate precipitation was very close to the equivalent of the added lime.

The overflow from the rapid-mix zone fell into the central compartment of the R/C, where it was gently mixed with added polymer (0.5 to 2 ppm). The slurry then flowed under the bottom edge of the central partition and into the apex of the conical bed of carbonate sludge.

Later, the partition was sealed to the base of the cone, and the slurry entered the sludge bed via 22 0.14-in.-diam holes drilled around the circumference of the partition ≈1 in. above the rim. Of the several modes tested, this modification provided the best distribution into the sludge bed. Some "rat-holing" occurred even with this distributor and led to jets of fines circulating up through the clarifier zone. The polymer type and dosage were varied in an attempt to minimize fines carryover. The worst condition was the use of the optimum dosage, 3 ppm of Betz 1100, as determined by the use of jar tests. At this dosage, the sludge blanket became a gummy mass. The best dosage was <1 ppm, but the system was never optimized. A reasonably well-behaved blanket ultimately developed near the end of the campaign while a 1-gpm recycle of liquid through the blanket was used.

Liquid recycles as high as 5 gpm had been tried in an effort to produce a fluidized sludge blanket. The recycle rate was slowly decreased and was ≈1 gpm at the end of the lime-soda campaign. The timing of the appearance of the well-behaved sludge blanket with the 1-gpm recycle could be coincidental. Further, the need for the recycle was probably an artifact of the clarifier configuration, since such recycle is generally unnecessary. Also, about this time, the analytical equipment (ICP unit) came back on-line. The ICP analyses showed that the dual-media filters had removed the fines carryover and that the trace elements were captured in the blanket and in the filter under all operating conditions. Thus, a sludge blanket R/C is a very forgiving unit. However, because optimum conditions were not established, it might be possible to greatly reduce the amount of

carbonate that has to be precipitated. Carbonate supersaturation was, at worst, small.

A summary of analytical data collected is given in tables in Appendix C, and the results are keyed to the sample points as shown in Fig. 17. The only set of "high" results out of the dual-media filter (sample point 8) occurred on August 30, 1985, when the toxic trace elements ranged between 70 and 110 ppb each. All of these values were well below the allowable limits. The cause of this poor performance is not known, although the lime addition record suggests that the lime feed rate might have been low. Unfortunately, the clarifier pH was not recorded for this date.

### 8.2.2 Caustic Precipitation

The R/C was modified to a reactor-settler configuration by overflowing the rapid-mix zone into a 10-min-residence slow-mix vessel and from this down an overflow tube to the apex of the upright cone in the original shell. The slurry settled into the circular vee trough. No interaction between new slurry and old sludge occurred. The clarifier was operated at a pH of 10.5 by metering caustic solution into the rapid-mix zone. Betz polymer at 1 ppm was also added at this point. Very few fines were produced under these conditions. However, a significant amount of sludge floated to the surface as flocs were suspended by attached gas bubbles.

Trace element removal was as efficient as in the R/C in the lime-soda campaign. Postprecipitation of calcium carbonate was a major problem in the small pilot-plant lines, as this occurrence could lead to concretion in the dual-media filters, although none was observed in the 1-month pilot-plant campaign.

## 8.3 DUAL-MEDIA FILTERS

The outflow from the clarifier was filtered through dual-media (anthracite and sand) filter beds prior to neutralization with sulfuric acid. The filter beds were composed of 12 in. of anthracite on top of 12 in. of sand. Line and control valve pressure drops led to a circuit

consisting of a 25-psi centrifugal pump, a level control valve, and another 25-psi centrifugal pump. The level of particulate milling inherent in this circuit is not anticipated in the full-scale plant. Despite the shredding action, the filters removed all but a few parts per million of solids. One visual observation indicated solids entrapment over the full depth of the beds. The rates of pressure rise across the filters were extremely variable. An attempt was made to measure the pressure drop-vs-flow rate profile across a clean dual-media filter using the pressure gages located at the inlet and outlet of filter No. 3. The filter was operated in the downflow mode, and the effluent was piped to the top of a tank whose elevation is above that of the filter head. The hydraulic head between the pressure gages was 2.2 psi. The following pressures were recorded as functions of flow rate:

Flow (gpm)	Top pressure (psig)	Bottom pressure (psig)	Corrected bottom pressure (psig)	Filter pressure drop (psi)
0.9	5.2	6.9	4.7	0.5
1.3	10.0	11.0	8.8	1.2
2.0	20.7	23.0	20.8	-0.1

It was concluded that the pressure drop across the clean dual-media filter bed was below the sensitivity of the pressure gages.

During the lime-soda campaign (see Table 24), the pressure drop across the filter remained <3 psi for 2 to 4 d, doubled in the next 1 to 1.5 d, and then began increasing rapidly. In one case, the rise was 16 psi in 24 h. During the caustic campaign (see Table 25), the low pressure-drop period was 1 to 3 d using two filters in parallel. The use of two filters in parallel in this latter case was dictated by the need to minimize pressure drop. The rate of pressure-drop rise caused by solids deposition in the transfer lines was such that the necessary flow through the filters could not always be maintained overnight. On a few occasions, deposition was noted downstream of the filters.

Table 24. Pressure drops across dual-media filters during lime-soda campaign

Date	Time	Sand Filter No. 2		Sand Filter No. 3		Comments
		Bed pressure drop (psi)	Outlet pressure (psig)	Bed pressure drop (psi)	Outlet pressure (psig)	
7/26		0	0			Tap water
7/29		0	0			
7/30		0	0			
7/31		0	4			
8/01						190 pond water
8/02		0	3			
8/04		0	2			
8/05				0	12	
8/06				0	12	
8/07				1	11	
8/08	0820			5	12	1st organic spike
8/08	1700			9	11	
8/09		0	7			Backwash No. 3
8/10		2	7			
8/12	1530	2	7			
8/12	2300	6	7			Backwash No. 2
8/13				0	7	Stopped system
8/21				0	6	Restart system
8/22				3	7	
8/23				8	7	
8/24				11	7	
8/25		0	8			Backwash No. 3
8/26		1	8			
8/27		2	8			
8/28		2	8			
8/29		3	8			2nd organic spike
8/30		19	8			Backwash No. 2
8/31				2	6	
9/01				2	7	
9/02				5	7	
9/03				10	7	Backwash No. 3
9/04		1	8			3rd organic spike
9/05		2	12			Backwash No. 2
9/06				1	8	
9/07				2	8	
9/08				5	8	
9/09				9	7	Backwash No. 3
9/10		4	7			4th organic spike
		9	9			

Table 25. Pressure drops across dual-media filters during caustic campaign

Date	Time	Sand Filter No. 2		Sand Filter No. 3		Comments
		Bed pressure drop (psi)	Outlet pressure (psig)	Bed pressure drop (psi)	Outlet pressure (psig)	
10/16				1	7	
10/17				4	8	Organic spike, purge exit line
10/18	1230			8	10	Backwash No. 3
10/18		1	10			Purge exit line
10/19	1100	8	8			Backwash No. 2
10/20				3	9	Backwash No. 3
10/21		10	10			Purge exit line
10/22		3	11			Organic spike, purge exit line
10/22	1210			0	19	Backwash No. 3
10/22	1600	4	11			Purge lines
10/22				0	10	
10/23	0845			4	6	Replace 3/8-in. lines with 1/2 in.
10/23	1340			5	12	
10/23	1440			7	12	Backwash No. 3
10/24				2	14	Backwash No. 3
10/25		1	12	5	14	
10/26		1	16	9	14	Backwash Nos. 2 and 3
10/27		1	17	3	16	
10/28	0820	3	16	3	16	Organic spike, purge exit lines
10/28				2	8	
10/29	0830	9	10			Backwash Nos. 2 and 3
10/29	1540	0	8	0	8	
10/30		0	8	3	9	
10/31	0815	6	10	7	9	Organic spike, backwash Nos. 2 and 3
10/31	1500			2	9	
11/01		1	10	3	10	
11/02		0	12	3	10	
11/03		1	17	2	16	
11/04		3	20	5	19	Backwash Nos. 2 and 3, purge lines
11/05		1	9	2	9	Backwash No. 2
11/06		4	11	4	11	Backwash No. 3
11/07		2	14			Purge lines
11/08	0900	6	10			Backwash No. 2
11/08	1500	0	9	1	9	

Table 25 (continued)

Date	Time	Sand Filter No. 2		Sand Filter No. 3		Comments
		Bed pressure drop (psi)	Outlet pressure (psig)	Bed pressure drop (psi)	Outlet pressure (psig)	
11/09		1	14	3	12	
11/10		5	10	5	10	
11/11		6	11	7	10	Backwash No. 3
11/12				2	12	Backwash No. 2
11/13		5	12			
11/14	0820	>30				Backwash No. 3
11/14				2	10	
11/15				11	12	

The pressure-drop increase caused by solid deposits on the pipe walls will be much slower in the full-scale plant. However, provision for occasional acid rinsing appears to be desirable.

Some shredding of the clarifier outflow may actually be desirable. During the earlier tests using a bench scale R/C unit, the clarifier overflow dropped directly onto the dual-media surface. The largest flocs were able to bridge the spaces between the granules, causing a filter cake to build up on the bed surface. The particles cemented together to produce a weak, brittle sheet, which did not disintegrate during air scouring. Indeed, it did not break up readily when rodded. Coarse floc must be shredded to the point where it is trapped throughout the depth of the bed. This aspect of filter design was not investigated.

#### 8.4 ADJUSTMENT OF pH

The 1-gpm stream exiting the dual-media filters was neutralized in tank T-201 using sulfuric acid. During the caustic campaign, it was noted that the acid consumption required to adjust the pH to 7 was in excess of that projected from the caustic addition to the precipitator feed. Carbon dioxide release during recirculation in tank T-201 was examined as a possible explanation.

A 250-mL sample of 190 pond water was raised from pH 7 to pH 10.6 using 5.9 mL of 0.1 N NaOH. The pH was then lowered to 6.0 using 7 mL of 0.1 N HCl at 0910 h. The sample was subsequently agitated to produce a small vortex at the surface using a magnetic stirrer. The pH was allowed to rise to  $\approx 7$  and was then titrated back to  $\approx 6.5$ . The history of this test follows:

<u>Time</u>	<u>Initial pH</u>	<u>Final pH</u>	<u>Accumulated 0.1 N HCl use</u>
0910		6.0	0.0
0930	7.0	6.6	0.5
1045	7.6	6.6	2.3
1230	7.6	6.6	2.7
1309	7.1	6.5	3.2
1615	6.9	6.2	3.7
1659	7.1	6.7	3.9

Total acid used = 7 + 3.9 = 10.9 mL.

Total base used = 5.9 mL.

It appears that bicarbonate was being replaced by chloride at pH 6.5 to 7 as the CO<sub>2</sub> was being stripped out by the air at the surface during stirring.

#### 8.5 AIR STRIPPER

The air stripper showed surprisingly low chloroform removal efficiencies. Based on data in the Chemical Engineers' Handbook, 4th ed.,<sup>10</sup> the NTU value for 30 in. of 5/8-in. Pall rings is  $\approx 3$ . Table 26 lists the chloroform levels at sample points along the process system. Sample point S-1 describes the 190 water entering the API separator, and S-2 describes supplemental waters which were fed only during the last 4 weeks of operation. During these weeks, S-1 was 0.6 gpm, and S-2 was 0.4 gpm. This mix entered the API separator. The effluent from the API separator, S-3, was treated in the R/C.

The 1 gpm of water leaving the sand filter and continuing to the stripper is designated S-8, while S-9 describes the 0.5 gpm of 3544 water which was mixed with the S-8 water. MIX is the calculated chloroform content in the water entering the stripper, and S-10 is the water leaving the stripper. The volumetric ratio of air to water within the stripper is expressed as  $V_G/V_L$ .

Percent removal is the percentage reduction of the chloroform content of MIX as a result of its transfer to the air stream. Assuming an NTU value, the reduction may be calculated from the relationship:<sup>11</sup>

Table 26. Chloroform levels at various sample points in the MPP

Date	Time	S-1	S-2	S-3	S-8	S-9	MIX	S-10	V <sub>G</sub> /V <sub>L</sub>	% removal
08/07	1900			32	50	6		4		
09/03	1715			282	21	236	97	29	56	70
09/04	0830			17	14	380	144	50	56	65
09/09	1500			98	200 <sup>a</sup>	225	86	26	56	70
09/10	0830			8	9	232	88	10	56	89
10/15		new packing in stripper								
10/17	1500			25	16	722	270	44	55	84
10/18	0900			412	13	347	133	86	55	35
10/22	1300			44	45	328	146	50	66	66
10/23	1400			10	7	424	156	38	76	76
10/25	1400	84	5	25	14	5		2	74	
10/28	1500	59	2	36	14	523	199	56	74	72
10/29	1500	14	3	9	8	709	252	71	74	71
10/30		steam-stripped packing								
10/31	1515	25	6	17	15	365	140	126	79	10
11/01	0900	966	2	10	10	1231	444	168	79	62
11/05		removed ≈4 in. (15%) of packing, steam-stripped remainder								
11/06	1500				9	1610	579	203	95	65
11/07	0900				8	1700	610	178	95	71
11/07	1400				15	1644	594	241	95	59
11/08	0900				9	1449	521	277	95	47
11/08	1300				9	1644	591	260	95	56
11/08	1400				10	783	285	159	95	44

<sup>a</sup>The value assumed for the calculation of MIX is 10 ppb since no chloroform should have been present in S-8, especially not higher than the value determined at S-3.

$$NTU = \frac{R}{R-1} \ln \frac{C_{in}}{C_{out}} (R-1) + 1 \quad R \quad ,$$

where

NTU = number of transfer units,

$R = HG/L\pi$ ,

$H = 170 \text{ atm CHCl}_3 \cdot \text{mol H}_2\text{O} \cdot \text{mol CHCl}_3^{-1}$  at 20°C,

$G = 25 \text{ g-mol air min}^{-1}$  (period 11/6-8/85),

$L = 328 \text{ g-mol water min}^{-1}$ ,

$C_{in}$  = MIX concentration,

$C_{out}$  = S-10 concentration,

$\pi$  = system pressure, atm.

For  $NTU = 3$ ,  $C_{in}/C_{out} \approx 15$ , removal  $\approx 93\%$ ; for  $NTU = 1$ ,  $C_{in}/C_{out} \approx 3$ , removal  $\approx 67\%$ .

Thus, the percent removal values fit an NTU of  $\approx 1$  compared to the literature value of 3.

The reasons for the low packing efficiency are not known. The packing was sprayed with jets of water from a distributor ring. These jets kept the upper 6 in. of packing spotless even when the remaining 24 in. was sheeted with biomass. The biomass undoubtedly caused channeling in the column. However, the column also showed low efficiencies immediately after replacing the packing on October 15, 1985. Volatile organics have been reduced to very low levels in units operating under similar conditions. The unusual performance of the pilot unit is believed to be associated with the unexpected and massive biofouling that was encountered. However, neither steaming nor peroxide treatment (to 100 ppm  $\text{H}_2\text{O}_2$ ) had a discernible effect on column performance. Some uncertainty exists concerning the assays. During the period October 25, 1985, to November 1, 1985, S-1 shows some high values, and S-2 shows some very low values. However, the S-3 values

are incompatible with the mix values calculated when S-1 was high. The S-3 value should be very close to S-8, but this was not the case on September 3, September 9, and October 18, showing significant random deviations can occur. However, the tests of November 6 through November 8 show consistent levels, which should be sufficiently above any noise level to make the tests fairly reliable. These assays also indicate low column efficiencies.

Batch air-stripping tests, described earlier, show that emulsified toluene and dissolved chloroform can be air stripped to low organics levels using gas-to-liquid volume ratios of 50 to 100. These tests are in direct contrast to the column tests.

The column tests have shown that biomass buildup is a major problem and that its control is uncertain. At least two possible sources could have accounted for the biomass buildup: the use of methanol to introduce the organic spikes, and the operation of a biodenitrification column in Bldg. 4505 during the time the MPP was in operation. Although that particular bioproject has since been completed, it should serve to remind us that the types of operations and experiments occurring at ORNL cover a broad range and are extremely variable. Thus, it will be prudent to be prepared for a wide range of conditions.

## 8.6 CARBON COLUMNS

### 8.6.1 Toxic Trace Elements

The carbon columns proved to be efficient trace element scavengers. Both particulate filtration and chemisorption are likely mechanisms; however, crediting one or the other is impossible because the solubilities of the trace elements are not accurately known. Except for iron and zinc, the residual trace elements are <20 ppb. The iron ranges from 0 to 30 ppb and is almost certainly in a particulate or possibly colloidal form. In general, zinc ranges from 25 to 50 ppb, which may be its solubility limit. If this is the case, then sorption is not important for zinc. The scavenging mechanisms may vary with the element.

### 8.6.2 Mercury Removal

The API separator effluent, S-3, ranged between 0.5 and 4.0 ppb of mercury, with an average value of 2 ppb. The mercury concentration leaving the dual-media filters, at sample point S-8, ranges between 0.4 and 1 ppb, showing that about half of the mercury is stripped out in the R/C system. The IX column, sample points S-3 to S-5, also removed about half the input mercury from a parallel stream. The mercury level drops from 0.4 to 1.0 at S-10 to 0.1 to 0.3 ppb at the outlet of the first carbon column, S-11. The S-11 values are at the limits of detection. The outlet values for the next two columns, S-12 and S-13, are similar. The carbon beds should be able to maintain the mercury outlet levels <0.5 ppb.

### 8.6.3 Organics Spiking

Volatile organics were represented by chloroform, and semivolatile and nonvolatile organics were represented by naphthalene and dibutyl phthalate (DBP), respectively. This selection was strongly influenced by the ease and sensitivities of the available assay procedures. Because the phthalate ester is susceptible to hydrolysis at high pH and because chloroform losses to the atmosphere might be high in the pilot-plant system, these two organics were introduced just ahead of the air stripper. The naphthalene was introduced ahead of the API separator.

Because of the difficulty of dissolving these organics in water, they were introduced as <0.1% solutions in methanol. The mixing of the methanol solution and water produces, at worst, an extremely fine emulsion of the organic in water. Design goals were 300 ppb of chloroform, 250 ppb of naphthalene, and 40 ppb of DBP. These values are well within the solubilities of the organics in water and well above the reported detection limits of the assay procedures.

The feed waters, 190 pond and 3544 plant waters, normally contain <20 ppb of chloroform and only traces of DBP and naphthalene. The most likely deviation would be very short-term spikes of chloroform in the 190 waters.

In light of the pilot-plant results, it is important to remember that only naphthalene was introduced into the 190 water ahead of the API separator and only chloroform and DBP were introduced into the 3544 water. Further, naphthalene was dissolved in methanol and added to the 190 feed pot, while chloroform and DBP were dissolved together in methanol and added to the 3544 feed pot. Any mix-up would have shown all three at high levels in a given pot because of the pot recharging procedures. Also, the concentration of naphthalene would have been very much greater than that of DBP. No evidence of a mix-up can be found; however, DBP and naphthalene do appear together in the assays where they should not have (see tables in Appendix C).

The feed pot assays should be 475 ppm naphthalene in the 190 pot and 40 ppm DBP plus 300 ppm chloroform in the 3544 pot. The assays of the 1-gpm discharge from the API separator, sample point S-3, should be  $\approx$ 250 ppb naphthalene, with only traces of DBP and perhaps 25 ppb chloroform. The assays of the 0.5-gpm 3544 water, S-9, should be  $\approx$ 300 ppb chloroform and 40 ppb DBP, with only traces of naphthalene. Only chloroform should be removed in the stripper. Because of the low observed stripper efficiency, the chloroform levels in the 3544 feed were nearly tripled near the end of the campaign in the hope that this would override any interference that might be influencing the assay results.

The activated-carbon columns should reduce the chloroform, DBP, and naphthalene levels to below detection limits, provided these materials are in solution. The same should apply to most emulsions. However, some emulsions (e.g., skim milk) are not removed by activated carbon. Whether material adsorbed onto biosolids or other particulates can be removed by the carbon is not known.

A major sampling/assay problem does exist. Chloroform appears by itself in the September assays of the 3544 feed pot at levels  $>100$  ppm, which is correct. However, the August and September assays show 50 to 350 ppm DBP in the 190 feed pot and only 0.1 to 5 ppm DBP in the 3544 feed pot, which is the reverse of what must be. Naphthalene assays of this time range from 1 to 100 ppm in the 190 feed pot, whereas the values should be greater than 100 ppm. On the other hand, most of the

October and November data show negligible quantities of DBP and naphthalene in either feed pot.

#### 8.6.4 Chloroform Removal

Practically all the chloroform entering the columns is removed in the first bed, and probably in the first foot or so, because the beds were only  $\approx 2$  ft deep after September 15, 1985. Because the chloroform levels were very high near the end of the program, the wave front must be very steep to completely remove the chloroform in the first bed.

#### 8.6.5 Naphthalene and DBP Removal

Naphthalene values at S-3 range from 30 to 100 ppb, against projected values of 250 ppb. During the lime-soda campaign, the naphthalene exiting the sand filters, S-8, was  $< 10$  ppb. During the caustic campaign, after September 15, S-3 ranged from 20 to 100 ppb, with one value at 480 ppb; S-8 ran from 70 to 580 ppb. The values must be questioned because S-8 levels are frequently above those of S-3.

The DBP numbers are even more confusing. The data for October 17, 1985, show both S-3 and S-9 at about 40 ppb DBP. Thus, the carbon column feed should also have been 40 ppb. However, the feed into and the assays along the carbon columns showed 130 to 220 ppb. Data for October 31 through November 1 show the reverse behavior, with the DBP disappearing in the column inlet and throughout the beds. The data for October 23 and October 25 show no removal by the carbon beds. Most of the data show low, but increasing, DBP concentrations as the exit of the carbon columns is approached.

The data are so conflicting that major flaws must exist in the sampling and analytical techniques. Similar problems with the batch stripping tests have been noted earlier in this report.

#### 8.6.6 Biogrowth in Granular Activated-Carbon Columns

Plugging of the granular activated carbon (GAC) by biogrowth was a major operating problem. During the lime-soda campaign, most of the growth appeared to be confined to the upper 25% of the first of the three columns (operated in series). No particular effort was made to

delineate the zones of high pressure drop. Water backwash was relatively ineffective in reducing the pressure drop. An air scour of the upper 25% of the first column followed by water backwash was very effective. The use of 20- $\mu$ m wound polypropylene filters ahead of the carbon beds had no noticeable effect.

The possibility of associated postprecipitation of calcium carbonate was considered. However, only one assay showed a calcium decrease, in excess of the normal scatter, across the column. Also, carbonate did not appear to be a constituent in the few backwashes examined.

Pressure drop data are presented in Table 27 for the lime-soda campaign. For the first 5 d, the columns operated on tap water, July 26 to August 1, and showed no pressure drop increase. The carbon columns were switched to plant water (190 pond) on August 1, and 3544 water was added on August 5. The first noticeable increase in pressure drop occurred on August 7. The next day, the pressure drop was high enough, 21 psi, to cause operating problems. Water backwash reduced the pressure drop to 6 psi. The pressure drop built up slightly during the overnight (August 8-9) organic spike and then increased exponentially after the termination of the spike, reaching 33 psi at 1200 h on August 10.

The columns were taken off-line on August 10 and brought back on-line with fresh carbon in column 1 (C-301) on August 21. After 4 d of operation with 190 plus 3544 water, the pressure drop became noticeable; it doubled in the next 48 h and almost doubled again in the next 8 h, reaching 20 psi across column 1 at 0830 on August 28. The last increase occurred despite treatment with 30 ppm hydrogen peroxide and the introduction of a 20- $\mu$ m wound polypropylene filter ahead of column 1.

Subsequently, air scouring followed by water backwash was needed on column 1 every 2 to 4 d. Note that treatment with up to 100 ppm  $H_2O_2$  had no noticeable effect. Further, the prefilter appeared to be of little value, and its use was discontinued on September 4.

The only organics in excess of the 4-8 ppm TOC in the feed waters were a few hundred parts per million of methanol for 24 h during the

Table 27. Pressure drops across GAC columns during lime-soda campaign

Date	Time	Column pressure drop (psi)		Inlet pressure (psig)	Organic spike	Comment
		No. 1	No. 2	No. 3		
7/26		2	3	3		Tap water
8/01						190 pond water
8/05		1	1	4		3544 water added
8/06		2	3	4		
8/07		7	2	4		
8/08					Start 1240	
8/08	1700	21	2	4		
8/09					End 1100	Backwash No. 1
8/09		6				
8/09	1500	10				
8/09	1700	9				
8/09	2050	18	1	2		
8/09	2310	22	1	2		
8/10	1200	33	1	2		
		GAC columns off-line			Bed No. 1 replaced	
8/21		GAC columns on-line				
8/22		0	0	2		
8/23		2	2	2		
8/24		7	0	2		
8/25		10	0	2		
8/26		12	2			
8/27	0830	13	0			Prefilter added, 27 ppm peroxide
8/27	2310	15	0	2		
8/28	0830	20	1	2		Backwash No. 1
8/28	1805	2	0	1		
8/29					Start 1340	
8/29	1700	10	1	2		New prefilter at 2110
8/30	0830	20	1	2	Stop 1100	Backwash No. 1 at 1415
8/30	1830					100 ppm peroxide
9/01		9	0	2		New prefilter
9/02		11	1	2		New prefilter
9/03	0840	16				Backwash No. 1
9/03	1400	5	1	2	Start 1300	
9/04		7	1		Stop 1245	Prefilter removed, backwash No. 1
9/05		7	1	2		Backwash No. 1
9/06		13	0	2		Backwash No. 1
9/07		2	0	2		
9/08		2	1	2		
9/09		3	1	2	Start 1007	
9/10		13	1	2	Stop 0845	

organic spikes. Part of the rapid rise in pressure drop at this time might be attributable to the methanol food supply. In any case, its effect rapidly disappeared.

The system was shut down between September 11 and October 16. During this shutdown, the plant was redesigned for operation with caustic only. The carbon columns were recharged with new carbon. Further, the fill in each was only 33%. The intent of the low fill was, in part, to permit intense air scouring.

During the shutdown, most of the process line segments were modified to permit blasting out any biogrowth or precipitates with 90 psi process water. The new operating philosophy was to purge or backwash when the pressure drop became significant and thereby minimize upsets associated with rapid pressure rises.

Table 28 presents the pressure drop histories of the shallow carbon beds. The histories are similar to those of the lime-soda campaign. The slow rise in the inlet pressure to column 3 is believed to be largely associated with the buildup of an adherent material in the drain line. The virtually trouble-free operation during the period between November 5 and November 15, during which waters from other sources were added to the 190 and 3544 waters, has not been explained. Samples of backwash from the first GAC column measured 346 ppm TSS and 8 ppm volatile suspended solids (VSS).

Measurements of pressure drop vs flow rate were made on the empty columns and shallow beds prior to restarting the MPP. Gages were located at mid-elevation on the inlet lines to every column. As can be seen in Table 29, the pressure drops are essentially the same with and without carbon. As was the case with the dual-media filters, the clean-carbon-bed pressure drops were below the sensitivity of the pressure gages.

#### 8.6.7 Radionuclide Accumulation

At the end of the lime-soda campaign, the carbon was removed from the three GAC columns and stored in two 55-gal drums. Samples removed from each drum were sent to ACD for radionuclide analysis, with the results listed in Table 30. The first sample (B-1685) was from the

Table 28. Pressure drops across 33%-full GAC columns during caustic campaign

Date	Time	Column pressure drop (psi)		Inlet pressure (psig)	Organic spike	Comment
		No. 1	No. 2	No. 3		
10/16		1	0	2		
10/17		1	0	2	Start 0935	
10/18		4	0	1	Stop 0910	
10/19		6	1	2		Backwash No. 1
10/20		0	1	2		
10/21		2	0	3		
10/22	1220	4	1	3	Start 1235	
10/23		5	1	4	Stop 1430	Backwash No. 1
10/24		0	0	2		Start supplemental feed
10/25		1	0	3		
10/26		1	1	4		
10/27		1	1	4		
10/28		1	1	5	Start 0945	
10/29	0815	6	0	6	Stop 1010	Backwash No. 1
10/30		0	2	4		
10/31		0	1	5	Start 1040	
11/01		3	4	12	Stop 0940	Backwash Nos. 1, 2, and 3
11/02		0	1	4		
11/03		1	2	8		
11/04		1	2	10		Backwash Nos. 1, 2, and 3, purge lines
11/05		0	0	5		
11/06		0	0	5	Start 0930	
11/07		1	0	5		
11/08		1	0	7	Stop 1300	
11/09		0	0	9		
11/10		1	0	8		
11/11		0	0	8	Start 1500	
11/12		0	0	8	Stop 1400	
11/13		0	0	8		
11/14		0	0	9		
11/15		1	0	9		Backwash Nos. 1, 2, and 3

Table 29. Pressure drops across empty and 33%-full GAC columns

Flow (gpm)	Column 1 inlet (psig)	Column 2 inlet (psig)	Column 3 inlet (psig)
Empty columns			
0.6	3	3	2
1.5	4	5	3.5
2.4	11	9	6
3.5	20.5	17	10
Charged columns			
0.6	3	2	2
1.5	6	5	2.5
2.4	12	9.5	6
3.2	22	15	9

Table 30. Radionuclide analyses on spent GAC<sup>a</sup>

Radionuclide (Bq/kg)	B-1685 <sup>b</sup>	B-1686 <sup>c</sup>	B-1689 <sup>d</sup>	B-1690 <sup>e</sup>	B-1691 <sup>f</sup>
Gross $\alpha$	4,200	460	3,800	2,200	1,400
Gross $\beta$	11,000	2,900	65,000	36,000	22,000
<sup>60</sup> Co	4,400	260	76,000	41,000	25,000
<sup>75</sup> Se	320		600	200	90
<sup>103</sup> Ru			130		
<sup>106</sup> Ru	1,400		6,200	3,300	1,500
<sup>137</sup> Cs	3,300	2,600	2,900	2,100	2,600
<sup>152</sup> Eu	840	130	5,200	3,500	2,100
<sup>154</sup> Eu	470	55	2,600	1,700	1,400
<sup>155</sup> Eu			420		

<sup>a</sup>A blank entry indicates that the radionuclide was not detected.

<sup>b</sup>Sample from drum containing primarily contents of the first GAC column.

<sup>c</sup>Sample from drum containing primarily contents of the third GAC column.

<sup>d</sup>Sample from first GAC column taken at end of MPP work.

<sup>e</sup>Sample from second GAC column taken at end of MPP work.

<sup>f</sup>Sample from third GAC column taken at end of MPP work.

drum containing primarily the contents of the first GAC column, while the second sample (B-1686) is more representative of the contents of the third column. It should be noted that only 190 and 3544 waters passed through the GAC columns during the lime-soda campaign. Samples from each of the three GAC columns were again taken at the end of the MPP work. Samples B-1689, B-1690, and B-1691 were taken from GAC columns 1, 2, and 3, respectively. These carbon samples had been exposed to all of the waters that will be treated in the NRWT plant. The results of the radionuclide analysis are also shown in Table 30. It is apparent that the spent carbon from the GAC columns of the NRWT plant will likely require special handling and disposal.

## 8.7 THE ION-EXCHANGE SYSTEM

### 8.7.1 Hydraulic Life

The ion-exchange (IX) column was fed 190 pond waters, which had been filtered through a dual-media filter (SF No. 1) and then acidified to pH 4.7 to 5.0 in tank T-301 using  $H_2SO_4$ . The column operated continuously and was periodically subjected to the same trace element spikes that were introduced into the R/C circuit. However, the column was not subjected to the organic spikes (except for naphthalene).

The column was on-line  $\approx 40$  d before the pressure drop became excessive. The pressure drop appears to be the result of biogrowth. Biomass formed in tank T-301 and periodically fouled the lines between it and the IX column and jammed the rotameter, FI-301, which indicated the flow into the IX column. About three quarters of the way through the run, the line between T-301 and the IX column had to be replaced because of unremoveable slime buildup.

The column was opened after  $\approx 35$  d of 190 water treatment. Biomass hung in sheets down the 8-in. tube wall, and a layer of slime covered the bed surface. The top 0.5 in. of resin was connected together and broke up, on rodding, like a fragile, brittle solid. In the upper 6 in., the beads were covered with a black film, and the interstices were at least partially filled with biomass. Stirring with a steel rod

suggested that, below the 6-in. level, the resin was not bonded and flowed readily; top-to-bottom mixing was avoided during this stirring.

The pressure drop across the column developed slowly over the 40-d operating period. Breakup of the top layer at 35 d and removal of the slime had little effect on the pressure drop. When restart of the column was attempted after a 1-month shutdown, the pressure drop went out of control after 2 d. Changes in the biomass within the bed during the month of anaerobic storage might have been responsible for this rapid "plugging."

#### 8.7.2 Ion-Exchange Column Performance

The IX column, at an inlet pH between 4.5 and 5, controlled the trace elements (see Table 31) during its life, which was determined by biomass buildup rather than bed saturation. There is no question that the resin efficiently removed Cd, Ni, Pb, and Zn. It may have been losing some of its capacity for cadmium toward the end of the run. It appears to be removing Cu, Cr, and Fe, but so much of these elements was removed by the dual-media filter that the resin efficiencies are hard to judge. The lone high chromium value, occurring August 27, may be in error because the feed concentration was only a third of the effluent concentration, and the earlier sample of this date showed low inlet values.

The IX system should be a practical means of controlling trace element spills providing it is placed on-line only during the periods of high metal levels. Biomass plugging prohibits continuous operation.

#### 8.8 PRECIPITATOR SLUDGE

Sludge was removed from the MPP precipitator on three occasions for radionuclide analysis and the EP Toxicity test: (1) after centrifugation following the lime-soda campaign, (2) after centrifugation following the first half of the caustic campaign in which the 190 feed water was spiked with metals, and (3) after dewatering in the Engineering-Science filter press from the second half of the caustic campaign in which no metal spikes were added.

Table 31. ICP results from the MPP around the IX column<sup>a</sup>

Sample point	Sample No.	Ca	Mg	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
S-4	B-0876	33	8	1	6	71	95	12	34	91	4.8	08/22/85	1000	N
S-5	B-0877	32	7	1	9	6	130	31	0	14	4.8	08/22/85	1000	N
S-3	B-0886	32	7	480	650	930	280	510	660	810	6.9	08/26/85	1800	Y
S-3.5	B-0887	31	7	340	27	84	28	340	70	230	0.0	08/26/85	1800	Y
S-4	B-0901	30	7	110	33	73	22	180	62	160	0.0	08/26/85	1800	Y
S-5	B-0888	32	7	21	23	19	26	40	0	35	0.0	08/26/85	1800	Y
S-3	B-0902	29	7	500	490	640	130	500	550	610	0.0	08/26/85	2200	Y
S-3.5	B-0903	31	7	400	10	46	19	410	56	120	0.0	08/26/85	2200	Y
S-4	B-0904	32	7	170	27	64	24	230	56	140	0.0	08/26/85	2200	Y
S-5	B-0905	32	7	36	17	17	20	40	0	40	0.0	08/26/85	2200	Y
S-3	B-0916	31	7	590	710	970	140	580	750	900	7.2	08/27/85	0900	Y
S-4	B-0918	29	7	350	15	51	37	350	93	110	0.0	08/27/85	0900	Y
S-5	B-0919	28	7	60	11	11	28	59	0	29	0.0	08/27/85	0900	Y
S-3	B-0928	31	6	650	750	950	180	630	790	910	7.2	08/27/85	1215	Y
S-4	B-0930	30	7	400	40	90	18	390	130	150	0.0	08/27/85	1215	Y
S-5	B-0931	30	7	63	121	18	21	56	0	29	0.0	08/27/85	1215	Y
S-3	B-1261	30	8	470	440	550	120	490	480	690	6.9	10/17/85	1500	Y
S-3.5	B-1262	35	9	460	170	230	82	570	170	320	6.7	10/17/85	1500	Y
S-4	B-1263	31	8	270	150	190	65	360	140	240	4.0	10/17/85	1500	Y
S-5	B-1264	30	8	1	14	5	47	0	0	12	5.2	10/17/85	1500	Y
S-3	B-1294	32	9	71	250	350	130	71	240	430	7.4	10/18/85	0900	Y
S-4	B-1296	35	9	320	210	270	84	380	210	330	3.7	10/17/85	1840	Y
S-5	B-1297	34	9	2	22	7	16	0	0	16	5.3	10/17/85	1840	Y

<sup>a</sup>Values for calcium and magnesium are expressed in ppm; other values are in ppb.

Prior to centrifugation, the slurries were typically  $\approx 1\%$  solids; afterwards, they were  $\approx 10\%$  solids. The caustic slurry dewatered in the filter press ran  $\approx 20\%$  solids after being pressed for 1 h. Since water was still exiting the press at the end of this time, a higher solids content could have been obtained if the press time had been extended. A total of 3.6 gal of sludge was produced during the second half of the caustic campaign without the addition of metal spikes to the 190 water. During this time, a total of 16,100 gal flowed through the precipitator, giving a sludge production rate of  $22 \times 10^{-5}$  gal sludge per gal of water treated.

The analytical results, given in Tables 32 to 34, show that all three sludges contained radionuclides, especially that formed from the treatment of all of the major streams required for treatment by the NRWT plant. The most likely treatment scheme, that of using caustic and polymer, did not produce an EP Toxic sludge when treating the unspiked waters. Thus, the NRWT plant will likely produce a nonhazardous, radioactive sludge. Provisions will have to be made both for the dewatering of this sludge and its disposal.

## 8.9 MISCELLANEOUS RESULTS

### 8.9.1 Arsenic and Selenium

Samples were taken for AA analysis on five occasions during operation of the MPP (8/7, 8/14, 8/26, 10/25, and 11/14) at the following sample points: S-3, S-4, S-5, S-8, S-9, S-10, and S-13. In all cases, the arsenic and selenium concentrations were below the detection limits of 2 ppb for arsenic and 5 ppb for selenium.

### 8.9.2 Total Suspended Solids (TSS)

Typical TSS were as follows:

S-7	24 ppm	(exit of precipitator/clarifier)
S-8	14 ppm	(exit of dual-media filter)
S-13	9 ppm	(exit of third GAC column).

Table 32. Centrifuged precipitator sludge from the lime-soda campaign

Element	EP Toxicity test							
	Ag	As	Ba	Cd	Cr	Pb	Hg	Se
Measured, ppm	<0.6	<1.1	0.4	3.8	<0.4	<2.2	0.001	<2.2
Limit, ppm	5	5	100	1	5	5	0.2	1

Corrosivity: No  
 Ignitability: No  
 Sulfides: 0.02 mg/L  
 CN/Liq: 0.070 mg/L  
 CN/Solid: 1.6 µg/g

Radionuclides, Bq/kg

8500 gross  $\beta$ , 510  $^{90}\text{Sr}$   
 290  $^{137}\text{Cs}$   
 70  $^{191}\text{Os}$   
 11  $^{60}\text{Co}$   
 9900 gross  $\alpha$   
 Alpha analysis, Bq/kg: 1500  $^{238}\text{U}$   
 700  $^{234}\text{U}$   
 150  $^{235}\text{U}$

Table 33. Centrifuged precipitator sludge from the caustic campaign with metal spikes

Element	EP Toxicity test							
	Ag	As	Ba	Cd	Cr	Pb	Hg	Se
Measured, ppm	0.05	<0.1	0.8	8.1	0.14	<0.2		<0.2
Limit, ppm	5	5	100	1	5	5	0.2	1
Pesticide	Endrin	Lindane	Methoxychlor	Toxaphene	2,4-D	Silvex		
Measured, ppb	<0.2	<2	<8	<5	<10	<10		
Limit, ppb	20	400	10000	500	10000	1000		

Corrosivity: No  
 Ignitability: No  
 Sulfides: 61 mg/L  
 CN/Solid: 3.7 µg/g

Radionuclides, Bq/kg

6100 gross α

2600 gross β

1700 <sup>60</sup>Co

940 <sup>137</sup>Cs

100 <sup>54</sup>Mn

46 <sup>152</sup>Eu

33 <sup>154</sup>Eu

Table 34. Dewatered precipitator sludge from the caustic campaign with no metal spikes

EP Toxicity test								
Element	Ag	As	Ba	Cd	Cr	Pb	Hg	Se
Measured, ppm	<0.05	<0.1	0.2	<0.005	<0.04	<0.2		<0.3
Limit, ppm	5	5	100	1	5	5	0.2	1
Pesticide	Endrin	Lindane	Methoxychlor	Toxaphene	2,4-D	Silvex		
Measured, ppb	<0.2	<2	<8	<5	<10	<10		
Limit, ppb	20	400	10000	500	10000	1000		

Corrosivity: No  
 Ignitability: No  
 Sulfides: 145 mg/L  
 CN/Solid: 0.25 µg/g  
 S<sup>2-</sup>: 160 µg/g

Radionuclides, Bq/kg

7,500 gross α  
 510,000 gross β  
 85,000 <sup>60</sup>Co  
 19,000 <sup>137</sup>Cs  
 2,500 <sup>152</sup>Eu  
 2,300 <sup>154</sup>Eu  
 410 <sup>155</sup>Eu

### 8.9.3 Total Dissolved Solids (TDS)

Typical TDS were as follows:

S-7	270 ppm
S-8	385 ppm
S-13	315 ppm

### 8.9.4 Total Organic Carbon (TOC)

Typical TOC analyses were as follows:

S-3	7 ppm	(exit of API separator)
S-10	5 ppm	(exit of air stripper)
S-13	3 ppm	

### 8.9.5 Biological Oxygen Demand (BOD)

One set of measurements taken near the end of the MPP operations yielded the following BOD results:

S-3	10 ppm
S-10	<5 ppm
S-13	<5 ppm

### 8.9.6 Biotoxicity Test

During the last week of MPP operation, final effluent from the MPP was sampled and subjected to two different acute bioassays: one used as an endpoint 24-h survival of fathead minnow larvae, Pimephales promelas, and the other used as an endpoint 24-h survival of the microcrustacean, Ceriodaphnia dubia/affinis. In the first test, all minnow larvae survived in all dilutions: 10%, 50%, and 100% full-strength effluent. Two replicates were run at each concentration, and 6 larvae were used per replicate. In the second test, all Ceriodaphnia survived in all dilutions: 1%, 10%, 25%, 50%, and 100% full-strength effluent. Ten replicates were run at each concentration, and one animal was used per replicate.

These results indicate that the sample was not acutely toxic to either fathead minnow larvae or Ceriodaphnia. It should be noted, however, that it is difficult to estimate chronic toxicity by extrapolating from results obtained using only 24-h acute tests.

## 9. CONCLUSIONS

The treatability work described herein resulted in running the MPP in two campaigns. In each, the goal of reducing the trace elements below the likely NPDES permit values was reached, as can be seen in Figs. 18 to 20. Thus, the flowsheet tested in the MPP should have no trouble in producing process wastewater that meets all applicable regulations. This flowsheet includes the following unit operations: oil/water separation, chemical precipitation, dual-media filtration, pH adjustment, air stripping, and granular activated carbon.

The removal efficiency of organics was less well demonstrated. Anomalous results indicate that problems exist in the collection, preparation, and analysis for very low organic concentrations. However, if biogrowth can be controlled in the NRWT plant, it is expected that air stripping will remove the volatile organics, while the GAC columns will remove any residual organics and also remove any mercury present.

The sludges from either lime-soda or caustic treatment should be nonhazardous (as determined by the EP Toxicity Test). Both treatments showed only cadmium exceeding the limits during the metal-spiking campaign. The caustic sludge produced during the organics-only spiking period near the end of the program showed values far below the allowable limits. Since that period should be representative of the actual NRWT plant operations, the sludge produced in the plant should be nonhazardous. Both the sludge produced in the precipitator and the spent carbon removed from the GAC column will have to be handled as low-level radioactive wastes.

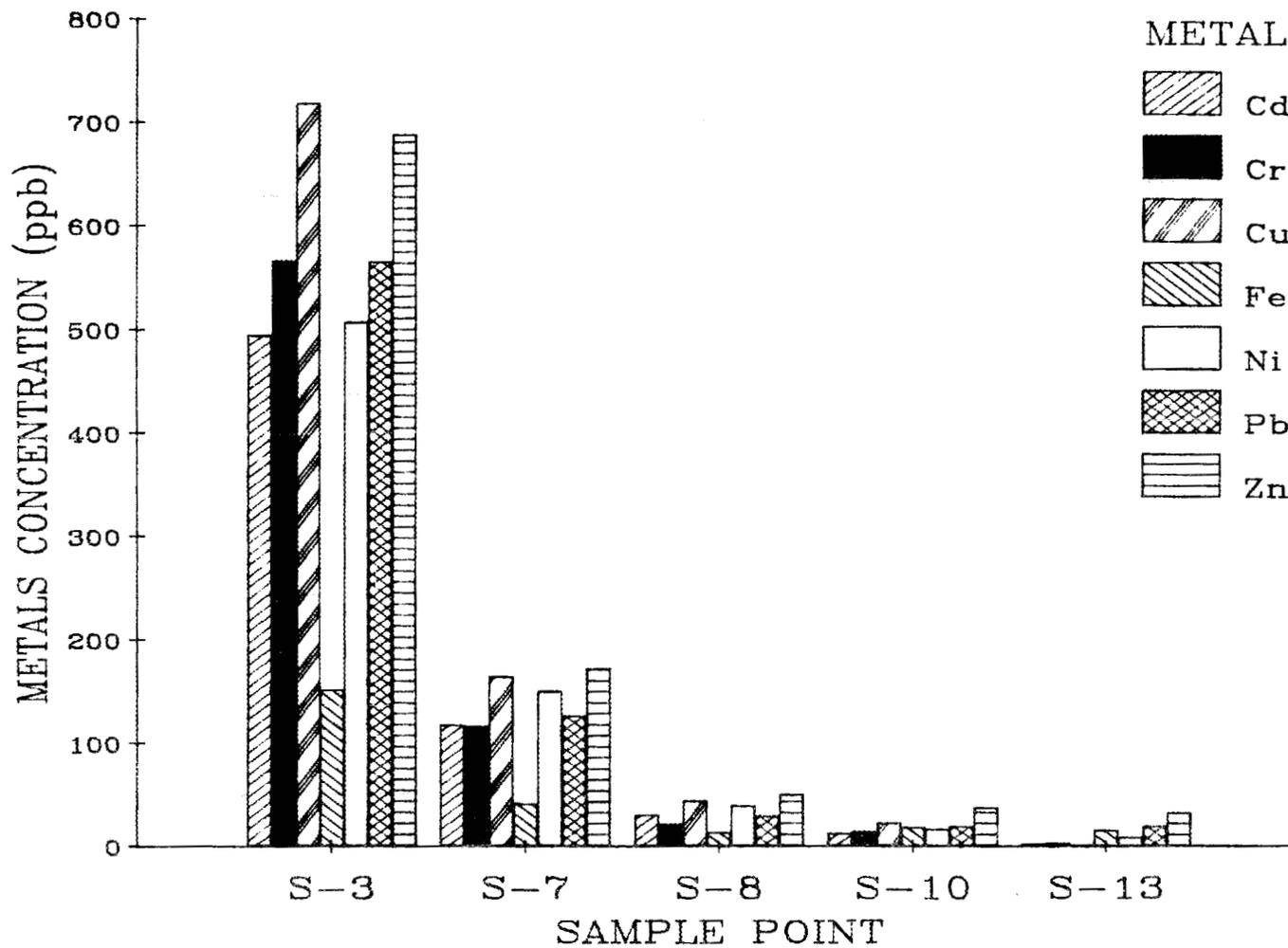


Fig. 18. Metals removal in the mini-pilot plant using lime precipitation.

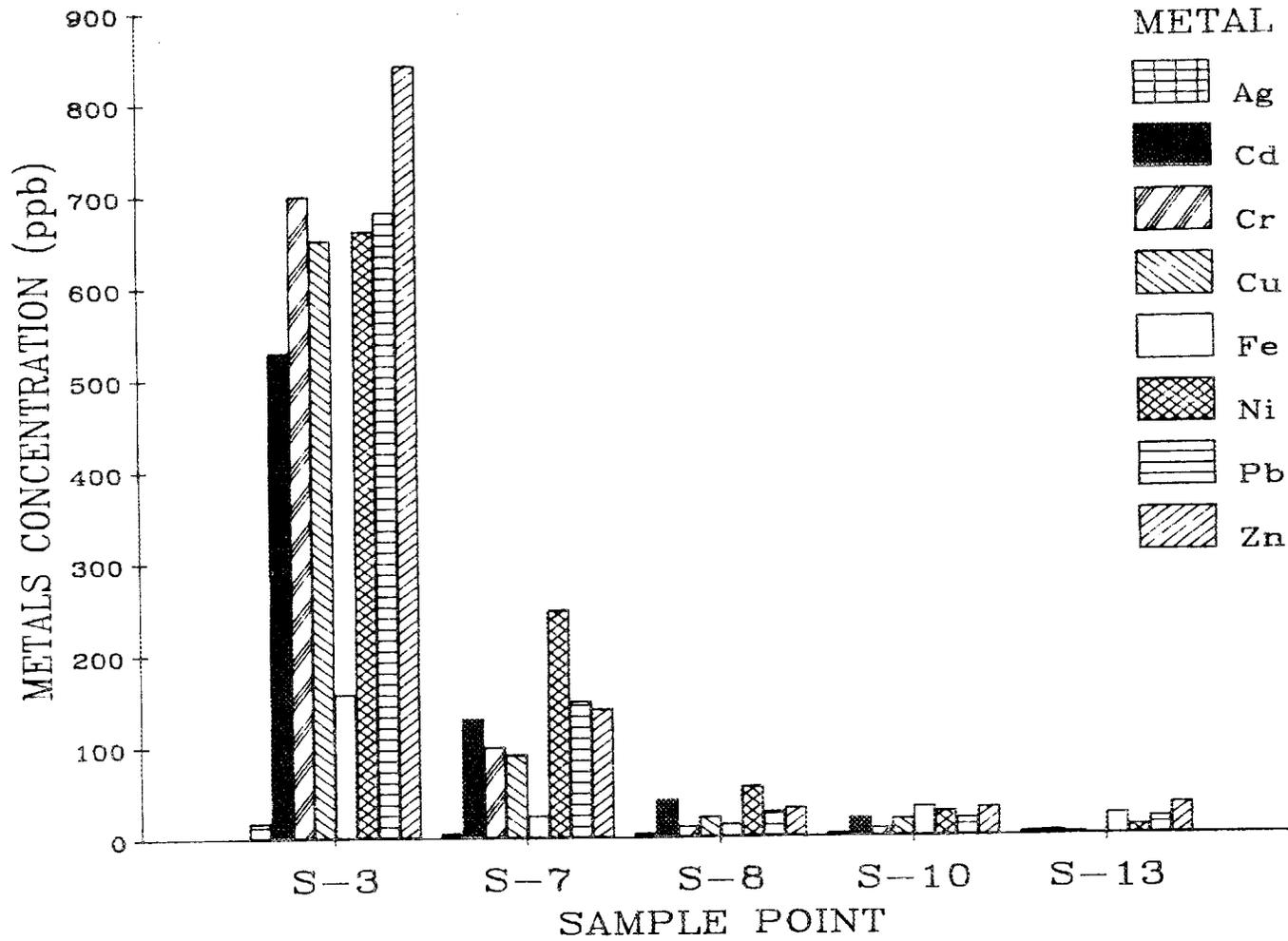


Fig. 19. Metals removal in the mini-pilot plant using caustic precipitation with metal spikes.

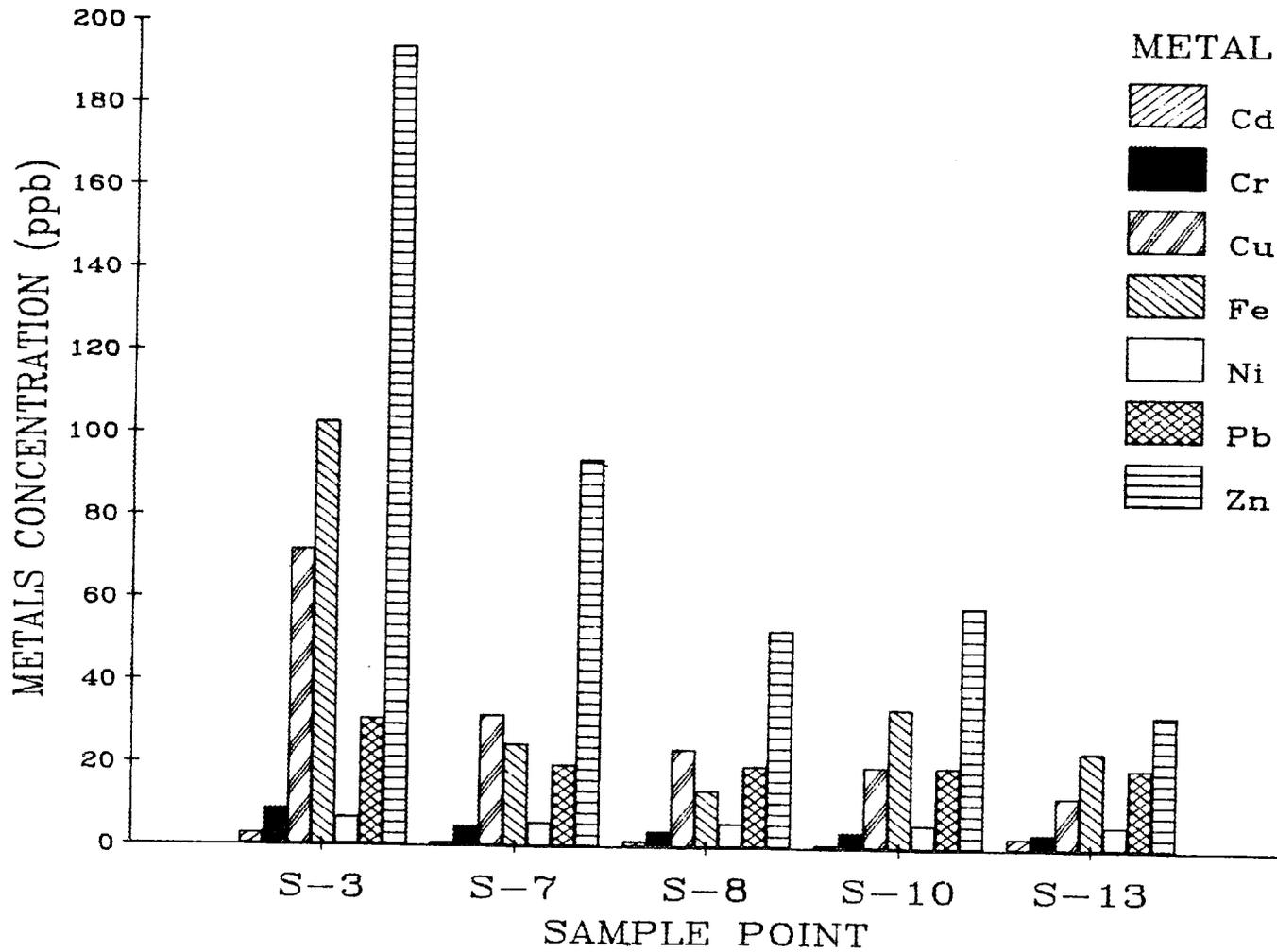


Fig. 20. Metals removal in the mini-pilot plant using caustic precipitation without metal spikes.



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A number of other people provided the bulk of the work that went into the treatability study. Technicians J. D. Hewitt and D. R. McTaggart were primarily responsible for the operation of the MPP, with assistance from D. W. DePaoli, G. B. Dinsmore, H. L. Jennings, and W. H. Woodruff. In the Analytical Chemistry Division, J. E. Caton and his staff provided the EP Toxicity tests and organic analyses; N. M. Ferguson and her staff provided the Hg, As, and Se analyses; T. G. Scott and his staff provided the radionuclide analyses; and J. H. Stewart and his staff provided the ICP, ammonia, and nitrate analyses. The quick turnaround for mercury and ICP results was especially helpful.



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APPENDIX A. RESULTS OF JAR TESTS



Table A.1. Jar test set 1 - sodium hydroxide<sup>a,b,c</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0745				72	41			84	N	14		190 water, no spike
A-0746		7		63				75	Y			
A-0747		720	390	430	51	850	430	460	N	3	<1	Blank
A-0748		490				730		39	Y			
A-0749		750	580	630	97	850	540	650	N	3	<1	pH adj to 8 using caustic
A-0750		470				680		28	Y			
A-0751		410	110	130		580	230	140	N	4	<1	pH adj to 9 using caustic
A-0752		300				480			Y			
A-0753		430	260	280	42	460	370	300	N	4	<1	pH adj to 10 using caustic
A-0754		51		21		70			Y			
A-0755			61		41			35	N	9	1	pH adj to 11 using caustic
A-0756	<5	12	9	13	55	<6	42	66	Y			
A-0757		41		31			310	79	N	9	1	pH adj to 12 using caustic
A-0758							230		Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>pH was adjusted using NaOH.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

<sup>c</sup>Metals spike did not contain silver.

Table A.2. Jar test set 2 - lime and soda ash<sup>a,b,c</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0759	270	670	440	470	87	780	480	610	N	19		pH adj to 8.5 using lime
A-0760	75	440				680		36	Y			
A-0761	130	260	110	120		270		150	N	19	3	pH adj to 10 using lime
A-0762	17	110	10	6	22	83	64	13	Y			
A-0763	72	36							N	28	6.5	pH adj to 11.5 using lime
A-0764	6	8	10	4	25	<6	48	14	Y			
A-0765	110	280	48	44		360		95	N	66	<1	50 ppm soda ash, pH adj to 10 using lime
A-0766	63	170				160			Y			
A-0767	69	29							N	24	3	50 ppm soda ash, pH adj to 11.5 using lime
A-0768	<5	7	8	4	10	7	37	10	Y			
A-0769	110	320	79	74		440		130	N	33	<1	100 ppm soda ash, pH adj to 10 using lime
A-0770	59	210				250			Y			
A-0771	69	54		44		74		42	N	0	10	100 ppm soda ash, pH adj to 11.5 using lime
A-0772		7							Y			
Y-12 BAT limits	240	260	120	500	1600	170	210	660				
Detection limits	50	5	40	20	30	60	200	20				

<sup>a</sup>pH was adjusted using lime.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

<sup>c</sup>TSS of influent = 14 ppm.

Table A.3. Jar test set 3 - sulfuric acid and lime<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0791	280	760	330	310	42	840	420	530	N	1	<1	Blank with spike
A-0792	67	660				810		310	Y			
A-0793	170	450	400	430	190	490	370	470	N	15	2.5	pH 4, then pH 9.5
A-0794	55	110				140			Y			
A-0795	110	110	100	100	31	110		110	N	12	4	pH 4, then pH 11
A-0796	<10	15	10	<4	19	<12	<40	13	Y			
A-0797	81	130	53	54		210		54	N	0	2	pH 3, then pH 9.5
A-0798	72	97		25		160			Y			
A-0799	85	84	71	67		77		86	N	12	4	pH 3, then pH 11
A-0800		18							Y			
A-0801				35	36			100	N	1		190 water, no spike
A-0802		9		36				100	Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>pH was adjusted using sulfuric acid and lime

<sup>b</sup>A blank entry indicates the value was below the detectable limit

Table A.4. Jar test set 4 - alum and ferric chloride<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0803	600	690	690	750	120	690	680	800	N			190 water with spike
A-0804	82	510		30		610		180	Y			
A-0805	220	600	190	210	47	660	210	330	N	5	<1	5 ppm alum
A-0806	86	540		22		620		150	Y			
A-0807	180	590	140	160	41	640		290	N	0	<1	15 ppm alum
A-0808	87	560		27		630		160	Y			
A-0809	440	690	640	680	110	700	630	760	N	9	<1	40 ppm alum
A-0810	88	530		24		620		150	Y			
A-0811	75	450		33	280	600		180	N	0	5	5 ppm ferric chloride
A-0812	64	430		21	33	580		150	Y			
A-0813	55	480		30	290	600		210	N	1	10	15 ppm ferric chloride
A-0814		450				580		200	Y			
A-0815	98	390	130	140	2600	550		280	N	4	17	40 ppm ferric chloride
A-0816		330			35	500		160	Y			
A-0817	190	580	190	200	69	630	270	440	N	0	<1	Blank with spike
A-0818	76	490		31		600		180	Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>Various amounts of alum and ferric chloride used; pH adjusted to 7 using lime.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

Table A.5. Jar test set 5 - sodium borohydride<sup>a,b,c</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0819	340	770	690	760	110	780	700	800	N			190 water with spike
A-0820	87	590		38		690		160	Y			
A-0821	120	590	75	100		690		220	N	0	<1	Blank with spike
A-0822	100	620		37		740		180	Y			
A-0823		120	58	67		62		63	N	2	3	pH adj to 10 with lime
A-0824		75							Y			
A-0825		100	41	57		60		66	N	5	4	pH adj to 10 with lime
A-0826	<5	61	4	6	12	7	37	9	Y			
A-0827		97		47				47	N	2	5	50 ppm soda ash, pH adj to 10 with lime
A-0828	<5	63	4	6	42	11	38	22	Y			
A-0829		94		31				44	N	1	5	100 ppm soda ash, pH adj to 10 with lime
A-0830		80						35	Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>5 ppm of sodium borohydride with 1 h reaction time used in each test except the blank and 190 water.

<sup>b</sup>pH adjusted to 10 with lime.

<sup>c</sup>A blank entry indicates the value was below the detectable limit.

Table A.6. Jar test set 6 - sodium sulfite<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
A-0834				77	59			200		N	21		190 water, no spike
A-0835		8		74	31			210		Y			
A-0836	690	790	790	860	140	790	790	990	1.2	N	21		190 water with spike
A-0837	65	660		27		740		320	0.6	Y			
A-0838	140	680	140	150	40	750	230	440		N	0	<1	Blank with spike
A-0839	56	640		21		710		310		Y			
A-0840	310	710	130	140	44	750	230	480	0.8	N	0	<1	10 ppm sulfite, pH 7
A-0841	73	670		26		720		370	0.5	Y			
A-0842	130	640	130	130	33	740	250	330	0.9	N	1	<1	10 ppm sulfite, pH 8.5
A-0843	100	580		22		710		180	0.9	Y			
A-0844	400	630	540	590	120	620	540	710	1.2	N	5	<1	10 ppm sulfite, pH 10
A-0845	300	230				160			1.0	Y			
A-0846	740	710	130	150	33	750	240	500	1.1	N	4	<1	50 ppm sulfite, pH 7
A-0847	710	660		38		690		390	1.3	Y			
A-0848	930	680	120	130	46	750	240	400	1.0	N	7	<1	50 ppm sulfite, pH 8.5
A-0849	930	660		30		710		210	1.0	Y			
A-0850	900	270		36		200		89	1.2	N	17	<1	50 ppm sulfite, pH 10
A-0851	830	200		23		70		22	2.8	Y			
A-0852	660	45		28		160		91	1.1	N	13	3	10 ppm sulfite, pH adj to 10 using lime and 50 ppm soda ash
A-0853	580	15						28	0.7	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Varying amounts of sodium sulfite used with pH adjusted using caustic except as noted.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

Table A.7. Jar test set 7 - polymer screening tests<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0900	100	510	110	130	92	660	250	190	N	6	2.1	4 ppm Percol 726, pH adj to 9 using caustic
A-0901		420		29	33	610		45	Y			
A-0902	270	720	450	510	120	730	810	600	N			190 water with 1 ppm metals spike
A-0903	51	630		27		710		130	Y			
A-0904	55	98		35	30	190		52	N	8	2	4 ppm Percol 726, pH adj to 11 using lime and 50 ppm soda ash
A-0905		27			32				Y			
A-0906		46		27		74		26	N	7	3	3 ppm Percol 727, pH adj to 11 using lime and 50 ppm soda ash
A-0907		17			37				Y			
A-0908		94	45	48	48	140		97	N	12	2.5	3 ppm Percol 728, pH adj to 11 using lime and 50 ppm soda ash
A-0909		21			31				Y			
A-0910		170	57	50	31	220		99	N	11	4	3 ppm Percol 757, pH adj to 11 using lime and 50 ppm soda ash
A-0911		23							Y			
A-0912	360	870	760	830	140	870	820	880	N	11		New 190 water with 1 ppm metals spike
A-0913		710				790		180	Y			
A-0914		200	63	65	39	180		89	N	25	5	2 ppm Betz 1100, pH adj to 11 using caustic
A-0915		70						23	Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>Polymer screening tests:

Percol 726 is a high MW, high charge, anionic polymer.  
Percol 727 is a very high MW, medium charge, anionic polymer.  
Percol 728 is a high MW, medium charge, cationic polymer.  
Percol 757 is a high MW, high charge, cationic polymer.  
Betz 1100 is a high MW, weak charge, anionic polymer.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

Table A.8. Jar test set 8 - optimum No. 1<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
A-0916	<5	2	7	37	100	<6	<20	93	1.4	N	0		190 water, no spike
A-0917		6		37	49			62	0.7	Y			
A-0918		21		46	75			66	1.3	N	0	<1	Blank
A-0919		23		45	70			69	1.0	Y			
A-0920		14		40	55			46	1.1	N	0	<1	pH adj to 11 using caustic
A-0921		8		24	61				0.3	Y			
A-0922				29	53				0.9	N	0	2	pH adj to 11.5 using lime and 50 ppm soda ash
A-0923				23	49				0.4	Y			
A-0924		20		50	52			47	0.8	N	0	<1	pH adj to 3 w/ acid then to 11 w/ caustic
A-0925		10		34	34				0.3	Y			
A-0926				23	36				0.9	N	0	2	pH adj to 10.5 w/ lime and 50 ppm soda ash, 5 ppm NaBH <sub>4</sub>
A-0927					57				0.5	Y			
A-0928				42	89			37	1.0	N	0	<1	pH adj to 10 w/ lime and 50 ppm soda ash, 10 ppm Na <sub>2</sub> SO <sub>3</sub>
A-0929				35	50			41	0.6	Y			
A-0930		7		43	75			67	1.1	N	0	<1	pH adj to 11 w/ caustic, 2 ppm Betz 1100
A-0931		6		26	40				0.2	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Optimum tests No. 1: Using raw 190 water.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

Table A.9. Jar test set 9 - optimum No. 2<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-0976	471	805	789	832	171	807	766	821	N	0		190 water with 1 ppm metals spike
A-0977		615		27	34	700		121	Y			
A-0978	137	663	124	111	60	744	216	253	N	0	<1	Blank with spike
A-0979	52	613		29	48	704		132	Y			
A-0980	55	97		25	32				N	0	<1	pH adj to 11 using caustic
A-0981		80		27					Y			
A-0982	60	25		32	34				N	0	1	pH adj to 11.5 using lime & 50 ppm soda ash
A-0983	26	9	6	5	38	<6	38	13	Y			
A-0984	52	64		46	33			31	N	0	<1	pH adj to 3 w/ acid, then to 11 w/ caustic
A-0985		39		26	48				Y			
A-0986		35		34	43				N	0	1	pH adj to 10.5 w/ lime and 50 ppm soda ash, 5 ppm NaBH <sub>4</sub>
A-0987		14		23	34				Y			
A-0988	209	165	92	76	54	313		120	N	0	2	pH adj to 10 w/ lime & 50 ppm soda ash, 10 ppm Na <sub>2</sub> SO <sub>3</sub>
A-0989	152	95		22		99			Y			
A-0990	69	166		34	33	149		47	N	0	2	pH adj to 11 w/ caustic, 2 ppm Betz 1100
A-0991		56		23	38				Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>Optimum tests No. 2: using 1 ppm metals spike.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

Table A.10. Jar test set 10 - optimum No. 3<sup>a,b</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
2211	5060	7870	8050	7980	885	7700	8070	7670	N	0		190 water with 10 ppm metals spike
2212	212	6390		54	40	6900	638	2240	Y			
2213	285	6660	313	320	58	7110	1120	2530	N	0	10	Blank with spike
2214	181	6270		40	59	6720	753	2200	Y			
2215	204	211	81	95	58	81	252	77	N	0	20	pH adj to 11 using caustic
2216	121	109		20	54				Y			
2217	253	95	143	149	44	83	496	121	N	0	40	pH adj to 11.5 using lime & 50 ppm soda ash
2218	133	28		25			325		Y			
2219	235	187	104	108	55	111	463	113	N	0	20	pH adj to 3 w/ acid, then to 11 w/ caustic
2220	165	64		24					Y			
2221	106	263	316	315	62	232	314	278	N	0	40	pH adj to 10.5 w/ lime & 50 ppm soda ash, 5 ppm NaBH <sub>4</sub>
2222		39		21	31				Y			
2223	231	328	503	273	56	455	218	228	N	0	30	pH adj to 10 w/ lime & 50 ppm soda ash, 10 ppm Na <sub>2</sub> SO <sub>3</sub>
2224	233	167	231		44	260			Y			
2225	233	276	257	262	56	201	375	218	N	0	20-40	pH adj to 11 w/ caustic, 2 ppm Betz
2226	6	67	7	8	13	10	94	21	Y			
2227	234	1100	581	571	101	1410	662	708	N	0	20-40	pH adj to 9.8 w/ and 35 ppm soda ash, 1 ppm Betz
2228	171	431		22	33	259			Y			
Detection limits	50	5	40	20	30	60	200	20				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>Optimum tests No. 3: using 10 ppm metals spike.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

Table A.11. Jar test set 11<sup>a,b,c,d</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
2233	200	99	91	90	39	86	540	81	0.9	N	9		Supernate from primary treatment
2234	140	18					390		0.5	Y			
2237	170	35		28			440	22	1.3	N	6		Blank
2238	120	12			31		290		0.6	Y			
2241	160	69	62	62			470	56	0.9	N	9	1	2 ppm NaBH <sub>4</sub> , pH 11
2242		10			35		310		0.4	Y			
2245	150	69	61	64	49		470	56	0.7	N	19		5 ppm NaBH <sub>4</sub> , pH 11
2246							310		0.4	Y			
2249	160	83	73	78	60	66	400	67	0.6	N	9		2 ppm NaBH <sub>4</sub> , pH 10
2250		8					310		0.4	Y			
2253	160	69	59	58	50		490	54	0.6	N	18		5 ppm NaBH <sub>4</sub> , pH 10
2254							310		0.3	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Secondary treatment using sodium borohydride. Primary treatment consisted of adjusting 190 water, spiked with 10 ppm metals, to a pH of 11 using lime and adding 0.5 ppm Percol 727.

<sup>b</sup>15 min reaction time used.

<sup>c</sup>Raw 190 water contained 1.2 ppb mercury.

<sup>d</sup>A blank entry indicates the value was below the detectable limit.

Table A.12. Jar test set 12<sup>a,b,c,d</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
2233	200	99	91	90	39	86	540	81	0.9	N	9	Supernate from primary treatment	
2234	140	18					390		0.5	Y			
2237	170	35		28			440	22	1.3	N	6	Blank	
2238	120	12			31		290		0.6	Y			
2257	130	43	40		31		460	31	0.4	N	6	1 5 ppm Na <sub>2</sub> S, pH 11	
2258	11	3	8		28	<6	54	9	0.2	Y			
2261	120	41	41		32		440	24	0.4	N	7	10 ppm Na <sub>2</sub> S, pH 11	
2262		6							0.2	Y			
2265	130	52	52				450	35	0.4	N	5	5 ppm Na <sub>2</sub> S, pH 10	
2266									<0.1	Y			
2269	120	55	52		34		410	37	0.4	N	5	10 ppm Na <sub>2</sub> S, pH 10	
2270					30				0.1	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Secondary treatment using sodium sulfide. Primary treatment consisted of adjusting 190 water, spiked with 10 ppm metals, to a pH of 11 using lime and adding 0.5 ppm Percol 727.

<sup>b</sup>Supernate has a tan or yellow color after Na<sub>2</sub>S is added. Some color filters out using a 0.45- $\mu$ m filter.

<sup>c</sup>Raw 190 water contained 1.2 ppb mercury.

<sup>d</sup>A blank entry indicates the value was below the detectable limit.

Table A.13. Jar test set 13<sup>a,b,c,d</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
2274	380	980	930	1000	130	940	1200	1000	1.1	N	9	1	Supernate from primary treatment
2275	93	52		31	38				0.7	Y			
2278	120	110	87	94	43	81	230	70	1.0	N	12	1	Blank
2279	74	48		57				53	1.0	Y			
2282	110	67		54	39		220	30	0.9	N	2	1	2 ppm NaBH <sub>4</sub> , pH 11
2283	<5	37	17	20	20	14	150	16	0.4	Y			
2286	100	80	50	69	50		220	51	0.7	N	8	1	5 ppm NaBH <sub>4</sub> , pH 11
2287		34							0.3	Y			
2290	110	150	89	100	37	95	220	77	0.9	N	6	1	2 ppm NaBH <sub>4</sub> , pH 10
2291		46							0.3	Y			
2294	110	100	55	71	32			50	0.8	N	12	1	5 ppm NaBH <sub>4</sub> , pH 10
2295		47			55				0.4	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Secondary treatment using sodium borohydride. Primary treatment consisted of adjusting 190 water, spiked with 10 ppm metals, to a pH of 11 using caustic and adding 2 ppm Percol 728.

<sup>b</sup>15-min reaction time used.

<sup>c</sup>A blank entry indicates the value was below the detectable limit.

<sup>d</sup>Raw 190 water contained 2.8 ppb (unfiltered sample).

Table A.14. Jar test set 14<sup>a,b,c,d</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
2274	380	980	930	1000	130	940	1200	1000	1.1	N	9		Supernate from primary treatment
2275	93	52		31	38				0.7	Y			
2278	120	110	87	94	43	81	230	70	1.0	N	6		Blank
2279	74	48		57				53	1.0	Y			
2298	76	150	120	79	46	120	230	120	0.8	N	6	1	5 ppm Na <sub>2</sub> S, pH 11
2299	6	22	14	10	24	11	63	14	0.4	Y			
2302	90	460	430	230	100	420	580	450	0.7	N	3	3	10 ppm Na <sub>2</sub> S, pH 11
2303		17							0.2	Y			
2306	78	310	270	230	78	280	420	270	0.7	N	2	1	5 ppm Na <sub>2</sub> S, pH 10
2307		26			38				0.1	Y			
2310	74	510	480	340	89	470	600	500	0.6	N	5	1	10 ppm Na <sub>2</sub> S, pH 10
2311		25							0.2	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Secondary treatment using sodium sulfide. Primary treatment consisted of adjusting 190 water, spiked with 10 ppm metals, to a pH of 11 using caustic and adding 2 ppm Percol 728.

<sup>b</sup>Supernate has a yellow color after Na<sub>2</sub>S is added.

<sup>c</sup>A blank entry indicates the value was below the detectable limit.

<sup>d</sup>Raw 190 water contained 2.8 ppb mercury (unfiltered sample).

Table A.15. Jar test set 15 - sodium sulfide<sup>a,b,c</sup>

Sample No.	ICP concentration (ppb)								AA Hg	Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn					
A-1045		6		53	79			190	0.8	N			Raw 190 water
A-1046		11		58	48			200	0.5	Y			
A-1047	880	950	960	990	160	960	930	1100		N			190 water with spike
A-1048	70	690	45	31		870		330		Y			
A-1051	390	870	760	790	140	940	750	1000	1.8	N	12	<0.5	Blank
A-1052		620		21		820		160	1.1	Y			
A-1055	200	780	610	430	110	810	620	780	0.6	N	10	<0.5	15 ppm Na <sub>2</sub> S, natural pH (7.5)
A-1056		36				560		73	0.1	Y			
A-1059	210	780	680	540	120	780	680	810	0.9	N	13	<0.5	15 ppm Na <sub>2</sub> S, pH 9 using caustic
A-1060		100				460		36	0.2	Y			
A-1063	84	260	270	120	58	270	250	310	0.3	N	12	20	15 ppm Na <sub>2</sub> S, pH 11.5 using caustic
A-1064									<0.1	Y			
A-1067	200	720	660	520	120	740	650	770	0.7	N	15	<0.5	15 ppm Na <sub>2</sub> S, pH 9 using lime
A-1068		64				410			<0.1	Y			
A-1071	52	64	68	48	59	77		160	0.2	N	15	10	15 ppm Na <sub>2</sub> S, pH 11.5 using lime
A-1072								27	<0.1	Y			
Detection limits	50	5	40	20	30	60	200	20	0.1				
Y-12 BAT limits	240	260	120	500	1600	170	210	660	3.5				

<sup>a</sup>Primary treatment using sodium sulfide on 190 water spiked with 1 ppm metals.

<sup>b</sup>Solids have a light brown color after Na<sub>2</sub>S is added. After settling or filtration, the supernate is clear.

<sup>c</sup>A blank entry indicates the value was below the detectable limit.

Table A.16. Jar test set 16 - sodium sulfide on raw 190 water<sup>a,b,c</sup>

Sample No.	ICP concentration (ppb)								Filtered (Y/N)	TSS (ppm)	Sludge volume (mL)	Comments
	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn				
A-1045		6		53	79			190	N			Raw 190 water
A-1046		11		58	48			200	Y			
A-1073	6	12	20	39	71	9		150	N	0	<0.5	Blank
A-1074		17	11	35	32	16		120	Y			
A-1075	6	17	23	36	70	14	24	170	N	0	<0.5	15 ppm Na <sub>2</sub> S, natural pH (7.8)
A-1076		6	10	11	69	12		67	Y			
A-1077		16	22	35	87	13	21	160	N	0	<0.5	15 ppm Na <sub>2</sub> S, pH 9 using caustic
A-1078	6	6	10	12	22	12		57	Y			
A-1079		6	14	17	57	7		96	N	13	17	15 ppm Na <sub>2</sub> S, pH 11.5 using caustic
A-1080		1	7	5	33			42	Y			
Detection limits	5	0.5	4	2	3	6	20	2				
Y-12 BAT limits	240	260	120	500	1600	170	210	660				

<sup>a</sup>Primary treatment using sodium sulfide on raw 190 water.

<sup>b</sup>Solids have no color after Na<sub>2</sub>S is added.

<sup>c</sup>A blank entry indicates the value was below the detectable limit.

APPENDIX B. SUMMARY OF MPP OPERATIONS



## SUMMARY OF MPP OPERATIONS

<u>Date</u>	<u>Page</u>	<u>Comments</u>
7/22	7	Started process water (PW) flow. Shakedown of system through LCV-30 & air stripper (A/S). Running at 1.5 gpm. Start loading F-300 into GAC columns.
7/23	9	Set-up skirt in reactor/clarifier (R/C) - clearance 1/8 to 1/4 in.
	11	Add 0.8 gpm of PW through A/S to simulate 3544 flow.
7/24	12	All carbon loaded and backflushed.
	16-17	Startup & shutdown procedures for R/C loop.
7/25	19	Sand filters loaded - 12 in. anthracite on top of 12 in. sand. Pall rings loaded - 30-in. depth.
	21	Startup & shutdown procedures for IX loop - 1 gpm.
	23	Start lime slurry flow to R/C.
7/26	25	pH control on T-201 and T-301 installed.
	28	Sludge ( $\approx 3$ kg from Phase II studies) loaded into R/C. Running on PW. Until now, system shut down each evening. Left R/C loop running overnight and through weekend.
7/29	32-35	Calibration curves for: FI-301, FRC-25, Peristaltic and LMI pumps.
	36	IX column loaded with 1 cu.ft. of IRC-718. Start PW flow.
	37	Start adding Purifloc A-23 to R/C.
7/30	39	Add 5 lb $\text{CaCO}_3$ in 20 L water to R/C center well. Add another 2 lb later.
7/31	44	Start flow through rest of system after R/C. R/C recycle jet installed. Chart speeds all set to 3/4 in. per min.
8/1	48	Started sampling 3544 feed daily for nitrate. Start real 190 water feed.
8/2	50	Problems with R/C.
	52	IX column inlet and outlet pH same.
	62	3544 acid rinse switched to 3518 basin.
8/5	66	Flow through A/S & GAC columns started with 3544 effluent.

8/6 70 Stop 190 flow for INSITUFORM repair of MH-190 for 4 h. Nitrate level in 3544 inlet water down to 8 ppm.

8/8 98 Metals spike on at 1220. Organics spike on at 1240. 190 organics feed pot contains naphthalene while 3544 feed pot contains chloroform and dibutyl phthalate (DBP).  
 100 Backwash C-301 at 1725. Organics spike stopped until 2010 when rest of system restarted.  
 102 System shutdown at 2030 due to R/C problems. R/C sludge drained and new slotted skirt installed. Recharged R/C at 2300 and put 190 water through at 1.5 gpm to drain.  
 103 Restarted IX unit at 2300 at 1 gpm.

8/9 103 Restart rest of system with 3544 effluent feed.  
 105 Sand filter (SF) No. 3 backwashed. Waxy organic skimmed from API separator. Flows scaled back - 1 gpm through R/C, 0.53 gpm 3544 effluent feed to A/S.  
 109 FRC-40, FRC-20, FRC-401, and FI-301 calibrations.

8/10 115 Effluent from LCV-50 sent to drain.

8/12 119 Material at top of C-301 removed - biogrowth.  
 120 API separator skimmed. Same biogrowth as in C-301? Installed prefilters (30  $\mu$ m cloth) in front of GAC columns. Removed carbon from C-301.  
 124 Backwash SF No. 1.  
 126 New reagent flows (for reduced 190 flow rate): 500 g/d of lime, 200 g/d of soda ash, and 3.5 g/d of polymer (Purifloc A-23).

8/13 127 Backwash SF No. 2.  
 130 Conduct sludge characterization tests - fluidization and settling.  
 135-137 S. Lewis' analyses of biogrowth from API separator and C-301.  
 139 Recycle of R/C sludge attempted. LCV-30 flow to drain.

8/14 142 R/C sludge recycle emptied 1/3 of R/C. Change to recycling liquid back to center well for higher velocity in clarifier and through the sludge blanket.  $\approx$ 5 gpm total through R/C.  
 145 Stop 190 flow and switch to PW. INSITUFORM will be working on 190 line in morning.  
 146 Added Purifloc to R/C - to get 3-5 ppm total.

8/15	150	New carbon in C-301 ready. 2.5 gal sludge removed from R/C.
	152-155	Polymer dosage jar tests.
	156-157	Jar tests.
8/16	159	Added Betz 1100 to R/C - $\approx$ 3 ppm total.
8/17	162	Shutdown entire system. Empty R/C and clean.
8/18	164	Installed new R/C skirt with twenty two 9/64-in.-diam holes. Sealed bottom of skirt.
8/19	166	More jar tests.
8/20	175	Put R/C sludge back into unit. Use liquid recycle at 4.1 gpm (total of 5.1 gpm through blanket). Restart 190 flow to R/C and IX.
8/21	177	Cut R/C recycle to 2 gpm.
	184	Start using Betz 1100 in R/C at 3 ppm. GAC prefilters removed. 3544 water started to A/S and GAC columns. Started 190 water through A/S and GAC also.
8/22	186	Hydrogen peroxide put through GAC columns.
8/23	194	Metals spike started at 1230. Lowered Betz to 1.5 ppm. R/C sludge thick - rod stands by itself in sludge.
8/24	196	Metals spike ended during night. SF No. 3 backwashed.
8/26	202	Peroxide put through GAC columns. R/C recycle rate set to 1 gpm (total of 2 gpm through blanket. Metals spike on at 1230.
	203	GAC prefilters reinstalled.
8/27	205	GAC prefilter changed.
	210	Metals spike off at 1230.
8/28	213	C-301 backwashed. Prefilter on 3544 feed installed. Cut Betz to 1 ppm.
8/29	219	Metals spike started at 1230. Organics spike on at 1340. GAC prefilter changed.
8/30	222	Spikes off at 1100. C-301 backwashed. Switch GAC prefilters. SF No. 2 backwashed. Peroxide put through T-201.

9/2	232	Switch GAC prefilters.
9/3	233	Backwash C-301. Metals spike started at 1232. Organics spike started at 1300. SF No. 1 and No. 3 backwashed.
9/4	243	Spikes off at 1300. Blow out FCV-40 and associated piping with 90 psi air. Backwash C-301. Heavy sludge removed from IX column. GAC prefilters taken out of system - ineffective anyway. API separator cleaned out.
	248	Backwash C-301 again. GAC prefilters back in system.
9/5	249	GAC prefilters bypassed. LCV-30 and associated piping backflushed. Air added to GAC columns to allow air agitation during backwash. Backwashed C-301.
9/6	255	IX lines cleaned out. C-301 backwashed. Thermometer added at T-30, T-50, & S-13. Empty T-201 and T-301 to get rid of biomass in each tank. Backflush almost all lines. Change out piping at bottom of C-301.
9/8	260	SF No. 1 backwashed.
9/9	261	R/C recycle rate set to 1.74 Lpm. SF No. 3 backwashed. Metals and organics spikes started at 1000.
	263	SF No. 1 backwashed. R/C recycle reset to 4 Lpm. Stripper flooding - reduced air flow from 25 to 20% (22 psig).
9/10	267	Spikes off at 0900. C-301 backwashed. Shut R/C loop down at 1400.
9/11	270	Backwash SF No. 1. Shutdown IX system. Biomass on top of resin. Sludge removed by gently stirring top 10-12 in. resin.
9/16-29	271-8	Jar tests by Engineering-Science. Carbon isotherms and air stripping tests.
	279	1 kg sludge removed from R/C for EP Tox testing.
9/24	280	E-S column settling and sludge dewatering tests. Further jar tests.
10/7	288	Pall rings from A/S covered with algae. Studied ways to remove. Lime sludge removed from R/C and stored in two 55-gal drums. Removed center well & acid cleaned unit.

10/8	291	Obtained empty column (SF) pressure drop profile. GAC columns emptied and flushed. Pressure drop-vs-flow rate test run.
10/9	291	P vs Q test in SF No. 3 - 13 in. each of sand and anthracite. Start recharging of GAC columns - $\approx 1/3$ full.
10/10	292	Wooden underflow dam installed in MH-190. P vs Q run in C-301, 2 & 3. Reactor modified for caustic use. Backwash circuits completed.
10/14	294	Removed 32 oz. of lime sludge from 55-gal drum for radionuclide analysis. First pickup of HFIR water - put into T-401.
10/15	295	190 water started through new system. 15 min RT in reactor. IX flow also restarted. Large impeller put into reactor. Betz addition at 2 ppm into rapid mixer setup.
10/16	298	Reagent flows started - caustic and Betz.
		<u>New logbook</u>
10/17	2	Spikes started at 1000.
	3	API separator surface skimmed. Air sparge in T-201 stopped. C-301 backwashed. IX column stopped at 1930. T-301 to be used for supplemental feed in future.
10/18	6	Spikes off at 0920. Metals had stopped during night. SF No. 3 backwashed.
	11	All lines backwashed as per procedure. Acid addition strength increased from 833 to 1700 mL concentrated sulfuric acid per 20 L water. Reduce Betz flow to 1 ppm. SF No. 1 backwashed.
10/19	12	Backwash C-301 and SF No. 2.
10/21	14	API separator surface skimmed. TRU and TURF water collected. SF No. 3 backwashed. 1505, MH-240, MH-235, and MH-149 collected.
10/22	16	Spikes started at 1240. MH-229 water pumped in. SF No. 3 backwashed.
10/23	23	Spikes off at 1430. Backwash C-301 and SF No. 3.
10/24	27	Start supplemental feed at 0.44 gpm.

10/25 30 Trouble with FRC-401 - wild oscillations. Rerouted flow from T-401 through SF No. 1 before FRC-401. Supplemental feed off for weekend at 1600.

10/26 31 SF No. 2 and No. 3 backwashed.

10/28 35 Supplemental feed restarted at 0930. Spikes started at 0940. ≈4 L sample of sludge taken from clarifier for EP Tox test. Sludge filtered poorly - used centrifuge.

10/29 36 Spikes off at 1010. SF No. 2 and No. 3 backwashed. C-301 backwashed. Lines purged. A/S steamed for 10 min at 100°C.

10/31 44 SF No. 2 and No. 3 backwashed. Spikes started at 1030.

11/1 46 Metals spike off at 1035. Organics off at 0940. A/S top removed - packing too high and close to air exit which probably led to flooding. Increasing amount of biogrowth going down through the packing. Steamed packing.  
49 C-301 backwashed. SF No. 2 and No. 3 backwashed. API separator surface skimmed.

11/2 49 C-301 backwashed.

11/4 50 Shut down system. Empty clarifier of metal-spiked sludge. Replace trim in FCV-401 with two sizes larger trim. Backwash SF No. 2 and No. 3. SF No. 1 taken out of supplemental feed circuit. Supplemental feed on at 1210. System restarted.

11/5 55 Recycle SF backwash to rapid mixer.

11/6 55 Collection of MH-235 and MH-149 terminated due to pumping into MH-235 with "hot" water. Reset FRC-401. Backwash SF No. 2 - ≈20 gal recycled to rapid mixer. Removed 2 gal of old caustic sludge for radionuclides analysis and EF Tox test.  
60 Organic spike (chloroform only) on at 0930.

11/7 57 Backwash SF No. 3.

11/8 58 C-301 backwashed. SF No. 2 backwashed. Supplemental feed stopped at 1400 for weekend. Using excess acid to neutralize T-201 water. Organic spike off at 1300.

11/11	65	SF No. 3 backwashed. A/S reset to 52% at 33 psig for an air to liquid volume ratio of 150. Chloroform spike started at 1500.
11/12	66	SF No. 2 backwashed. HFIR water too "hot" to collect. Reset FRC-401. Chloroform spike off at 1400.
11/14	72	Backwash SF No. 3.
11/15	73	SF No. 2 and No. 3 backwashed. C-301 backwashed. All flows off at 1325.

The above information is summarized from registered notebooks No. A-101836-G and A-101913. The sample information data were recorded in notebook No. A-101837-G.



APPENDIX C. MPP DATA SUMMARY



Table C.1. ICP results from the MPP for the period  
08/22 - 09/10/85 using lime plus soda ash precipitation<sup>a,b</sup>

Sample point	Sample No.	Ca	Mg	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
ACD <sup>c</sup>				1	4	2	3	6	20	2				
S-4	B-0876	33	8.0	1	6	71	95	12	34	91	4.8	08/22/85	1000	No
S-5	B-0877	32	7.0	1	9	6	130	31		14	4.8	08/22/85	1000	No
S-7	B-0889	32	5.0	100	90	160	65	140	93	190	9.9	08/26/85	1800	Yes
S-10	B-0891	23	4.0	4	25	18	19	13		28		08/26/85	1800	Yes
S-3	B-0886	32	7.0	480	650	930	280	510	660	810	6.9	08/26/85	1800	Yes
S-3.5	B-0887	31	7.0	340	27	84	28	340	70	230		08/26/85	1800	Yes
S-4	B-0901	30	7.0	110	33	73	22	180	62	160		08/26/85	1800	Yes
S-5	B-0888	32	7.0	21	23	19	26	40		35		08/26/85	1800	Yes
S-8	B-0890	32	6.0	23	22	47	16	57		58	9.9	08/26/85	1800	Yes
S-7	B-0906	37	6.0	130	120	160	53	170	140	170		08/26/85	2200	Yes
S-10	B-0908	22	4.0	7	20	19	22	19		24		08/26/85	2200	Yes
S-13	B-0909	21	4.0	1			16			16		08/26/85	2200	Yes
S-3	B-0902	29	7.0	500	490	640	130	500	550	610		08/26/85	2200	Yes
S-3.5	B-0903	31	7.0	400	10	46	19	410	56	120		08/26/85	2200	Yes
S-4	B-0904	32	7.0	170	27	64	24	230	56	140		08/26/85	2200	Yes
S-5	B-0905	32	7.0	36	17	17	20	40		40		08/26/85	2200	Yes
S-7	B-0920	36	6.0	170	140	180	49	180	180	180	9.6	08/27/85	0900	Yes
S-10	B-0922	19	4.0	11	10	18	27	16		41		08/27/85	0900	Yes
S-13	B-0925	18	4.0	1			34			25		08/27/85	0900	Yes
S-11	B-0923	19		3		3	39	10		29		08/27/85	0900	Yes
S-3	B-0916	31	7.0	590	710	970	140	580	750	900	7.2	08/27/85	0900	Yes
S-4	B-0918	29	7.0	350	15	51	37	350	93	110		08/27/85	0900	Yes
S-5	B-0919	28	7.0	60	11	11	28	59		29		08/27/85	0900	Yes
S-8	B-0921	29	6.0	26	12	21	13	24	27	28	9.6	08/27/85	0900	Yes
S-7	B-0932	39	6.0	180	140	180	63	190	180	190		08/27/85	1215	Yes
S-10	B-0934	20	5.0	19	9	16	27	17		32		08/27/85	1215	Yes
S-13	B-0937	19	5.0	2	4		10			23		08/27/85	1215	Yes
S-3	B-0928	31	6.0	650	750	950	180	630	790	910	7.2	08/27/85	1215	Yes
S-4	B-0930	30	7.0	400	40	90	18	390	130	150		08/27/85	1215	Yes
S-5	B-0931	30	7.0	63	121	18	21	56		29		08/27/85	1215	Yes
S-8	B-0933	33	7.0	48	11	28	18	32	34	25	9.4	08/27/85	1215	Yes
S-10	B-0945	20	4.0	22	10	22	17	17		54		08/27/85	1715	No
S-13	B-0946	18	4.0	1			14			40		08/27/85	1715	No
S-3	B-0947	32	8.0	3	91	21		44		41	5.7	08/28/85	1630	No
S-3	B-0953	34	8.0	3	7	83	45		26	110	7.2	08/28/85	2300	No
S-8	B-0956	29	7.0	7	5	35			24	39	8.7	08/28/85	2300	No
S-10	B-0958	20	5.0	8	62	32			21	50		08/28/85	2300	No
S-13	B-0959	2	4.0							3		08/28/85	2300	No
S-3	B-0963	32	8.0	510	590	620	270	540	440	700	7.2	08/29/85	1700	Yes

Table C.1 (continued)

Sample point	Sample No.	Ca	Mg	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
S-7	B-0967	33	7.0	130	120	160	30	190	100	180	9.2	08/29/85	1700	Yes
S-8	B-0968	27	7.0	17		42		31		46	9.2	08/29/85	1700	Yes
S-10	B-0970	19	4.0	6		25				41		08/29/85	1700	Yes
S-13	B-0973	21	5.0	4				7		49		08/29/85	1700	Yes
S-11	B-0971	21		8						47		08/29/85	1700	Yes
S-3	B-0995	28	8.0	490	720	740	120	520	570	730		08/29/85	2140	Yes
S-7	B-0999	24	6.0	82	89	120		120	80	130	9.5	08/29/85	2140	Yes
S-8	B-1000	25	6.0	23	9	49		34	26	58	9.2	08/29/85	2140	Yes
S-10	B-1002	18	4.0	12		25		10		61		08/29/85	2140	Yes
S-13	B-1003	20	4.0	6				18		56		08/29/85	2140	Yes
S-3	B-1022	29	4.0	490	550	650	170	520	550	670		08/30/85	1000	Yes
S-7	B-1026	33	4.0	130	130	190	24	180	160	180	9.5	08/30/85	1000	Yes
S-8	B-1027	33	4.0	70	68	110	11	95	73	110		08/30/85	1000	Yes
S-10	B-1029	21	4.0	30	9	21	24	25		35		08/30/85	1000	Yes
S-13	B-1030	20	4.0	6	5		23	16		54		08/30/85	1000	Yes
S-3	B-1057	40	7.0	4	14	110	34		66	110	7.3	08/31/85	1330	No
S-8	B-1065	41	6.0	1	6	13	20	22		35		09/03/85	0845	No
S-13	B-1066	32	5.0	3		4	22	7		36		09/03/85	0845	No
S-3	B-1068	37	6.0	360	330	380	110	360	340	390	7.2	09/03/85	1715	Yes
S-7	B-1072	28	6.0	74	85	110	36	93	72	98	8.9	09/03/85	1715	Yes
S-8	B-1073	25	5.0	34	38	56	41	41		46	1	09/03/85	1715	Yes
S-10	B-1075	23	4.0	20	52	58	33	15	23	35		09/03/85	1715	Yes
S-13	B-1076	17	3.0	2			12			12		09/03/85	1715	Yes
S-3	B-1098	26	6.0	380	430	560	96	390	490	560	7.3	09/04/85	0830	Yes
S-7	B-1102	22	6.0	73	99	130	33	120	77	140	8.6	09/04/85	0830	Yes
S-8	B-1103	19	6.0	11	13	19	12	25		48	9.8	09/04/85	0830	Yes
S-10	B-1105	12	4.0	8	10	19	15	22		57		09/04/85	0830	Yes
S-13	B-1108	13	5.0	4	6	3	19	9		36		09/04/85	0830	Yes
S-11	B-1106	12		8	7	34	11	22		120	6.3	09/04/85	0830	Yes
S-3	B-1130	31	7.0	450	2200	820	100	470	470	660	6.9	09/04/85	1240	Yes
S-7	B-1134	37	7.0	130	180	260	53	140	200	280	9.3	09/04/85	1240	Yes
S-8	B-1135	29	6.0	29	19	35	11	26	34	52	9.8	09/04/85	1240	Yes
S-10	B-1137	13	4.0	9	9	14	22	15		32		09/04/85	1240	Yes
S-13	B-1138	12	4.0	3	5		17	7		34		09/04/85	1240	Yes
S-3	B-1171	30		2	12	96	97		91	69	7.1	09/05/85	1500	No
S-8	B-1173	31	7.0	2	14	50	38		40	23	9.0	09/05/85	1500	No
S-10	B-1176	28	5.0	8	12	61	63	9	28	95	7.2	09/05/85	1500	No
S-13	B-1177	23	5.0	5	5		27	9		25	6.9	09/05/85	1500	No
S-3	B-1178	29	7.0	1	9	120	62		100	84	7.3	09/06/85	0830	No
S-7	B-1179	44	7.0	1	8	54	44		34	50	10.1	09/06/85	0830	No
S-8	B-1180	35	6.0	1	7	23	19		21	25	1	09/06/85	0830	No
S-7	B-1200	36	7.0	100	99	170	53	140	110	160	8.3	09/09/85		Yes
S-3	B-1196	29	7.0	450	430	650	160	480	550	620	7.2	09/09/85	1500	Yes

Table C.1 (continued)

Sample point	Sample No.	Ca	Mg	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
S-8	B-1201	32	7.0	29	23	40	16	35	24	34	8.3	09/09/85	1500	Yes
S-10	B-1203	21	4.0	10	19	29	22	23		51		09/09/85	1500	Yes
S-13	B-1206	22	4.0	3	5		14	10		29		09/09/85	1500	Yes
S-11	B-1204	20		1	5	4	10			18		09/09/85	1500	Yes
S-3	B-1228	32	8.0	590	590	720	71	590	630	710	7.4	09/10/85	0830	Yes
S-10	B-1235	18	4.0	24	7	14	15	21		22	6.8	09/10/85	0830	Yes
S-13	B-1238	18	4.0	2	5		22			30	7.1	09/10/85	0830	Yes
S-11	B-1236	19		5	4					20	7.1	09/10/85	0830	Yes

<sup>a</sup>Calcium and magnesium results expressed as ppm; other values expressed as ppb.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

<sup>c</sup>ICP x 10 detection limits.

Table C.2. ICP results from the MPP for the period 10/17 - 11/18/85<sup>a,b</sup>

Sample point	Sample No.	Ca	Mg	Na	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
Y-12 <sup>c</sup>					240	260	120	500	1600	170	210	660				
ACD <sup>d</sup>					5	1	4	2	3	6	20	2				
S-3	B-1261	30	7.9	18	6	470	440	550	120	490	480	690	6.9	10/17/85	1500	Yes
S-3.5	B-1262	35	8.8	16		460	170	230	82	570	170	320	6.7	10/17/85	1500	Yes
S-4	B-1263	31	8.0	25		270	150	190	65	360	140	240	4.0	10/17/85	1500	Yes
S-5	B-1264	30	7.6	26		1	14	5	47			12	5.2	10/17/85	1500	Yes
S-7	B-1265	27	7.4	120		160	56	87	28	190	130	120	10.6	10/17/85	1500	Yes
S-8	B-1266	23	6.9	120		81	8	31	13	94	37	55	10.6	10/17/85	1500	Yes
S-9	B-1267			70				17	84			20	7.4	10/17/85	1500	Yes
S-10	B-1268	16	4.8	93		39	8	23	43	52		51	7.0	10/17/85	1500	Yes
S-13	B-1269	16	4.8	92					40			21	8.2	10/17/85	1500	Yes
S-4	B-1296	35	9.2	30		320	210	270	84	380	210	330	3.7	10/17/85	1840	Yes
S-5	B-1297	34	8.7	28		2	22	7	16			16	5.3	10/17/85	1840	Yes
S-3	B-1294	32	8.5	32	9	71	250	350	130	71	240	430	7.4	10/18/85	0900	Yes
S-7	B-1298	31	8.3	120		31	29	67	27	20	39	110	10.5	10/18/85	0900	No
S-8	B-1299	19	7.0	110		18	11	31	11	9		56	10.5	10/18/85	0900	No
S-9	B-1300	28	5.4	300			4	7	140		27	38	7.0	10/18/85	0900	No
S-10	B-1301	21	6.0	170		14	5	15	33	8		40	8.4	10/18/85	0900	No
S-13	B-1302	28	6.5	200		28		5	36	29		150	7.8	10/18/85	0900	No
S-3	B-1343	31	8.2	30	9	690	670	750	110	820	640	860	7.1	10/22/85	1300	Yes
S-7	B-1344	28	7.4	110		140	66	110	38	190	96	130	10.7	10/22/85	1300	Yes
S-8	B-1345	26	6.4	110		37	9	25	19	33		34	10.7	10/22/85	1300	Yes
S-9	B-1346	1	0.1	100				34	98	7		19	6.3	10/22/85	1300	Yes
S-10	B-1347	16	4.6	110		9	8	37	67	16		39	7.2	10/22/85	1300	Yes
S-11	B-1348	16	5.1	120		3		10	34			45	7.0	10/22/85	1300	Yes
S-12	B-1349	15	4.6	110		2		3	37			48	7.0	10/22/85	1300	Yes
S-13	B-1350	14	4.3	95		2			26			36	7.7	10/22/85	1300	Yes
S-3	B-1385	30	8.1	45		260	500	290	110	700	570	680	7.5	10/23/85	1400	Yes
S-7	B-1386	27	7.3	120		130	100	73	22	260	150	150	10.6	10/23/85	1400	Yes
S-8	B-1387	21	6.8	120		69	18	18	15	27	33	15	10.6	10/23/85	1400	Yes
S-9	B-1388			140				12	60			15	7.1	10/23/85	1400	Yes
S-10	B-1389	13	4.3	120		52	18	20	23	23	25	24	7.3	10/23/85	1400	Yes
S-11	B-1390	14	4.4	120		20	7	8	58	15		24	7.1	10/23/85	1400	Yes
S-12	B-1391	15	4.8	130		11	5	2	24	14		31	6.9	10/23/85	1400	Yes
S-13	B-1392	13	4.1	120		7			31	12		38	7.2	10/23/85	1400	Yes
S-1	B-1416	26	7.1	34	7	42	330	450	150	61	320	510	7.5	10/25/85	1400	No
S-2	B-1417	25	6.8	14		13		50	130	19		56	7.9	10/25/85	1400	No
S-3	B-1418	26	6.8	27	16	77	630	790	410	130	630	990	7.5	10/25/85	1400	No
S-7	B-1419	24	6.7	78		14	39	110	75	16	44	100	10.5	10/25/85	1400	No
S-8	B-1420	16	5.5	69		9	7	53	17			28	10.4	10/25/85	1400	No

Table C.2 (continued)

Sample point	Sample No.	Ca	Mg	Na	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
S-9	B-1421	1	0.2	79				9	38			13	7.5	10/25/85	1400	No
S-10	B-1422	13	4.3	82		6		27	32			20	7.7	10/25/85	1400	No
S-13	B-1423	14	4.4	84		2			8			13	8.3	10/25/85	1400	No
S-1	B-1455	32	8.9	32	91	1100	5700	2000	750	3500	5500	7100	7.1	10/28/85	1500	Yes
S-2	B-1456	31	8.7	10		15	13	63	91	24		79	8.1	10/28/85	1500	Yes
S-3	B-1457	30	8.9	24	10	100	250	130	93	560	250	340	7.5	10/28/85	1500	Yes
S-7	B-1458	28	8.2	76	6	43	86	55	36	250	94	120	10.1	10/28/85	1500	Yes
S-8	B-1459	24	7.6	78		16	22	19	9	53	22	26	10.0	10/28/85	1500	Yes
S-9	B-1460	1	0.1	56				14	100	21		16	6.6	10/28/85	1500	Yes
S-10	B-1461	8	2.4	34		5	15	12	13	14		24	7.5	10/28/85	1500	Yes
S-11	B-1462	16	5.0	71		5	16	7	33	14		41	7.1	10/28/85	1500	Yes
S-12	B-1463	17	5.3	76		5	6	2	16	8		46	6.9	10/28/85	1500	Yes
S-13	B-1464	15	4.7	64		7			30	9		44	7.0	10/28/85	1500	Yes
S-1	B-1488	32	9.0	40	115	980	4900	1600	360	2600	4700	5600	7.3	10/29/85	1000	Yes
S-2	B-1489	30	8.5	13	12	73	260	130	35	200	280	360	8.1	10/29/85	1000	Yes
S-3	B-1490	29	8.6	28	65	1100	6100	2000	320	2700	5700	7000	7.7	10/29/85	1000	Yes
S-7	B-1491	24	6.9	81	9	67	140	53	12	270	210	170	10.6	10/29/85	1000	Yes
S-8	B-1492	15	5.6	64		4	5	7	14	18		18	10.5	10/29/85	1000	Yes
S-9	B-1493		0.1	78				12	53			18	7.3	10/29/85	1000	Yes
S-10	B-1494	13	5.1	98		3	6	9	31	14		18	7.1	10/29/85	1000	Yes
S-11	B-1495	12	4.6	90		4		3	7	9		24	6.9	10/29/85	1000	Yes
S-12	B-1496	13	5.0	97		6			12	11		36	6.8	10/29/85	1000	Yes
S-13	B-1497	11	4.4	83		5			6	9		36	6.7	10/29/85	1000	Yes
S-1	B-1518	32	7.8	20	8	16	25	32	11	18	43	120	7.4	10/30/85	1400	No
S-2	B-1519	30	7.1	9		11		53	32	8		110	7.8	10/30/85	1400	No
S-3	B-1520	31	7.4	16	5	13	10	51	55	12	26	120	7.4	10/30/85	1400	No
S-8	B-1521	22	7.5	87	6	8	11	21	13			37	10.4	10/30/85	1400	No
S-1	B-1527	32	7.5	55	11	1000	1600	1400	240	1600	1400	1600	7.2	10/31/85	1515	Yes
S-2	B-1528	33	7.6	17	14	400	950	870	160	490	850	1100	7.5	10/31/85	1515	Yes
S-3	B-1529	32	7.7	36		710	1200	1100	220	900	1200	1400	7.4	10/31/85	1515	Yes
S-7	B-1530	28	6.7	82	7	180	160	170	30	300	200	200	10.4	10/31/85	1515	Yes
S-8	B-1531	28	7.8	96	10	91	32	52	25	180	53	79	10.4	10/31/85	1515	Yes
S-9	B-1532	1	0.1	160			5	10	120	19		15	7.4	10/31/85	1515	Yes
S-10	B-1533	16	5.5	110		30	10	24	31	56		48	7.7	10/31/85	1515	Yes
S-11	B-1534	17	5.9	120		7	7	9	16	13		35	7.3	10/31/85	1515	Yes
S-12	B-1535	16	5.6	110		5	5	3	11	9		30	7.2	10/31/85	1515	Yes
S-13	B-1536	17	6.1	130		6			28	12		38	7.2	10/31/85	1515	Yes
S-1	B-1564	30	7.2	56	7	940	580	520	120	1400	630	540	7.1	11/01/85	0900	Yes
S-2	B-1565	31	7.4	8		8		64	27			130	7.7	11/01/85	0900	Yes
S-3	B-1566	30	7.3	35	35	850	1600	1400	160	1100	1400	1500	7.3	11/01/85	0900	Yes
S-7	B-1567	26	7.4	83	6	200	91	97	12	280	170	98	10.4	11/01/85	0900	Yes
S-8	B-1568	21	6.7	98	5	16		12		21		17	10.3	11/01/85	0900	Yes

Table C.2 (continued)

Sample point	Sample No.	Ca	Mg	Na	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn	pH	Date	Time	Spike on?
S-9	B-1569		0.1	93		1	6	12	51	17		21	6.8	11/01/85	0900	Yes
S-10	B-1570	15	5.4	110		12	4	12	22	19		19	7.1	11/01/85	0900	Yes
S-11	B-1571	14	5.4	100		14		5	10	28		26	7.1	11/01/85	0900	Yes
S-12	B-1572	14	5.2	100		14			18	28		29	6.9	11/01/85	0900	Yes
S-13	B-1573	13	4.7	92		11			9	25		30	6.9	11/01/85	0900	Yes
S-8	B-1594	21	6.2	89		18		16	18	24	22	15	10.4	11/01/85	1000	Yes
S-1	B-1607	30	8.1	35		9	24	72	160	9	70	180	7.5	11/07/85	1400	No
S-2	B-1608	30	7.8	6		1	4	35	120			170	7.6	11/07/85	1400	No
S-7	B-1609	31	8.4	81		2	6	25	47			110	10.2	11/07/85	1400	No
S-8	B-1610	27	8.3	81		2		18	23			57	10.2	11/07/85	1400	No
S-9	B-1611			97				3	79			16	8.8	11/07/85	1400	No
S-10	B-1612	15	4.5	86		1		14	38			39	7.8	11/07/85	1400	No
S-11	B-1613	16	4.8	81		3		6	21	7		33	7.0	11/07/85	1400	No
S-12	B-1614	16	4.8	79		4			19			30	6.8	11/07/85	1400	No
S-13	B-1615	16	4.8	83		5		42	40	9		33	6.7	11/07/85	1400	No
S-3	B-1644	28	7.8	25		1		35	66			100	7.4	11/12/85	1400	No
S-7	B-1645	26	8.3	95		1		37	15			91	10.3	11/12/85	1400	No
S-7	B-1655	22	7.8	96		1		29	7			25	10.3	11/12/85	1400	No
S-8	B-1646	22	8.0	100		1		25	6			19	10.2	11/12/85	1400	No
S-8	B-1647	24	8.4	100		2		29	15			48	10.3	11/12/85	1400	No
S-13	B-1648	13	5.6	83		3	5	4	42			45	6.9	11/12/85	1400	No
T-201	B-1649	19	7.7	96		2		21	14			55	7.0	11/12/85	1400	No
T-201	B-1650	14	8.8	110		4		30	40			58	6.9	11/12/85	1400	No
S-13	B-1657	14	5.5	88		2			4			26	7.2	11/13/85	0915	No
S-1	B-1659	34	8.5	47	6	3		150	18	6	25	210	7.4	11/14/85	1300	No
S-7	B-1661	33	7.6	97		1	5	37	31			150	10.5	11/14/85	1300	No
S-8	B-1662	25	7.7	88		1		25	13			89	10.5	11/14/85	1300	No
S-9	B-1663		0.1	68				8	38			18	6.9	11/14/85	1300	No
S-10	B-1664	15	5.2	89		1		25	30	9		78	7.5	11/14/85	1300	No
S-11	B-1665	12	4.9	85		1		5	16			44	7.3	11/14/85	1300	No
S-12	B-1666	12	5.3	93		2		2	11			40	7.3	11/14/85	1300	No
S-13	B-1667	11	4.6	83		1			8			26	7.3	11/14/85	1300	No
S-2	B-1660	35	7.8	8	6	1	9	69	150	12		310	7.6	11/14/85	1500	No
S-13 <sup>e</sup>	B-1656	14	5.6	91		9	62	45	27	28	47	110		11/18/85	1530	No

<sup>a</sup>Calcium, Mg, and Na results are expressed as ppm; other values are in ppb.

<sup>b</sup>A blank entry indicates the value was below the detectable limit.

<sup>c</sup>Y-12 BAT limits.

<sup>d</sup>ICP x 10 detection limits.

<sup>e</sup>Same as B-1657, but held for 5 d.

Table C.3. Volatile organics results from the mini-pilot plant

Sample point	Sample No.	CHCl <sub>3</sub> (ppb)	Date	Time	Spike on?
S-3	B-0729	32	08/07/85	1900	No
S-8	B-0734	50	08/07/85	1900	No
S-9	B-0737	6	08/07/85	1900	No
S-10	B-0739	4	08/07/85	1900	No
S-11	B-0742	2	08/07/85	1900	No
S-12	B-0744	1	08/07/85	1900	No
S-13	B-0746	1	08/07/85	1900	No
S-3	B-1086	282	09/03/85	1715	Yes
S-8	B-1087	21	09/03/85	1715	Yes
S-9	B-1088	236	09/03/85	1715	Yes
S-10	B-1089	29	09/03/85	1715	Yes
S-11	B-1090	3	09/03/85	1715	Yes
S-12	B-1091	0	09/03/85	1715	Yes
S-13	B-1092	2	09/03/85	1715	Yes
190F <sup>a</sup>	B-1093	7	09/03/85	1715	Yes
3544F <sup>b</sup>	B-1094	99,999	09/03/85	1715	Yes
S-3	B-1118	17	09/04/85	0830	Yes
S-8	B-1119	14	09/04/85	0830	Yes
S-9	B-1120	380	09/04/85	0830	Yes
S-10	B-1121	50	09/04/85	0830	Yes
S-11	B-1122	0	09/04/85	0830	Yes
S-12	B-1123	2	09/04/85	0830	Yes
S-13	B-1124	2	09/04/85	0830	Yes
190F	B-1125	0	09/04/85	0830	Yes
3544F	B-1126	99,999	09/04/85	0830	Yes
S-3	B-1216	98	09/09/85	1500	Yes
S-8	B-1217	200	09/09/85	1500	Yes
S-9	B-1218	225	09/09/85	1500	Yes
S-10	B-1219	26	09/09/85	1500	Yes
S-11	B-1220	3	09/09/85	1500	Yes
S-12	B-1221	1	09/09/85	1500	Yes
S-13	B-1222	1016	09/09/85	1500	Yes
190F	B-1223	0	09/09/85	1500	Yes
3544F	B-1224	258	09/09/85	1500	Yes
S-3	B-1248	8	09/10/85	0830	Yes
S-8	B-1249	9	09/10/85	0830	Yes

Table C.3 (continued)

Sample point	Sample No.	CHCl <sub>3</sub> (ppb)	Date	Time	Spike on?
S-9	B-1250	232	09/10/85	0830	Yes
S-10	B-1251	10	09/10/85	0830	Yes
S-11	B-1252	0	09/10/85	0830	Yes
S-12	B-1253	0	09/10/85	0830	Yes
S-13	B-1254	0	09/10/85	0830	Yes
190F	B-1255	0	09/10/85	0830	Yes
3544F	B-1256	218	09/10/85	0830	Yes
S-3	B-1282	25	10/17/85	1500	Yes
S-8	B-1283	16	10/17/85	1500	Yes
S-9	B-1284	722	10/17/85	1500	Yes
S-10	B-1285	44	10/17/85	1500	Yes
S-11	B-1286	3	10/17/85	1500	Yes
S-12	B-1287	2	10/17/85	1500	Yes
S-13	B-1288	2	10/17/85	1500	Yes
190F	B-1289	0	10/17/85	1500	Yes
3544F	B-1290	1000	10/17/85	1500	Yes
S-3	B-1312	412	10/18/85	0900	Yes
S-8	B-1313	13	10/18/85	0900	Yes
S-9	B-1314	347	10/18/85	0900	Yes
S-10	B-1315	86	10/18/85	0900	Yes
S-11	B-1316	3	10/18/85	0900	Yes
S-12	B-1317	1	10/18/85	0900	Yes
S-13	B-1318	2	10/18/85	0900	Yes
190F	B-1319	0	10/18/85	0900	Yes
3544F	B-1320	1000	10/18/85	0900	Yes
S-3	B-1363	44	10/22/85	1300	Yes
S-8	B-1364	45	10/22/85	1300	Yes
S-9	B-1365	328	10/22/85	1300	Yes
S-10	B-1366	50	10/22/85	1300	Yes
S-11	B-1367	2	10/22/85	1300	Yes
S-12	B-1368	1	10/22/85	1300	Yes
S-13	B-1369	0	10/22/85	1300	Yes
190F	B-1370	0	10/22/85	1300	Yes
3544F	B-1371	623	10/22/85	1300	Yes
S-3	B-1402	10	10/23/85	1400	Yes
S-8	B-1403	7	10/23/85	1400	Yes
S-9	B-1404	424	10/23/85	1400	Yes
S-10	B-1405	38	10/23/85	1400	Yes
S-11	B-1406	4	10/23/85	1400	Yes
S-12	B-1407	0	10/23/85	1400	Yes

Table C.3 (continued)

Sample point	Sample No.	CHCl <sub>3</sub> (ppb)	Date	Time	Spike on?
S-13	B-1408	5	10/23/85	1400	Yes
S-1	B-1433	84	10/25/85	1400	Yes
S-2	B-1434	5	10/25/85	1400	Yes
S-3	B-1435	25	10/25/85	1400	Yes
S-8	B-1436	14	10/25/85	1400	Yes
S-9	B-1437	5	10/25/85	1400	Yes
S-10	B-1438	2	10/25/85	1400	Yes
S-11	B-1439	4	10/25/85	1400	Yes
S-12	B-1440	2	10/25/85	1400	Yes
S-13	B-1441	2	10/25/85	1400	Yes
S-1	B-1474	59	10/28/85	1500	Yes
S-2	B-1475	2	10/28/85	1500	Yes
S-3	B-1476	36	10/28/85	1500	Yes
S-8	B-1477	14	10/28/85	1500	Yes
S-9	B-1478	523	10/28/85	1500	Yes
S-10	B-1479	56	10/28/85	1500	Yes
S-11	B-1480	6	10/28/85	1500	Yes
S-12	B-1481	2	10/28/85	1500	Yes
S-13	B-1482	2	10/28/85	1500	Yes
S-1	B-1507	14	10/28/85	1500	Yes
S-2	B-1508	3	10/29/85	1500	Yes
S-3	B-1509	9	10/29/85	1500	Yes
S-8	B-1510	8	10/29/85	1500	Yes
S-9	B-1511	709	10/29/85	1500	Yes
S-10	B-1512	71	10/29/85	1500	Yes
S-11	B-1513	8	10/29/85	1500	Yes
S-12	B-1514	2	10/29/85	1500	Yes
S-13	B-1515	30	10/29/85	1500	Yes
S-1	B-1548	25	10/31/85	1515	Yes
S-2	B-1549	6	10/31/85	1515	Yes
S-3	B-1550	17	10/31/85	1515	Yes
S-8	B-1551	15	10/31/85	1515	Yes
S-9	B-1552	365	10/31/85	1515	Yes
S-10	B-1553	126	10/31/85	1515	Yes
S-11	B-1554	9	10/31/85	1515	Yes
S-12	B-1555	2	10/31/85	1515	Yes
S-13	B-1556	2	10/31/85	1515	Yes
190F	B-1557	1	10/31/85	1515	Yes
3544F	B-1558	5775	10/31/85	1515	Yes
S-1	B-1583	966	11/01/85	0900	Yes
S-2	B-1584	2	11/01/85	0900	Yes
S-3	B-1585	10	11/01/85	0900	Yes
S-8	B-1586	10	11/01/85	0900	Yes
S-9	B-1587	1231	11/01/85	0900	Yes
S-10	B-1588	168	11/01/85	1000	Yes

Table C.3 (continued)

Sample point	Sample No.	CHCl <sub>3</sub> (ppb)	Date	Time	Spike on?
S-11	B-1589	19	11/01/85	1000	Yes
S-12	B-1590	0	11/01/85	1000	Yes
S-13	B-1591	0	11/01/85	1000	Yes
S-8	B-1596	7	11/01/85	1000	Yes
S-8	B-1598	9	11/06/85	1500	Yes
S-9	B-1599	1610	11/06/85	1500	Yes
S-10	B-1600	203	11/06/85	1500	Yes
S-13	B-1601	2	11/06/85	1500	Yes
S-8	B-1603	8	11/07/85	0900	Yes
S-9	B-1604	1700	11/07/85	0900	Yes
S-10	B-1605	178	11/07/85	0900	Yes
S-13	B-1606	2	11/07/85	0900	Yes
S-8	B-1622	15	11/07/85	1400	Yes
S-9	B-1623	1644	11/07/85	1400	Yes
S-10	B-1624	241	11/07/85	1400	Yes
S-13	B-1625	3	11/07/85	1400	Yes
S-8	B-1626	9	11/08/85	0900	Yes
S-9	B-1627	1449	11/08/85	0900	Yes
S-10	B-1628	277	11/08/85	0900	Yes
S-13	B-1629	2	11/08/85	0900	Yes
S-8	B-1631	9	11/08/85	1300	Yes
S-9	B-1632	1644	11/08/85	1300	Yes
S-10	B-1633	260	11/08/85	1300	Yes
S-13	B-1634	2	11/08/85	1300	Yes
S-8	B-1651	10	11/12/85	1400	Yes
S-9	B-1652	783	11/12/85	1400	Yes
S-10	B-1653	159	11/12/85	1400	Yes
S-13	B-1654	2	11/12/85	1400	Yes

<sup>a</sup>190 Feed pot organic spike solution; naphthalene dissolved in methanol.

<sup>b</sup>3544 Feed pot organic spike solution; chloroform and DBP dissolved in methanol.

Table C.4. Semi-volatile organics results from the mini-pilot plant

Sample point	Sample No.	Naphthalene (ppb)	Dibutyl Phthalate (ppb)	Date	Time	Spike on?
ACD <sup>a</sup>		7	9	06/01/85	0800	No
S-3	B-0731	2	7	08/07/85	1900	No
S-8	B-0736	2	3	08/07/85	1900	No
S-9	B-0738	2	0	08/07/85	1900	No
S-10	B-0741	4	0	08/07/85	1900	No
S-11	B-0741	4	5	08/07/85	1900	No
S-12	B-0745	4	7	08/07/85	1900	No
S-13	B-0748	5	4	08/07/85	1900	No
S-3	B-0974 <sup>e</sup>	2	1	08/29/85	1700	Yes
S-8	B-0975	25	6	08/29/85	1700	Yes
S-9	B-0976 <sup>e</sup>	5	1	08/29/85	1700	Yes
S-10	B-0977	6	3	08/29/85	1700	Yes
S-11	B-0978	9	15	08/29/85	1700	Yes
S-12	B-0979	9	10	08/29/85	1700	Yes
S-13	B-0980	9	13	08/29/85	1700	Yes
190F <sup>b</sup>	B-0981 <sup>d</sup>	23800	206500	08/29/85	1700	Yes
3544F <sup>c</sup>	B-0982 <sup>d</sup>	1206	5600	08/29/85	1700	Yes
S-3	B-1004 <sup>d</sup>	128	55	08/29/85	2140	Yes
S-8	B-1005	9	13	08/29/85	2140	Yes
S-9	B-1006 <sup>e</sup>	12	35	08/29/85	2140	Yes
S-10	B-1007	6	3	08/29/85	2140	Yes
S-11	B-1008	10	19	08/29/85	2140	Yes
S-12	B-1009	11	14	08/29/85	2140	Yes
S-13	B-1010	8	13	08/29/85	2140	Yes
190F	B-1011 <sup>d</sup>	4908	18040	08/29/85	2140	Yes
3544F	B-1012 <sup>d, f</sup>	559	1962	08/29/85	2140	Yes
S-3	B-1031 <sup>f</sup>	7	6	08/30/85	1000	Yes
S-8	B-1032 <sup>f</sup>	6	8	08/30/85	1000	Yes
S-9	B-1033 <sup>f</sup>	5	13	08/30/85	1000	Yes
S-10	B-1034 <sup>f</sup>	4	15	08/30/85	1000	Yes
S-11	B-1035 <sup>f</sup>	6	3	08/30/85	1000	Yes
S-12	B-1036	5	5	08/30/85	1000	Yes
S-13	B-1037 <sup>f</sup>	6	6	08/30/85	1000	Yes
190F	B-1038 <sup>f</sup>	5	8	08/30/85	1000	Yes
3544F	B-1039 <sup>f</sup>	6	0	08/30/85	1000	Yes
S-3	B-1077	27	8	09/03/85	1715	Yes
S-8	B-1078	5	1	09/03/85	1715	Yes
S-9	B-1079 <sup>e</sup>	4	0	09/03/85	1715	Yes
S-10	B-1080	4	0	09/03/85	1715	Yes
S-11	B-1081	7	18	09/03/85	1715	Yes
S-12	B-1082	11	33	09/03/85	1715	Yes
S-13	B-1083	8	15	09/03/85	1715	Yes

Table C.4 (continued)

Sample point	Sample No.	Naphthalene (ppb)	Dibutyl Phthalate (ppb)	Date	Time	Spike on?
190F	B-1084	17348	57339	09/03/85	1715	Yes
3544F	B-1085 <sup>d</sup>	89	247	09/03/85	1715	Yes
S-3	B-1109	56	299	09/04/85	0830	Yes
S-8	B-1110	14	23	09/04/85	0830	Yes
S-9	B-1111 <sup>e</sup>	4	6	09/04/85	0830	Yes
S-10	B-1112	5	2	09/04/85	0830	Yes
S-11	B-1113	6	10	09/04/85	0830	Yes
S-12	B-1114	5	8	09/04/85	0830	Yes
S-13	B-1115	13	25	09/04/85	0830	Yes
190F	B-1116 <sup>d</sup>	34502	114682	09/04/85	0830	Yes
3544F	B-1117 <sup>d</sup>	2791	8727	09/04/85	0830	Yes
S-3	B-1139	44	215	09/04/85	1240	Yes
S-8	B-1140	13	23	09/04/85	1240	Yes
S-9	B-1141 <sup>e</sup>	5	2	09/04/85	1240	Yes
S-10	B-1142	4	0	09/04/85	1240	Yes
S-11	B-1143	10	13	09/04/85	1240	Yes
S-12	B-1144	10	23	09/04/85	1240	Yes
S-13	B-1145	22	42	09/04/85	1240	Yes
190F	B-1146 <sup>d</sup>	1790	346296	09/04/85	1240	Yes
3544F	B-1147 <sup>d</sup>	325	1618	09/04/85	1240	Yes
S-3	B-1207 <sup>e</sup>	60	232	09/09/85	1500	Yes
S-8	B-1208	7	10	09/09/85	1500	Yes
S-9	B-1209 <sup>e</sup>	4	2	09/09/85	1500	Yes
S-10	B-1210	4	8	09/09/85	1500	Yes
S-11	B-1211	8	35	09/09/85	1500	Yes
S-12	B-1212	4	1	09/09/85	1500	Yes
S-13	B-1213	15	90	09/09/85	1500	Yes
190F	B-1214 <sup>d</sup>	17453	57457	09/09/85	1500	Yes
3544F	B-1215 <sup>d</sup>	71	170	09/09/85	1500	Yes
S-3	B-1239	73	297	09/10/85	0830	Yes
S-8	B-1240	7	1	09/10/85	0830	Yes
S-9	B-1241	4	0	09/10/85	0830	Yes
S-10	B-1242	7	2	09/10/85	0830	Yes
S-11	B-1243	8	4	09/10/85	0830	Yes
S-12	B-1244	8	14	09/10/85	0830	Yes
S-13	B-1245	9	20	09/10/85	0830	Yes
190F	B-1246 <sup>d</sup>	97009	306770	09/10/85	0830	Yes
3544F	B-1247 <sup>d</sup>	420	4420	09/10/85	0830	Yes
S-3	B-1273	36	46	10/17/85	1500	Yes
S-8	B-1274	16	12	10/17/85	1500	Yes
S-9	B-1275	0	40	10/17/85	1500	Yes
S-10	B-1276	0	130	10/17/85	1500	Yes

Table C.4 (continued)

Sample point	Sample No.	Naphthalene (ppb)	Dibutyl Phthalate (ppb)	Date	Time	Spike on?
S-11	B-1277	0	220	10/17/85	1500	Yes
S-12	B-1278	0	190	10/17/85	1500	Yes
S-13	B-1279	0	140	10/17/85	1500	Yes
190F	B-1280	195	0	10/17/85	1500	Yes
3544F	B-1281	0	132	10/17/85	1500	Yes
S-3	B-1303	22	170	10/18/85	0900	Yes
S-8	B-1304	93	160	10/18/85	0900	Yes
S-9	B-1305	9	140	10/18/85	0900	Yes
S-10	B-1306	53	164	10/18/85	0900	Yes
S-11	B-1307	0	106	10/18/85	0900	Yes
S-12	B-1308	0	99	10/18/85	0900	Yes
S-13	B-1309	0	189	10/18/85	0900	Yes
190F	B-1310	192	0	10/18/85	0900	Yes
3544F	B-1311	0	137	10/18/85	0900	Yes
S-3	B-1354	29	100	10/22/85	1300	Yes
S-8	B-1355	71	0	10/22/85	1300	Yes
S-9	B-1356	6	50	10/22/85	1300	Yes
S-10	B-1357	12	66	10/22/85	1300	Yes
S-11	B-1358	0	50	10/22/85	1300	Yes
S-12	B-1359	0	50	10/22/85	1300	Yes
S-13	B-1360	0	50	10/22/85	1300	Yes
190F	B-1361	145	0	10/22/85	1300	Yes
3544F	B-1362	0	87	10/22/85	1300	Yes
S-3	B-1393	112	0	10/23/85	1400	Yes
S-8	B-1394	70	0	10/23/85	1400	Yes
S-9	B-1395	12	117	10/23/85	1400	Yes
S-10	B-1396	0	50	10/23/85	1400	Yes
S-11	B-1397	0	50	10/23/85	1400	Yes
S-12	B-1398	0	40	10/23/85	1400	Yes
S-13	B-1399	0	30	10/23/85	1400	Yes
S-1	B-1424	0	45	10/25/85	1400	No
S-2	B-1425	0	67	10/25/85	1400	No
S-3	B-1426	0	50	10/25/85	1400	No
S-8	B-1427	0	60	10/25/85	1400	No
S-9	B-1428	0	40	10/25/85	1400	No
S-10	B-1429	0	45	10/25/85	1400	No
S-11	B-1430	0	37	10/25/85	1400	No
S-12	B-1431	0	38	10/25/85	1400	No
S-13	B-1432	0	40	10/25/85	1400	No
S-1	B-1465	1099	0	10/28/85	1500	Yes
S-2	B-1466	0	52	10/28/85	1500	Yes
S-3	B-1467	598	0	10/28/85	1500	Yes
S-8	B-1468	416	0	10/28/85	1500	Yes
S-9	B-1469	0	40	10/28/85	1500	Yes
S-10	B-1470	35	0	10/28/85	1500	Yes
S-11	B-1471	32	0	10/28/85	1500	Yes
S-12	B-1472	0	51	10/28/85	1500	Yes

Table C.4 (continued)

Sample point	Sample No.	Naphthalene (ppb)	Dibutyl Phthalate (ppb)	Date	Time	Spike on?
S-13	B-1473	0	35	10/28/85	1500	Yes
S-1	B-1498	48	100	10/29/85	1000	Yes
S-2	B-1499	18	100	10/29/85	1000	Yes
S-3	B-1500	100	73	10/29/85	1000	Yes
S-8	B-1501	286	220	10/29/85	1000	Yes
S-9	B-1502	557	0	10/29/85	1000	Yes
S-10	B-1503	9	40	10/29/85	1000	Yes
S-11	B-1504	0	15	10/29/85	1000	Yes
S-12	B-1505	0	25	10/29/85	1000	Yes
S-13	B-1506	0	25	10/29/85	1000	Yes
S-1	B-1537	381	250	10/31/85	1515	Yes
S-2	B-1538	30	25	10/31/85	1515	Yes
S-3	B-1539	78	25	10/31/85	1515	Yes
S-8	B-1540	384	25	10/31/85	1515	Yes
S-9	B-1541	14	0	10/31/85	1515	Yes
S-10	B-1542	0	0	10/31/85	1515	Yes
S-11	B-1543	0	0	10/31/85	1515	Yes
S-12	B-1544	0	0	10/31/85	1515	Yes
S-13	B-1545	0	0	10/31/85	1515	Yes
190F	B-1546	0	50690	10/31/85	1515	Yes
3544F	B-1547	174	13070	10/31/85	1515	Yes
S-1	B-1574	326	4000	11/01/85	0900	Yes
S-2	B-1575	44	0	11/01/85	0900	Yes
S-3	B-1576	480	159	11/01/85	0900	Yes
S-8	B-1577	582	0	11/01/85	0900	Yes
S-9	B-1578	102	0	11/01/85	0900	Yes
S-10	B-1579	0	0	11/01/85	1000	Yes
S-11	B-1580	0	0	11/01/85	1000	Yes
S-12	B-1581	0	0	11/01/85	1000	Yes
S-13	B-1582	0	0	11/01/85	1000	Yes
S-8	B-1595	573	30	11/01/85	1000	Yes

<sup>a</sup>ACD detection limits.

<sup>b</sup>Feed pot organic spike solution for Pond 190 water; naphthalene dissolved in methanol.

<sup>c</sup>Feed pot organic spike solution for Building 3544 water; chloroform and DBP dissolved in methanol.

<sup>d</sup>Results exceed calibration curve. Could be lower than actual.

<sup>e</sup>Samples gave very high pressure drop during extraction. Results may be low.

<sup>f</sup>Samples experienced very irregular flow during extraction. Results may be suspect.

Table C.5. Cold vapor AA results for mercury  
from the mini-pilot plant

Sample point	Sample No.	Hg (ppb)	Date	Time
S-3	B-0762	0.5	08/08/85	1450
S-8	B-0763	0.1	08/08/85	1450
S-10	B-0764	0.2	08/08/85	1450
S-11	B-0765	0.1	08/08/85	1450
S-12	B-0766	0.1	08/08/85	1450
S-13	B-0767	0.1	08/08/85	1450
S-4	B-0855	1.7	08/14/85	1300
S-5	B-0856	1.2	08/14/85	1300
S-3	B-1049	4.0	08/30/85	1705
S-5	B-1050	2.7	08/30/85	1705
S-10	B-1051	1.0	08/30/85	1705
S-13	B-1052	0.1	08/30/85	1705
S-3	B-1160	2.4	09/04/85	1730
S-5	B-1161	0.4	09/04/85	1730
S-10	B-1163	0.3	09/04/85	1730
S-11	B-1164	0.2	09/04/85	1730
S-12	B-1165	0.2	09/04/85	1730
S-13	B-1166	0.1	09/04/85	1730
S-8	B-1162	0.3	09/04/85	1850
S-3	B-1184	2.4	09/08/85	1400
S-5	B-1185	1.1	09/08/85	1400
S-8	B-1186	1.0	09/08/85	1400
S-10	B-1187	1.1	09/08/85	1400
S-11	B-1188	0.3	09/08/85	1400
S-12	B-1189	0.4	09/08/85	1400
S-13	B-1190	0.3	09/08/85	1400
S-3	B-1325	1.0	10/17/85	1715
S-3.5	B-1326	1.6	10/17/85	1715
S-5	B-1327	0.4	10/17/85	1715
S-3	B-1328	2.0	10/18/85	1330
S-8	B-1329	0.6	10/18/85	1330
S-10	B-1330	0.4	10/18/85	1330
S-11	B-1331	0.3	10/18/85	1330
S-12	B-1332	0.3	10/18/85	1330
S-13	B-1333	0.2	10/18/85	1330
S-3	B-1372	1.7	10/22/85	1300
S-8	B-1373	0.3	10/22/85	1300
S-9	B-1374	0.2	10/22/85	1300
S-10	B-1375	0.5	10/22/85	1300
S-11	B-1376	0.3	10/22/85	1300
S-12	B-1377	0.3	10/22/85	1300
S-13	B-1378	0.2	10/22/85	1300
S-2	B-1444	0.9	10/25/85	1400

Table C.5 (continued)

Sample point	Sample No.	Hg (ppb)	Date	Time
S-3	B-1616	2.2	11/07/85	1400
S-8	B-1617	0.4	11/07/85	1400
S-9	B-1618	0.7	11/07/85	1400
S-11	B-1619	0.3	11/07/85	1400
S-12	B-1620	0.3	11/07/85	1400
S-13	B-1621	0.2	11/07/85	1400
S-3	B-1668	1.5	11/14/85	1300
S-8	B-1669	0.4	11/14/85	1300
S-9	B-1670	0.4	11/14/85	1300
S-11	B-1671	0.3	11/14/85	1300
S-12	B-1672	0.2	11/14/85	1300
S-13	B-1673	0.2	11/14/85	1300
MH229	MH-229	5.4	01/14/86	1030

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