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EVALUATION OF EFFECTS OF PHENOL RECOVERY ON BIOOXIDATION AND TERTIARY TREATMENT OF SRC-I WASTEWATER

Final Technical Report

By
John W. Mitchell
Joe C. Watt
William F. Cowan
Stephen E. Schuyler

September 1983

Work Performed Under Contract No. AC05-78OR03054

International Coal Refining Company
Allentown, Pennsylvania

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Distribution Category UC-89

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ABSTRACT

Addition of phenol recovery to the wastewater treatment scheme in the Baseline Design for the SRC-I Demonstration Plant was evaluated as a major post-Baseline effort. Phenol recovery affects many downstream processes, but this study was designed to assess primarily its effects on biooxidation and subsequent tertiary treatment. Two parallel treatment schemes were set up, one to treat dephenolated wastewaters and the other for processed nondephenolated wastewaters, a simulation of the Baseline Design. The study focused on comparisons of five areas: effluent quality; system stability; the need for continuous, high-dose powdered activated carbon (PAC) augmentation to the bioreactor; minimum bioreactor hydraulic residence time (HRT); and tertiary treatment requirements. The results show that phenol recovery improves the quality of the bioreactor effluent in terms of residual organics and color. With phenol recovery, PAC augmentation is not required; without phenol recovery, PAC is needed to produce a comparable effluent. Dephenolization also enhances the stability of biooxidation, and reduces the minimum HRT required. With tertiary treatment, both schemes can meet the effluent concentrations published in the SRC-I Final Environmental Impact Statement, as well as the anticipated effluent limits. However, phenol recovery does provide a wider safety margin and could eliminate the need for some of the tertiary treatment steps. Based solely on the technical merits observed in this study, phenol recovery is recommended. The final selection should, however, also consider economic tradeoffs and results of other studies such as toxicology testing of the effluents.

I. EXECUTIVE SUMMARY

To reduce America's dependence on imported petroleum, the U.S. Department of Energy (DOE) contracted with International Coal Refining Company (ICRC), a partnership betwen Air Products and Chemicals, Inc. and Wheelabrator-Frye, Inc., to design a Solvent-Refined Coal (SRC-I) Demonstration Plant. The plant, which is to be located in Newman, Kentucky, would convert 6,000 tons per day (tpd) of high-sulfur, high-ash bituminous coal (Ky #9) into a wide range of clean-burning solid and liquid fuels.

In April 1982, ICRC completed a Baseline Design for the plant, which provided a comprehensive basic design that could be refined in the future. One of the potential refinements evaluated during the period following submission of the Baseline to DOE was inclusion of a phenol recovery process for wastewater treatment.

The SRC-I Demonstration Plant will produce more than 1,000 gallons per minute (gpm) of wastewater from numerous sources, of which 440 gpm will come from sour-water streams laden with a high concentration of phenolics. These four streams will contribute the majority of the organic load to the wastewater treatment system, and the phenolics will be the major organic constituents. Hence, recovering the phenolic compounds will greatly reduce the organic loading to the wastewater treatment system.

Removing phenolics from the four sour-water streams will impact many downstream processes, including ammonia-sulfide stripping, numerous intermediate pretreatment steps before biological treatment, biological treatment (biooxidation), and subsequent tertiary treatment. Tertiary treatment consists of coagulation, filtration, carbon adsorption, and ozonation. Phenol recovery could affect ammonia-sulfide stripping by minimizing emulsion, as well as volatile organics carryover in the stripper overhead to the Claus sulfur recovery unit. Too much organic carryover will foul the catalyst in the Claus unit and contaminate the recovered elemental sulfur, a by-product, rendering it unmarketable.

Phenol recovery was expected to minimize pretreatment requirements before biooxidation. One pretreatment step is tar acid removal. Tar acid is a term being used for a complex mixture of as yet unidentified organic compounds that can be removed by acidifying the wastewater. If not removed, tar acids will impede biooxidation, but their removal requires a large amount of acid, which is a significant disadvantage. Phenol recovery will affect biooxidation by minimizing the need for tar acid removal, reducing and stabilizing the organic load to the bioreactors, and therefore resulting in a better quality effluent. In turn, a better quality bioreactor effluent will reduce the loading to tertiary treatment.

Because of the large impact of phenol recovery on a wide variety of processes, the evaluation had to be divided into several segments. The initial solvent screening for phenol extraction was conducted by R. Luthy at Carnegie-Mellon University. Lummus (a division of Combustion Engineering) had access to proprietary data for several commercial phenol recovery processes, which they screened. They recommended the Chem-Pro process for further evaluation. Consequently, ICRC subcontracted with Chem-Pro for a laboratory study to confirm the technical feasibility of their process. R. Luthy also experimentally assessed the effect of phenol recovery on organic volatilization during ammonia-sulfide stripping. Catalytic, Inc. evaluated the impact of phenol recovery on biooxidation and tertiary treatment. Finally, ICRC integrated the results, and conducted tradeoff studies.

This report summarizes the work performed by Catalytic, Inc. to evaluate the effect of extracting phenols from the SRC-I wastewater. Two treatment schemes were set up--one for the dephenolated wastewater and one as a control, representing the Baseline Design. Process recycle wastewater from the Ft. Lewis pilot plant was pretreated either by (a) phenol extraction, steam stripping to remove ammonia and hydrogen sulfide, and concentration adjustment, to produce dephenolated (DP) feed, or (b) by steam stripping, tar acid precipitation, and concentration adjustment to produce nondephenolated (NDP) feed (the control). The pretreated feeds were then fed to separate continuous flow bioreactors with internal sludge recycle--the DP feed was treated in three

different systems and the NDP in two. The five systems differed in feeds as well as hydraulic residence time (HRT), the number of bioreactor stages, and the presence or absence of powdered activated carbon (PAC) augmentation to the bioreactors.

The 9-month biooxidation study focused on five areas: bioreactor effluent quality, system stability, the need for PAC addition, the need for tar acid precipitation, and the minimum hydraulic residence time needed for each system. For each type of wastewater, serial two-stage operation was compared with single-stage operation in which PAC was added (system 3 for DP feed and system 5 for NDP feed). The control system without PAC (system 4) was set at a 30-day solids residence time and a hydraulic retention time of 3 days per stage. All other systems were compared to this system. For the DP feed, two systems were run without PAC--system 2 was equivalent to the control system 4, but system 1 had a longer HRT in case the higher loaded system 2 ran into operational problems.

During biooxidation, selected data were obtained daily to monitor operational parameters and adjust the system. Effluent COD was analyzed on a daily basis and other pollutant parameters were analyzed from composite samples.

Following biooxidation, the dephenolated effluent from systems 1 and 3 underwent tertiary treatment. The results for the dephenolated effluents were compared with results for the nondephenolated effluents that had been conducted previously (ICRC, 1983a). Comparison included the ability of the fully treated effluents to meet the projected effluent concentrations published in the SRC-I Final Environmental Impact Statement (DOE, 1981), and the anticipated effluent limits estimated from the EPA effluent guidelines for industries generating wastewaters similar to that of SRC-I.

The results of this study led to the following conclusions and recommendations:

- Phenol recovery reduced the organic loading to the bioreactors and resulted in good effluent quality without PAC augmentation. Without phenol recovery, PAC must be added to the

bioreactor to attain a bioreactor effluent of comparable quality.

- Phenol recovery also removes color. As a result, the dephenolated bioreactor effluents had much less color than the nondephenolated.
- Without PAC augmentation, a two-stage bioreactor configuration is better than single-stage, assuming that both systems have an equal total HRT.
- Dephenolization also reduced the minimum HRT required. Under steady-state conditions, this laboratory-scale study shows that a combined HRT of 2 days is adequate. For a two-stage configuration, the minimum HRT in each stage is 1 day. Without dephenolization, the minimum HRT for PAC augmentation is 3 days.
- Although no systematic study was conducted, the solids residence times (SRT) selected from the literature for this study were adequate for organic removal. With dephenolization, the two-stage non-PAC systems had an SRT of 30 days in each stage. Without dephenolization, the single-stage PAC system was operated at 40- to 50-day SRTs.
- Although a biokinetic study was not part of this program, the apparent yield coefficient can be calculated from the data generated. Apparent yield is the ratio of the amount of biomass wastage to the amount of chemical oxygen demand (COD) removed. This study observed an apparent yield ranging from 0.10 to 0.19, for all wastewaters.
- Nitrification was attained for the dephenolated wastewaters, but only after a long period of acclimation. Nitrification was not reliable; it was very sensitive to feed condition changes. For this reason, biological nitrification will not provide reliable backup to steam-stripping for ammonia control. Effective steam-stripping is crucial to compliance with effluent limits.
- Coagulation of bioreactor effluents from both dephenolated and nondephenolated wastewaters with 800 mg/L of $FeCl_3 \cdot 6H_2O$,

coupled with 0.5 mg/L of Magnifloc 835-A, effectively removed more than half of the remaining organics in the bioreactor effluents.

- Granular activated carbon (GAC) following coagulation further reduced TOC and color in both nondephenolated and dephenolated wastewaters. The isotherm data do not show whether dephenolization affected the adsorption capacity of the GAC. The effect of phenol recovery is probably more dependent on the loading to the GAC than its adsorption capacity.
- If disinfection were not a requirement, phenol recovery would eliminate the need for ozonation. Ozonation is required for nondephenolated wastewater in order to consistently meet the anticipated COD limit of 180 mg/L.
- All fully treated wastewaters, both with or without phenol recovery, can meet the FEIS values and the anticipated effluent limits, with some insignificant exceptions. However, phenol recovery would provide a wider safety margin and could eliminate some tertiary treatment steps.
- Based solely on technical merits, phenol recovery is recommended. However, the final selection should also be based on economic tradeoffs and results of other studies, such as toxicology assays.

II. INTRODUCTION

BACKGROUND

To reduce America's dependence on imported petroleum, the U.S. Department of Energy (DOE) initiated the solvent-refined coal (SRC-I) project to demonstrate the technical and economic feasibility as well as the environmental acceptability of direct coal liquefaction. In April 1982, under its prime contract with DOE (No. DE-AC05-78-ORO-3054), International Coal Refining Company (ICRC) completed the Baseline Design for a 6,000-tpd SRC-I Demonstration Plant.

Since then, DOE has decided to postpone construction of the demonstration plant indefinitely. Because pressure to meet the original ambitious construction schedule no longer exists, major effort since the Baseline has been directed toward upgrading the design.

One area that was investigated was phenol extraction of the plant's wastewater, which was not included in the Baseline Design. Extracting phenolics from about 400 gpm of heavily contaminated sour waters would be a major design change, and evaluation of the feasibility of phenol extraction represented a major post-Baseline task. Figure 1 shows the Baseline Design and the alternative wastewater treatment scheme that includes phenol extraction.

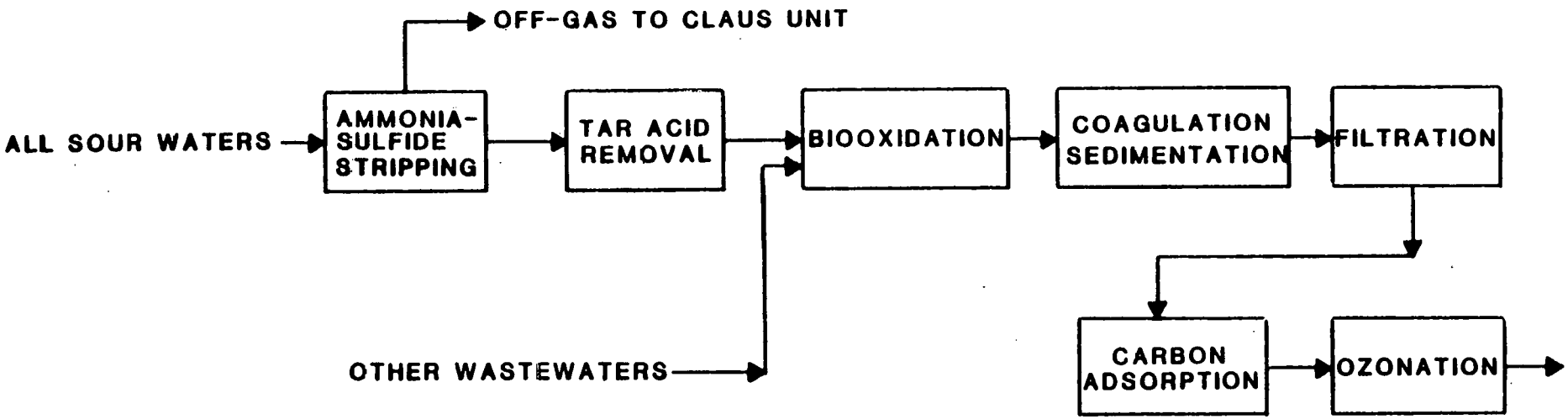
Evaluation of phenol extraction entails the following tasks:

1. Determining the feasibility of phenol extraction itself
2. Assessing the effects of phenol extraction on downstream wastewater treatment processes, including:
   a. Ammonia-sulfide stripping
   b. Tar acid removal before biooxidation
   c. Biooxidation
   d. Tertiary treatment (coagulation, filtration, activated carbon adsorption, and ozonation) following biooxidation

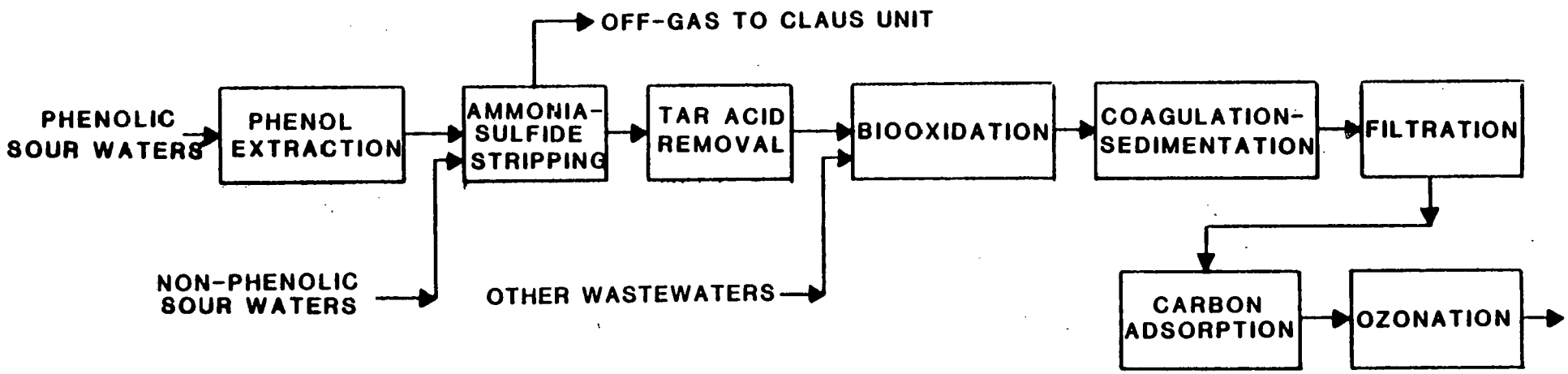
   Phenol extraction, ammonia-sulfide stripping, and tar acid removal are often referred to as "pretreatment" for biooxidation.

Figure 1

Baseline Design and Alternative Scheme



BASELINE DESIGN: WITHOUT PHENOL EXTRACTION



ALTERNATIVE DESIGN: WITH PHENOL EXTRACTION

3. Conducting trade-offs between the alternative treatment scheme and the Baseline Design.

Because of the large impact of phenol extraction on wastewater treatment and the many unit processes affected, the experimental work had to be divided among two subcontractors. Chem-Pro Corporation (Fairfield, N.J.) performed Parts 1 and 2a of the evaluation, and Catalytic, Inc. (Philadelphia, Pa.) performed Parts 2b, 2c, and 2d. ICRC integrated experimental results, which included Part 3.

This report documents only the work performed by Catalytic, i.e., Parts 2b (tar acid removal), 2c (biooxidation), and 2d (tertiary treatment). For the remainder of the work on phenol recovery and evaluation, the reader is referred to the SRC-I Environmental R&D Integration Report (Yen, 1984) and the Phenol Extraction and Ammonia-Sulfide Stripping Report (Chem-Pro Corporation, 1983).

OBJECTIVES OF WORK

The primary objective of this work was to produce information that could facilitate comparison of the two alternative wastewater treatment schemes shown in Figure 1. The scheme included in the Baseline Design does not have phenol extraction; the other does. Data were generated on the effects of phenol extraction on tar acid removal, biooxidation, and tertiary treatment and then compared with data for the Baseline Design. To facilitate comparison of the two treatment schemes, bioreactors simulating the Baseline Design were run as a control.

In addition to its primary objective, this work had two secondary objectives. First, since parts of the Baseline Design were based on suppositions and data from the literature and had never been confirmed experimentally, the control bioreactors were used to generate information to bridge that data gap. The information was used for the post-Baseline task "Data Base Expansion," which is documented elsewhere (Yen, 1984).

Secondly, this work also generated treated wastewater samples that were used for the post-Baseline Zero-Discharge Evaluation, which deter-

mined in part the need for zero discharge. Treated wastewater samples were required to generate toxicological data to provide an indication of the need for zero discharge. The toxicological tests included microbial mutagenicity (Ames test) and aquatic ecotoxicity tests (48-hr acute toxicity and 21-day reproduction study with Daphnia magna, 74-day algal growth inhibition, and 96-hr fathead minnow toxicity). Detailed results of the Zero-Discharge Evaluation are reported elsewhere (Yen, 1984).

III. ORIGIN AND PREPARATION OF SAMPLES

ORIGIN

The raw wastewater used for this study was obtained from the DOE-owned, 50-tpd coal liquefaction pilot plant in Ft. Lewis, Washington. Forty-five 55-gal drums of process recycle water (PRW) were collected from August 12 to 14, 1980, when the plant was running in the SRC-I mode.

The wastewater was thoroughly characterized in an earlier study (ICRC, 1983a). In that study, the wastewater was also compared with samples obtained from another SRC-I pilot plant in Wilsonville, Alabama, whose design more closely resembles the SRC-I Demonstration Plant. The Wilsonville plant was too small to produce the amount of wastewater needed for this study. Comparison indicated that the two wastewaters were remarkably similar.

When the characterization study was completed in July 1982, all remaining PRW was transferred to Catalytic, Inc.'s Environmental Systems Laboratory at Marcus Hook, Pennsylvania, for use in this program and others. Prior to its being moved, any PRW remaining in galvanized drums was transferred into stainless steel drums to minimize potential corrosion.

STORAGE AND HANDLING

All raw wastewater as well as samples produced from subsequent processing were stored in closed stainless steel, glass, or polyethylene containers at 4 ± 2°C. Pressurized gases were used to transfer large quantities of the wastewater from the 55-gal drums, which allowed transfer to be performed in a closed system.

PRETREATMENT BEFORE OXIDATION

Each of the two treatment schemes shown earlier in Figure 1 can be conceptually divided into three sections with respect to biooxidation:

(1) pretreatment before biooxidation, which includes phenol extraction (if used), ammonia-sulfide stripping, and tar acid removal; (2) biooxidation; and (3) tertiary treatment after biooxidation, which includes coagulation/sedimentation, filtration, carbon adsorption, and ozonation. Figure 2 illustrates the pretreatment steps taken in the laboratory before biooxidation for both schemes.

To simulate wastewater treatment with phenol recovery (the left train in Figure 2), the raw wastewater was first extracted to remove phenolics and then steam-stripped to remove ammonia and hydrogen sulfide. Also, during the initial part of the study, tar acids were precipitated in the next step, but this was discontinued when the data showed it was not necessary following dephenolization. The final step of pretreatment was concentration adjustment. This step dilutes the PRW (the most contaminated stream) to the same degree as that designed for the full-scale SRC-I Demonstration Plant and makes minor alterations to the feed to the bioreactors so that its characteristics are as close as possible to those expected in the demonstration plant, based on material balances.

The train simulating the Baseline Design (the right train in Figure 2) entails ammonia-sulfide stripping, tar acid precipitation, and concentration adjustment. The earlier wastewater study (ICRC, 1983a) indicated a need for tar acid precipitation of nondephenolated wastewater, which was confirmed by this study.

The feed generated from the train with phenol extraction is often referred to as dephenolated (DP) feed, while that produced from the other train is called nondephenolated (NDP) feed. The NDP train serves as the control, and is a simulation of the Baseline Design.

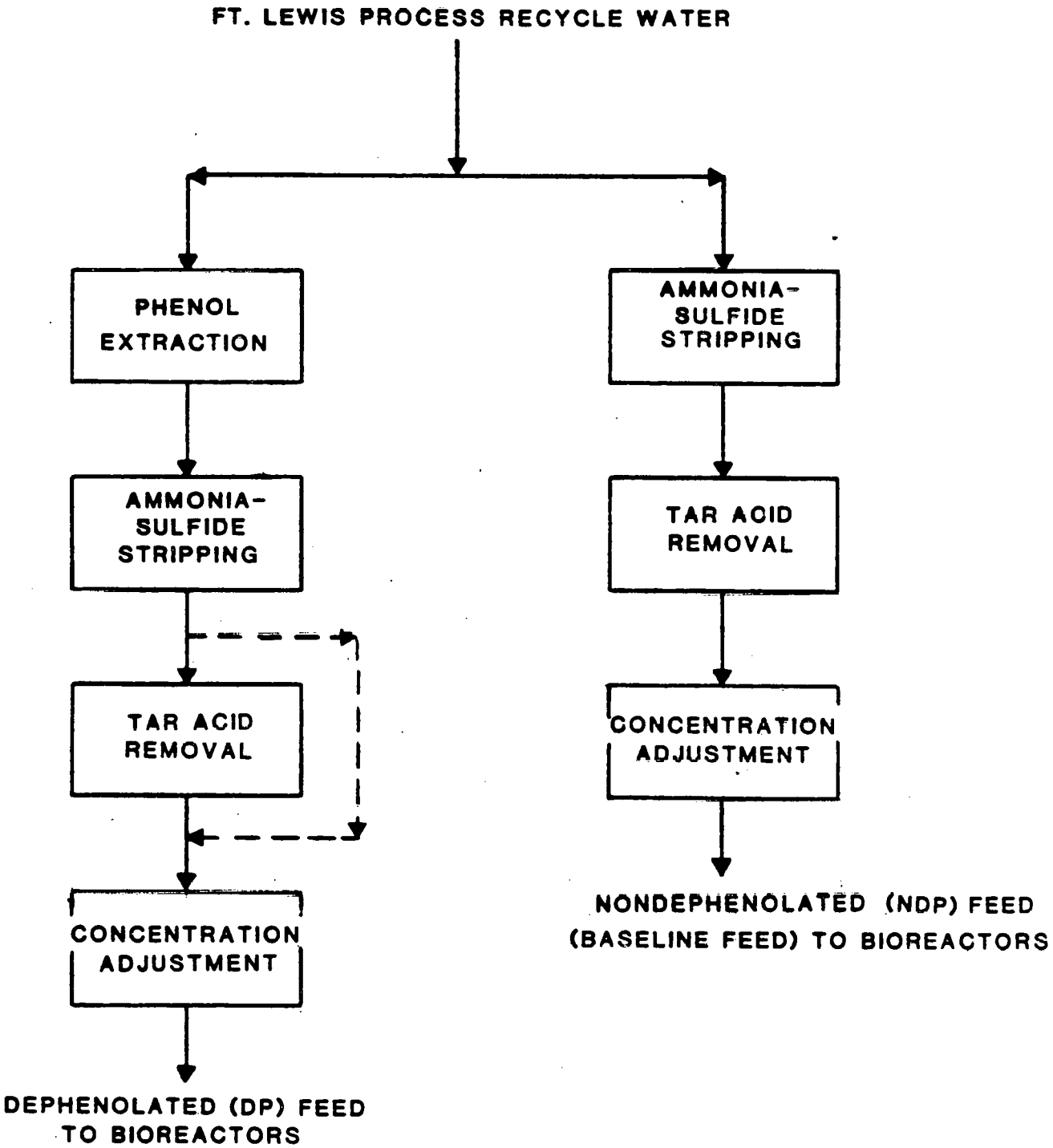
The experimental design for each of the pretreatment steps are detailed in the following sections.

Phenol Extraction

Luthy (1982) evaluated the feasibility of phenol extraction for SRC-I wastewaters, including Ft. Lewis PRW and Wilsonville process condensate from the solvent decanter (V-105), for ICRC by using three commercial solvents. All of the solvents tested (n-butyl acetate, methyl isobutyl ketone, and diisopropyl ether) effectively extracted

Figure 2

Pretreatment before Biooxidation



phenolics from the wastewaters, but methyl isobutyl ketone (MIBK) was the most effective. The distribution coefficient, K_D, for MIBK was 76. For that reason, MIBK was used in the early phase of Catalytic's work.

Catalytic extracted phenols from the wastewater in batches, and the residual phenolic concentration after extraction was targeted at 125 mg/L maximum. The following equation was used to estimate the solvent-to-water ratio, and number of extraction steps needed:

$$V_s/V_w = [(C_{out}/C_{in})^{-1/n} - 1]/K_D$$

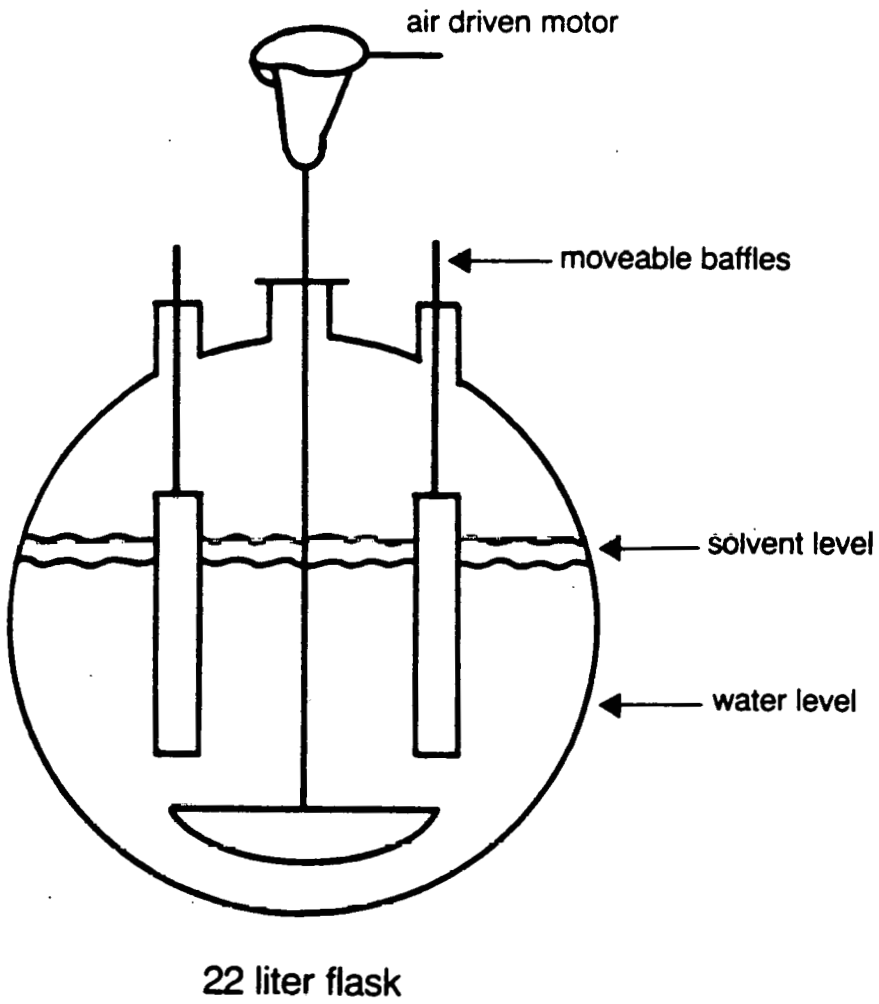
where: n = number of extraction steps with equal volume of solvent
K_D = distribution coefficient (76 for MIBK)
V_s = volume of solvent in each extraction step
V_w = volume of water
C_{in} = raw water phenolics concentration
C_{out} = desired water phenolics concentration (100 mg/L)

The extractor was a 22-L round-bottomed pyrex glass flask, as shown in Figure 3. Mixing was accomplished by a variable speed, air-driven mixer. Two 1-in. baffles, 6-in. long, were installed in the reaction vessel to improve the mixing. Raw Ft. Lewis PRW was added to the 16-L level of the extraction vessel, MIBK was added, and the mixer was turned on. The solution was allowed to mix for 15 min and then allowed to separate for at least 1 hr. After separation, the saturated MIBK was decanted and fresh MIBK was added. The solution was again mixed for 15 min and allowed to separate for 1 hr. The MIBK was again decanted and the wastewater held for stripping of hydrogen sulfide and ammonia in the next pretreatment step. Initially, various amounts of MIBK were tried; 1.5 L was eventually selected as the optimal amount. Target effluent phenolics levels of <125 mg/L (by the 4-aminoantipyrene analytical method) and residual solvent levels of <25 mg/L were easily met by extracting in two steps with 1.5 L of MIBK.

At first, Catalytic generated the feed for the bioreactors using its batch extraction process. However, later in the study, the feed for the bioreactors at Catalytic was generated by Chem-Pro, using continuous

Figure 3

Phenol Extractor



flow extractors. Chem-Pro generated the bioreactor feed in conjunction with its laboratory studies of phenol extraction and ammonia-sulfide stripping; detailed descriptions of their apparatus and procedures are available elsewhere (Chem-Pro Corporation, 1983). Chem-Pro used a proprietary solvent for extraction, which did not result in any significant differences in the characteristics of the feed to the bioreactors. However, Chem-Pro maximized phenol extraction, whereas Catalytic operated its extraction to minimize solvent consumption. Therefore, chemical oxygen demand (COD) and color concentration were 50% less in the Chem-Pro-extracted wastewater. Also, Chem-Pro-processed wastewater contained much higher concentrations of sodium ion than Catalytic's, because NaOH, rather than $Ca(OH)_2$, was used to free the fixed ammonia for stripping.

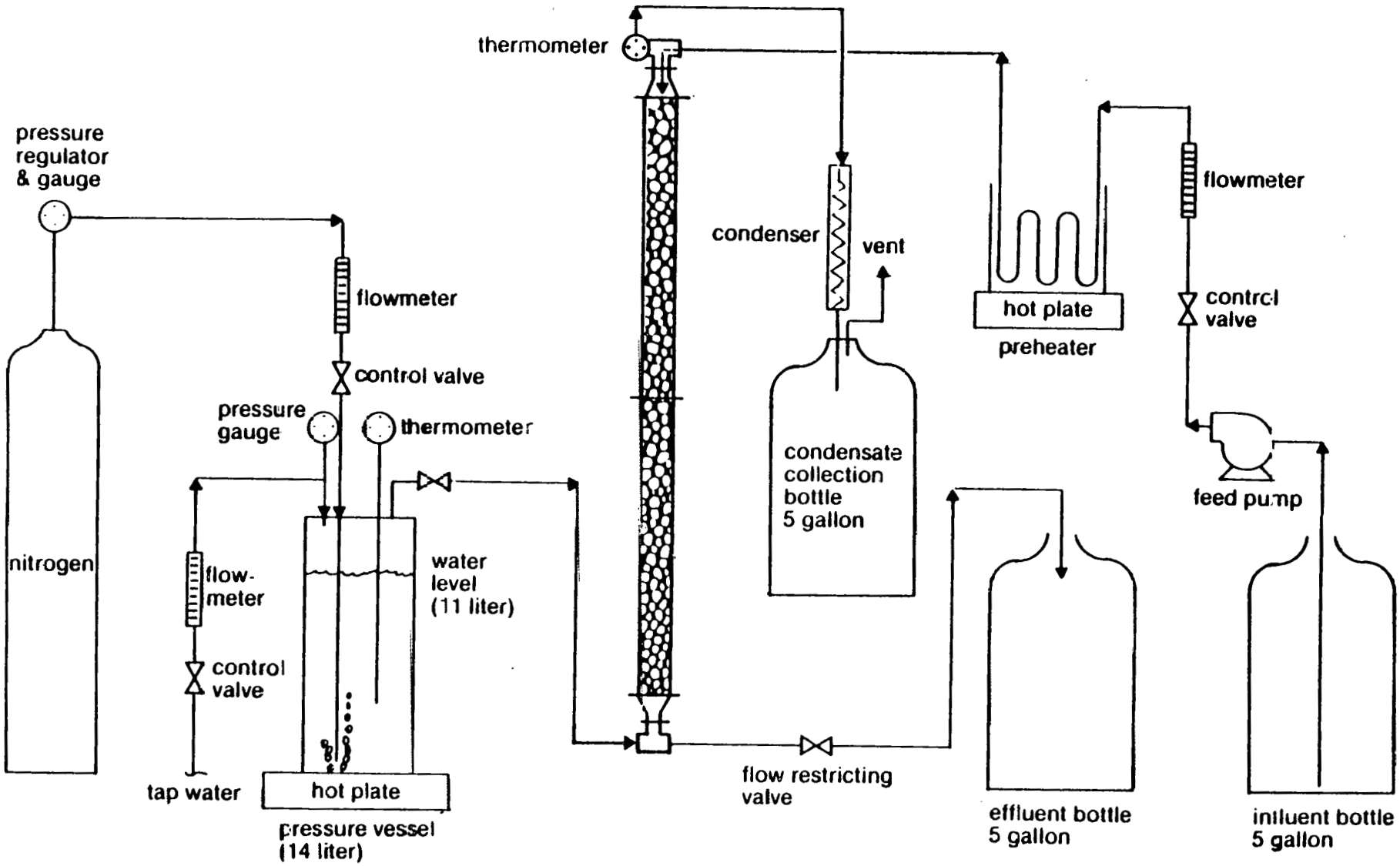
Steam Stripping [Ammonia-Sulfide Water Stripper (ASWS)]

Ammonia and hydrogen sulfide were removed from both dephenolated and nondephenolated wastewater, initially by Catalytic and later by Chem-Pro. The stripping by Catalytic was accomplished in two passes, each pass through one of two continuously operating packed columns. The first pass, performed at the original raw wastewater pH (usually about 9.5), was primarily for hydrogen sulfide removal; however, approximately 90% of the ammonia was also removed. The second pass, at pH 11.5 with the addition of lime, lowered the ammonia level of the wastewater to less than 200 mg/L.

The pyrex glass column used for the first-pass stripping operation was 3-in. in diameter by 5.5-ft long. The packing was 1/2-in.-diameter by 1/2-in.-long ceramic raschig rings. A ceramic distribution plate was located at the top of the packing. A 14-L stainless steel pressure vessel with a nitrogen gas diffusion system at the bottom was used to heat and moisten the nitrogen. The heated nitrogen and steam were then used to heat the column. The flow of this hot vapor stream to the vessel was controlled by a flowmeter with a control valve, and the flow of makeup water to the steam-generating vessel was controlled by a similar flowmeter arrangement. A schematic of Catalytic's equipment arrangement is contained in Figure 4.

Figure 4

3-Inch-Diameter Packed Column



The glass column used for the second pass was 6-in. in diameter by 3-ft long, packed to a depth of 2.5 ft with ceramic raschig rings. The steam and heating system for this column was similar to that for the first column. A schematic of the equipment arrangement is contained in Figure 5.

In both columns, the wastewater was pumped to the top of the column at a constant rate, controlled by a flowmeter/control valve arrangement. Prior to entering the column, the wastewater was preheated by a coil-type heat exchanger. The off-gases passed through a condenser and were collected in a 5-gal glass bottle. Just prior to the second pass, the wastewater pH was adjusted to 11.5 using lime [$Ca(OH)_2$]. Both the control system wastewater and the phenol-extracted wastewater were stripped under the same operating parameters. The wastewaters were processed under the following operating conditions:

1st Pass

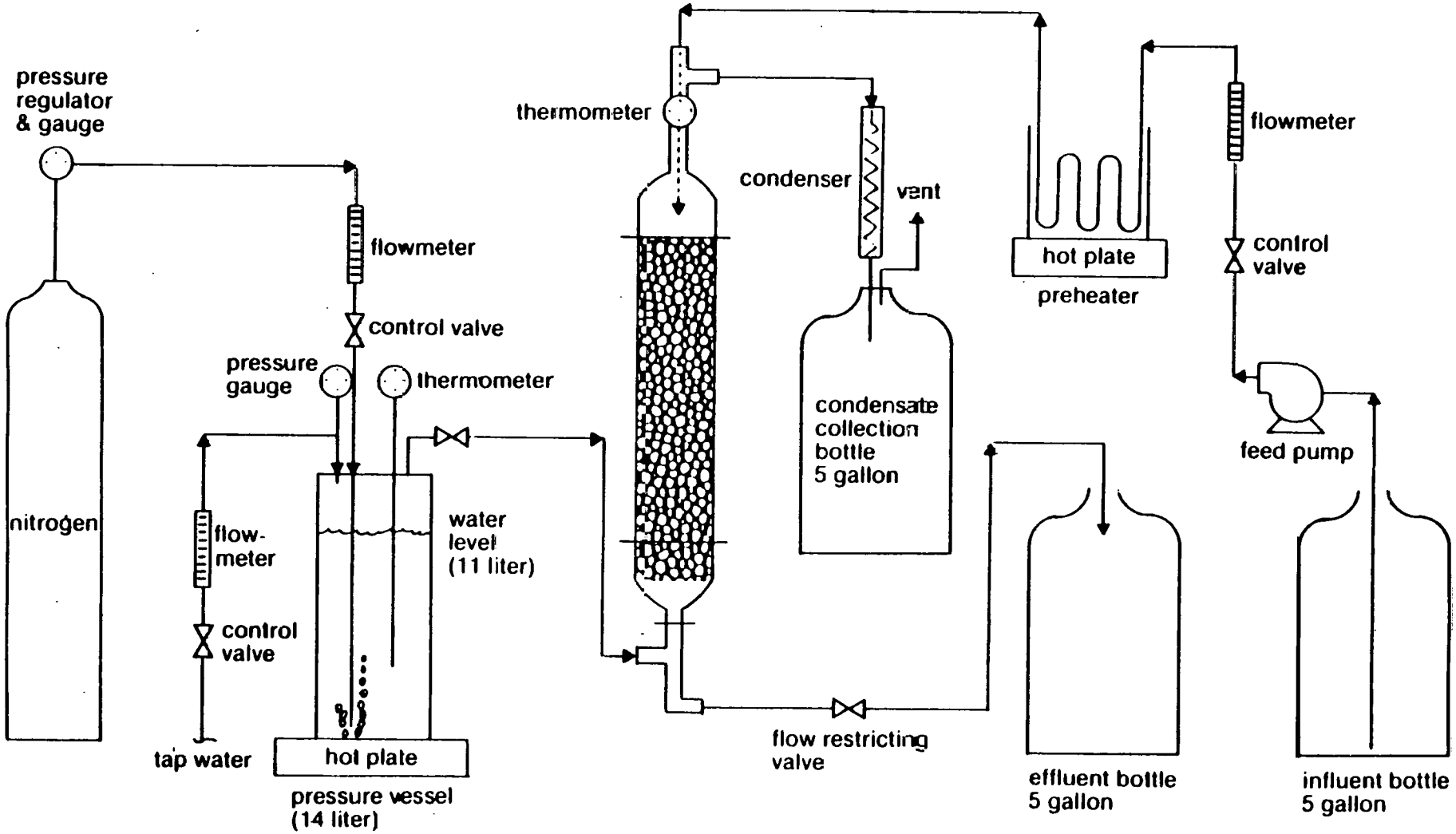
Temperature at bottom of column (°F)	215 at 1 psig
Temperature at top of column (°F)	195 at atm
Temperature of preheater bath (°F)	175 at atm
Nitrogen flow rate (L/min)	2 at 10 psig
Wastewater flow rate (L/hr)	7
Wastewater dilution (bottoms) (%)	10
Overhead condensate (%)	20-25 (of throughput)
Water makeup for steam (mL/min)	50

2nd Pass

Temperature at bottom of column (°F)	220 at 1 psig
Temperature at top of column (°F)	205 at atm
Temperature of preheater bath (°F)	180 at atm
Nitrogen flow rate (L/min)	1.0 at 5 psig
Wastewater flow rate (L/hr)	11
Wastewater dilution (bottoms) (%)	10 (increase)
Overhead condensate (%)	10 (of throughput)
Water makeup for steam (mL/min)	27

Figure 5

6-Inch-Diameter Packed Column



Occasionally, a first pass was done on the 6-in. column because the time required to complete a second pass was considerably less than a first pass. Also, occasionally a third pass was required because the wastewater did not meet specifications. This did not happen very often, approximately 3% of the time. The third pass was run under the same operating conditions as the second pass.

Catalytic stripped the dephenolated wastewater only during the initial stage of work, as was the case for extraction. During the later stages of Catalytic's study, Chem-Pro stripped the DP wastewater, using a continuous flow system that had a higher throughput capacity than Catalytic's system. The only significant difference between the stripped waters prepared by the two organizations was the amount of sodium ion in Chem-Pro's water. Chem-Pro used NaOH in ammonia stripping, whereas Catalytic employed lime. The stripping apparatus at Chem-Pro was not equipped to handle lime. Although lime is the chemical to be used at the SRC-I Demonstration Plant, caustic was considered acceptable because it had been used in the early characterization study (ICRC, 1983a) without causing any problems to the biological degradation. More detailed descriptions of the Chem-Pro work are available elsewhere (Chem-Pro Corporation, 1983).

Tar Acid Removal

Ammonia-sulfide stripping was followed by tar acid precipitation for both dephenolated and nondephenolated wastewaters (see Figure 2). The precipitation step was conducted in the 5-gal glass collection bottle used in the stripping step.

The stripped wastewater was treated with sulfuric acid to pH ±4.5, causing tar acids to precipitate. This pH was selected from prior experimentation (ICRC, 1983a) to yield the maximum tar acid solids. Following a settling period of at least several hours, the liquid was separated from the tar acid sludge layer.

Throughout all stages of this study, tar acids were precipitated from the NDP water, but they were only removed from the DP water during the initial stage. Precipitation was deleted after results from the first biooxidation experiments indicated that it was not necessary for DP water, at least in the laboratory.

Concentration Adjustments and Final Feed Composition

After tar acid precipitation, the wastewater was diluted and the pH was adjusted to about 7. Supplementary chemicals were added to achieve the composition shown in Tables 1 and 2, and the pH was fine-tuned.

Basis for Feed Composition. The PRW is the strongest major SRC-I wastewater stream in terms of phenolics, total organic carbon (TOC), and COD. In the demonstration plant, the stream is diluted when it combines with several streams having lower concentrations of these contaminants, before it enters the bioreactors. The dilution provided by combining streams was compensated for in these experiments by diluting the PRW to meet a given global parameter, calculated from the demonstration plant material balance and individual waste stream analyses. TOC was the initial dilution control parameter. COD was later adopted.

Dephenolated and control feeds were originally diluted to adjust the TOC concentration to 700 and 2,500 mg/L, respectively. With the use of a COD:TOC ratio of 3:1 established previously (ICRC, 1983a), the COD was expected to fall within corresponding values. However, after several months into the program, the ratio became highly variable and resulted in high COD values in some feed batches. Thus, the basis for dilution was changed to COD targets of 2,000 and 6,000 mg/L for dephenolated and control feeds, respectively.

After dilution, dephenolated and nondephenolated PRWs were treated with specified chemicals to meet the respective bioreactor feed compositions shown in Tables 1 and 2 for nondephenolated and dephenolated feeds, respectively.

In addition to the TOC/COD change, several other specifications were revised from original limits.

Phosphorus. The initial PO_4^{3-}-P specification of 20 mg/L for both feeds was found to provide an inadequate nutrient level. In addition to being consumed during cell growth and production, another fraction of phosphorus was precipitated.

Calcium. Without considering the solubility limitation, the calcium concentration of the wastewater should be about 1,350 mg/L. The actual soluble calcium concentration is much less. When calcium (as lime) was used in the ammonia-sulfide stripping or neutralization steps,

Table 1

Nondephenolated (Baseline) Feed Composition

Component	Concentration (mg/L)
PO_4^{3-}-P	20
NH_3-N	200 ± 20
SCN^-	200 ± 20
CN^-	10 ± 2
Ca^{2+}	1,350 ± 200[a]
Fe^{3+}	7
Mg^{2+}	14
COD	6,000 ± 750
Phenolics	800 ± 40

[a]Or to saturation if less.

Table 2

Dephenolated Feed Composition[a]

Component	Concentration (mg/L)
PO_4^{3-}-P	20
NH_3-N	200 ± 20
SCN^-	200 ± 20
CN^-	10 ± 2
Ca^{2+}	1,350 ± 200[a]
Fe^{3+}	7
Mg^{2+}	14
COD	2,000 ± 300
Phenolics	55 ± 50

[a]Or to saturation, if less.

no further addition was made. When lime was not used either in stripping or neutralization, e.g., tar acid study feed batches using Chem-Pro water, a target of 600 mg/L calcium, added as lime, was employed.

The targeted ammonia concentration for both nondephenolated and dephenolated water was 200 ± 20 mg/L (see Tables 1 and 2). Note that the ammonia concentration in the SRC-I Demonstration Plant should be considerably less; virtually all the ammonia-bearing streams will be steam-stripped to 50 mg/L or less (see ICRC, 1983b). Of that amount, most, if not all, will be used by the microorganisms in the bioreactors to support their growth and reproduction. ICRC selected the 200-mg/L concentration for these experiments primarily to determine the feasibility of biological ammonia removal.

Neutralization. Following tar acid precipitation, the individually treated batches were combined for neutralization to approximately pH 7. Normally, five batches were processed at one time, which upon dilution would yield a final feed volume of about 55 gal. Beginning with neutralization, the remaining steps in feed preparation were conducted in a 55-gal stainless steel drum, for convenience of handling and storage.

The acid-treated wastewater was first diluted with tap water to adjust the COD concentration. The pH was then raised to about 7. Lime was originally specified for this step for the wastewater stripped by Catalytic, but concern over additional formation of insoluble calcium salt led to a change to caustic. A 50% sodium hydroxide solution was used in batches prepared by Catalytic, which used lime in the ammonia stripping step. Wastewater processed by Chem-Pro did not contain calcium ion, so lime was used to provide a calcium concentration more equivalent to the Catalytic-processed material. The pH of the final feed was fine-tuned following dilution.

Concentration Adjustments. After neutralization, final concentration adjustments were needed to ensure that concentrations of the constituents were within the desired range.

Final pH Adjustment. Because chemical additions were not always in the same ratio, the resulting pH was variable and rarely held at the same value of the initial adjustment. A final adjustment was made using

either 50% caustic solution or 98% sulfuric acid, as appropriate As nitrification increased during the program, insufficient alkalinity caused reactor pH levels to drop, and feeds were adjusted to higher pH values to offset the natural drop.

IV. EXPERIMENTAL PROCEDURES FOR BIOOXIDATION AND TERTIARY TREATMENT

This section documents the equipment and procedures that were used to complete that portion of the study dealing with biooxidation and tertiary treatment, including coagulation, softening, clarification, filtration, granular activated carbon adsorption, and ozonation (see Figure 6). The equipment and procedures for pretreatment were described in Section III. Test procedures and operational parameters that were used to evaluate the different unit processes for biooxidation and tertiary treatment and to generate wastewater for toxicological studies are described in this section. Analytical methods including quality control procedures are in Appendix 1. The data derived from this work are discussed under Results and Discussion (Section V).

BIOOXIDATION

The primary goal of the biooxidation study was to generate data evaluating the effects of phenol recovery on biooxidation. The purpose was comparison with the Baseline Design; full-fledged optimization was never intended. Therefore, the experiments were designed accordingly.

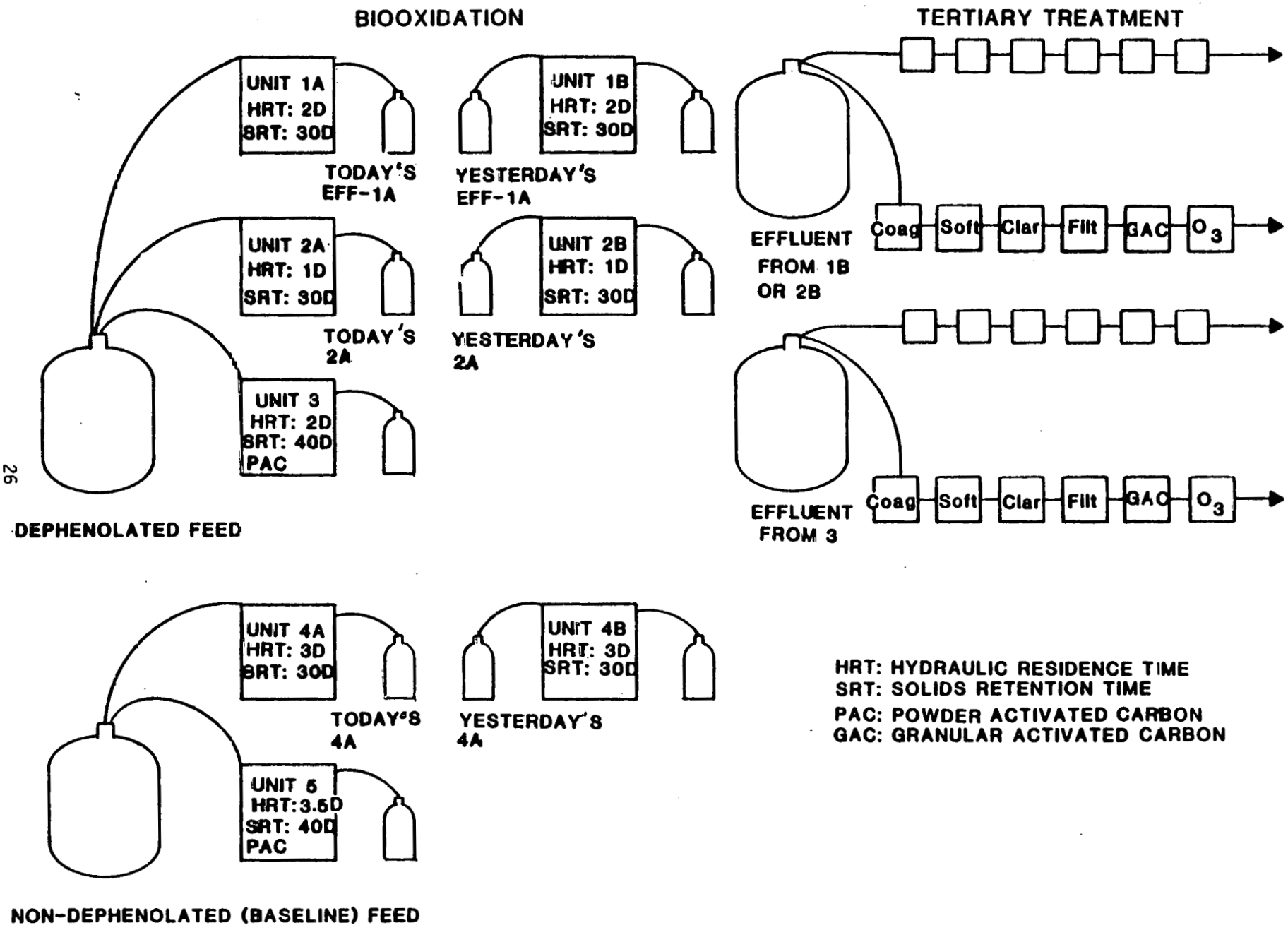
As Figure 6 illustrates, five biological treatment systems were evaluated. Each consisted of completely mixed, continuous-flow bioreactor(s) with internal sludge recycle.

The first three systems used dephenolated (DP) wastewater as feed, and the last two systems treated nondephenolated (NDP) wastewater. Each of the first two DP systems consisted of two bioreactors in series. The two systems differed in hydraulic residence times (HRT) in order to determine how HRT affected bioreactor performance. The third system treating DP wastewater had only one stage, but a high dose of powdered activated carbon (PAC) was continuously added to the bioreactor to evaluate the effects of PAC addition.

The two systems treating the NDP wastewater also differed in the number of stages they contained. System 4 consisted of two stages in series, without continuous, high-dose PAC addition, whereas System 5 had

Figure 6

Fundamental Program Schematic



only one stage, but with PAC. The two NDP systems were to serve as a control for comparison with the DP systems. Additionally, they were intended to generate more information that could bridge the data gap related to the Baseline Design, such as the minimum HRT requirement for the bioreactor. The HRTs for the NDP systems 4 and 5 were selected based on the results of a previous study (ICRC, 1983a).

Because nondephenolated pretreated wastewater had not been previously studied, operating conditions were tested. System 2 was equivalent to System 4. The dephenolated feed TOC/COD concentration was about 1/3 that of the control feed, so the System 2 HRT was set at 1 day per stage (compared to 3 days for System 4) and the SRT was 30. System 1 was run at a 2-day HRT and a 30-day SRT, in case the higher loaded System 2 had unexpected operational problems.

Following is a description of the physical systems and operating conditions for each of the biological systems.

Equipment

All equipment in contact with wastewater and treated effluent was glass, Type 316 stainless steel, or plastic in order to minimize adsorption and leaching. Each bioreactor was an independent unit consisting of feed pumps, an agitator, and feed/effluent handling containers.

Bioreactors. Two sizes were used, primarily to maintain the same hydraulic load in both stages of the two-stage systems. The first-stage effluent was feed to the second stage, although it was reduced in volume due to sample-taking, evaporation, etc. The larger first-stage reactor was constructed of stainless steel; its total capacity was 12 L, and it was approximately 127 mm wide, 254 mm long, and 405 mm high (up to the outlet nozzle invert).

The reactor was divided into two sections by a removable baffle: a 9.3-L aeration zone and a 2.7-L clarification zone. The baffle was adjustable for clearance between it and the sloped bottom in the clarifier section.

The smaller reactor was constructed of poly(methyl methacrylate). Its total volume was 8.6 L and it was approximately 114 mm wide, 240 mm

long, and 340 mm high (to the overflow nozzle). The design was the same as the larger reactor, and it provided a 7.0-L aeration zone and 1.6-L clarification zone.

Pumps. Feed was pumped from individual glass bottles holding a 24-hr supply by a peristaltic pump with variable-speed drive. Silicone tubing was used in the pump head, and it was connected to teflon tubing on the suction and discharge ends. To achieve the low flow rates necessary, all pumps were electrically controlled by a timer, which ran 20 sec in a 2-min cycle. Each pump had a separate speed controller for individual adjustment.

Agitators. Electrically driven agitators with two speed ranges and individual variable-speed controllers were used. These were equipped with standard three-blade stainless steel propellers.

System Operation

All systems were initiated on November 18, 1982 (reference point day 1), and they were operated continuously, 24 hr/day, 7 days/week. Monitoring was performed during one shift, 7 days/week. All systems were fed from a container holding a 24-hr feed volume requirement. Second-stage units received effluent from the first-stage unit collected over the previous 24 hr. Both units in two-stage systems were operated at the same SRT and HRT. Major differences between stages were in the food-to-mass (F/M) ratio limits; also, a small dosage of PAC was used only in the second-stage unit as a settling aid. Complete operational specifications are listed below for each system.

System 1 consisted of two stages, designated Units 1A and 1B, and operated under the following specifications:

	Unit 1A (first stage)	Unit 1B (second stage)
Aerated volume (L)	9.3	7.0
SRT (days)	30	30
HRT (days)	2	2
F/M (g COD/g MLVSS[1])	<0.5	<0.2
Mixed-liquor PAC concn (mg/L)	0	500
pH (reactor)	6.75-8.0	7.0-8.5
Temperature (°C)	19-26	19-26
D.O.[1] (mg/L)	>2.0	>2.0
Feed	Dephenolated pre-treated PRW	Effluent from Unit 1A
Feed rate (L/day)	4.65	3.50

One additional program was conducted on System 1. A feed was prepared in which the tar acid removal step had been deleted. This feed (containing tar acids) was initiated on day 189 of the program.

System 2 also consisted of two stages, designated Units 2A and 2B, and operated under the following specifications, except during one of the additional studies in which the HRT was varied:

	Unit 2A (first stage)	Unit 2B (second stage)
Aerated volume (L)	9.3	7.0
SRT (days)	30	30
HRT (days)	1	1
F/M (g COD/g MLVSS)	<0.5	<0.2
Mixed-liquor PAC concn (mg/L)	0	500
pH (reactor)	6.75-8.0	7.0-8.5
Temperature (°C)	19-26	19-26
D.O. (mg/L)	>2.0	>2.0
Feed	Dephenolated pre-treated PRW	Effluent from Unit 2A
Feed rate (L/day)	9.30	7.00

[1]MLVSS, mixed-liquor volatile suspended solids; D.O., dissolved oxygen.

Note that the bioreactors in System 2 have the same volume as the corresponding bioreactors in System 1. However, the HRTs in System 2 were half those of System 1. As a result, the feed rate to System 2 was twice that to System 1.

Two additional programs were conducted on System 2 after an extended steady-state run. Use of the feed without tar acid precipitation was initiated on day 123 and continued for the duration of the program. On day 189, a program to gradually increase the HRT from 1 to 2 days was begun. The objective and results of these studies will be discussed later.

System 3 consisted of a single-stage reactor using PAC. An initial dose of 11,500 mg/L PAC was added at start-up, and then daily doses of 500 mg/L of feed volume were added. Following are the complete operating specifications for the steady-state period. Parameters affected under two additional programs are marked with an asterisk. The additional programs were conducted after an extended steady-state run. A program to study the effects of a longer HRT (from 2 to 2.5 days) was begun on day 122, and on day 169, a program to reduce the PAC dose by 3% a day was instituted. Both programs were in effect through the duration of operation, which was terminated on day 216.

	System 3
Aerated volume (L)	7.0
SRT (days)	40
HRT (days)	2*
F/M (g COD/g MLVSS)	<0.5
PAC dose (mg/L of feed)	500*
pH (reactor)	6.75-8.5
Temperature (°C)	19-26
D.O. (mg/L)	>2.0
Feed rate (L/day)	3.5
Feed	Dephenolated pretreated PRW

System 4 consisted of two stages, designated as Units 4A and 4B, and operated under the following specifications. Parameters affected during additional studies are indicated by an asterisk.

	Unit 4A (first stage)	Unit 4B (second stage)
Aerated volume (L)	9.3	7.0
SRT (days)	30	30
HRT (days)	3*	3*
F/M (g of COD/g of MLVSS)	<0.5	<0.2
Mixed-liquor PAC concn (mg/L)	0	500
pH (reactor)	6.75-8.0	7.0-8.5
Temperature (°C)	19-26	19-26
D.O. (mg/L)	>2.0	>2.0
Feed rate (L/day)	3.1	2.3
Feed	Pretreated PRW w/o dephenolization	Effluent from Unit 4A

The HRT was changed several times during the program to gain better operational control of the system. On day 121, the HRT was increased to 3.5 days. After a return to more stable conditions, a planned program to slowly decrease the HRT to about 2 days was started on day 170. The program was modified on day 189 and operations terminated on day 203.

System 5 consisted of a single-stage PAC reactor. An initial dose of 13,700 mg of PAC/L was added at start-up and maintained by a daily dose of 1,200 mg/L of feed volume. Following are the complete operating specifications for the steady-state period. No additional studies were planned or conducted in System 5. The operation was terminated on day 149.

	System 5
Aerated volume (L)	7.0
SRT (days)	40
HRT (days)	3.5
F/M (g of COD/g of MLVSS)	<0.5
PAC dose (mg/L of feed)	1,200
pH (reactor)	6.75-8.5
Temperature (°C)	19-26
D.O. (mg/L)	>2.0

	System 5 (Continued)
Feed rate (L/day)	2.0
Feed	Pretreated PRW w/o dephenolization

Monitoring

Selected data were obtained daily to monitor operational parameters and adjust the system. In addition to pH, temperature, and dissolved oxygen (D.O.) specifications listed for each system, total suspended solids (TSS) in the basin and effluent were measured in order to calculate daily sludge wasting and, thus, to control SRT. Volatile (biological) suspended solids (VSS) were measured twice a week, and the daily value required for F/M calculations was produced by applying the ratio (VSS/TSS) of the previous data set. All solids data involved with a system containing PAC were further adjusted to show concentrations without PAC.

Feed throughput and collected effluent volumes were accurately measured by transferring the liquids to calibrated volumetric glassware. Volume data were required in SRT, HRT, F/M, and sludge wasting calculations.

Data were recorded in several documents, e.g., the operator's log book, laboratory notebooks, and analysis report forms. These were compiled into summary sheets, forwarded to ICRC, and ultimately stored in a computer.

Sampling and Analysis

Only effluent COD was analyzed on a daily basis. Other pollutant parameters were analyzed from composite samples in accordance with two different schedules.

During normal operations, including start-up and all steady operation, except for special characterization periods, the analytical schedule shown in Table 3 was followed. Feed and effluent were sampled daily and refrigerated. Composite samples were prepared by mixing equal portions of daily samples from the interval needed. For example, once-a-week analyses were performed on a sample containing equal volumes of daily samples collected during the preceding 7 days.

Table 3

Number of Weekly Analyses Required
during Normal Operations

	First stage			Second stage	
	Feed	Basin	Eff.	Basin	Eff.
Parameter	2[a]	5	5	3	3
COD	2	0	7	0	7
NH_3	2	0	2	0	2
CN^-	1	0	1	0	1
SCN^-	1	0	1	0	1
NO_2^-	0	0	1	0	1
NO_3^-	0	0	1	0	1
TSS	1	7[b]	7	7[b]	7
VSS	1	2[b]	2	2[b]	2
Temp.	0	7	0	7	0
pH	7	7	7	7	0
D.O.	0	7	0	7	0
O.U.R.[c]	0	3	0	3	0

[a]Number of sample points.
[b]Sample to be taken with the baffle pulled.
[c]Oxygen uptake rate.

Special characterization periods were designated to obtain a more complete parameter profile. This called for additional data at the end of weeks 1, 2, and 5 of the designated period to further characterize system performance. Samples were taken and composited in the same manner as during normal operation, although a larger sample was required for the additional analyses. The system characterization program is shown in Table 4.

Data Management

Because of the voluminous data generated by this study, a computerized data management system was set up. Daily data were entered, statistical analyses were performed, and graphs were routinely plotted so that the performance of each bioreactor could be monitored closely and quickly.

TERTIARY TREATMENT

Tertiary treatment consisted of the following unit processes: (1) coagulation and clarification, (2) dual media filtration, (3) activated carbon adsorption, and (4) ozonation. A post-biooxidation tar acid precipitation step was originally included upstream of coagulation, but it was later dropped.

The primary purpose of the tertiary treatment tests was to compare the effects of these unit processes on dephenolated and nondephenolated water. The nondephenolated water underwent tertiary treatment under a separate program (Reverse Osmosis) and is reported separately (Watt et al., 1984). Another reason for the tertiary treatment study was to produce samples for toxicology studies performed by others. The effluent was collected at various stages of the tertiary treatment train. The toxicology work is reported separately and not discussed in this report (Bailey, 1984; Drozdowicz and Kelly, 1983).

Screening tests were run on some unit processes to optimize them before the large batches of water were treated for the toxicology studies. A total of 14 different samples in 5-, 10-, and 15-gal aliquots were generated and shipped to the subcontractor. Figures 7A and 7B show block flow diagrams of the treatment train and the sampling points.

Table 4

Number of Weekly Analyses Required
during System Characterizations

Parameter	First stage			Second stage	
	Feed	Basin	Eff. (2° Feed)	Basin	Eff.
	2[a]	5	5	3	3
TOC	2	0	3	0	3
BOD_5	2	0	3	0	3
COD	2	0	7	0	7
NH_3	2	0	2	0	2
Phenolics	2	0	2	0	2
Org-N	2	0	2	0	2
CN^-	2	0	2	0	2
SCN^-	2	0	2	0	2
NO_2^-		0	2	0	2
NO_3^-		0	2	0	2
PO_4^{3-}	2	0	2	0	2
TDS	1	0	1	0	1
TSS	1	7[b]	7	7[b]	7
VSS	1	2[b]	2	2[b]	2
Temp	0	7	0	7	0
pH	7	7	7	7	0
D.O.	0	7	0	7	0
Color	1	0	2	0	2
O.U.R.	0	3	0	3	0

[a] Number of sample points.
[b] Sample to be taken with the baffle pulled.

Figure 7A

Toxicology Study Sampling Points for
Aquatic Bioassay and Mutagenicity Tests: Systems 1, 2, and 3

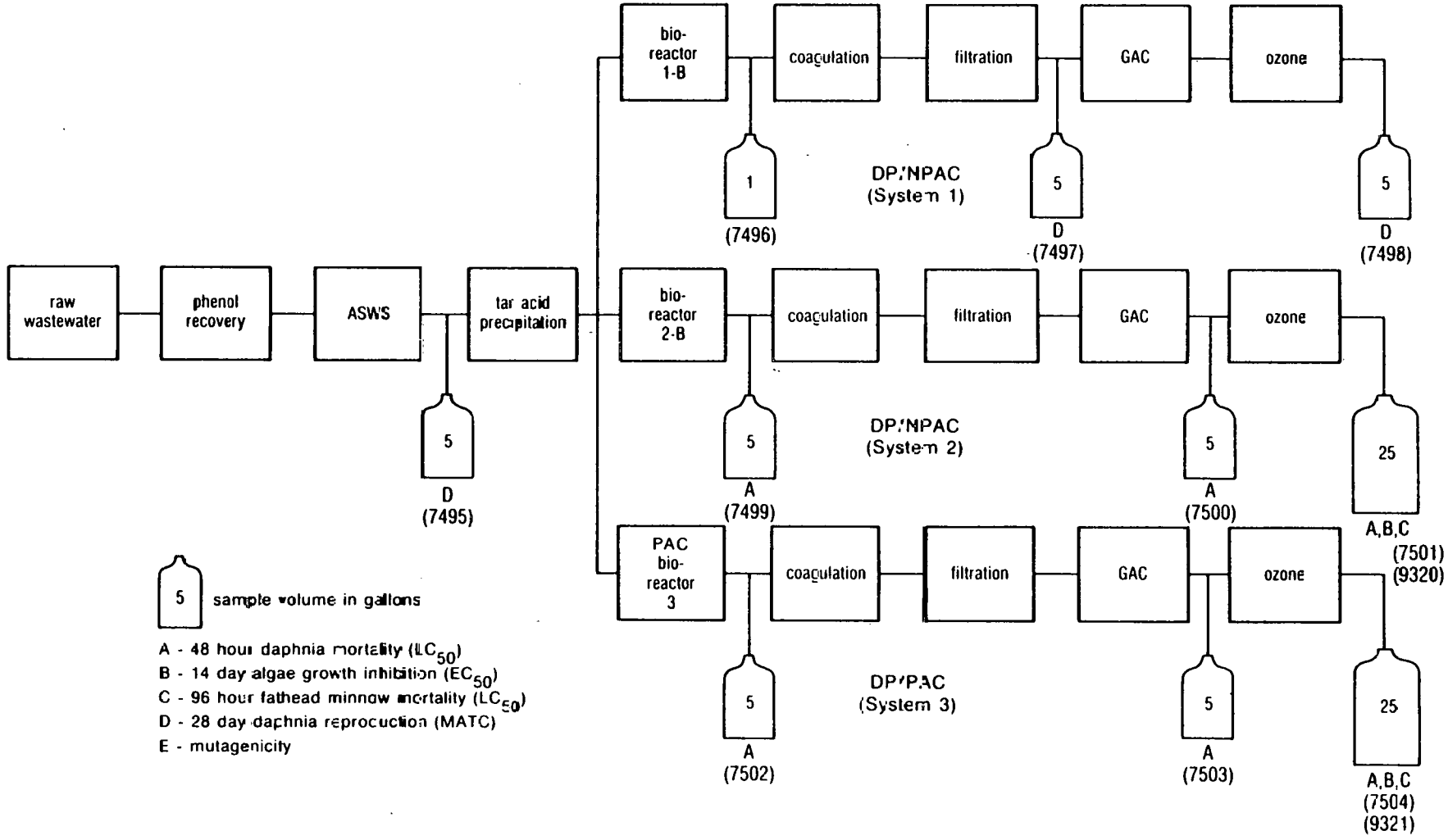
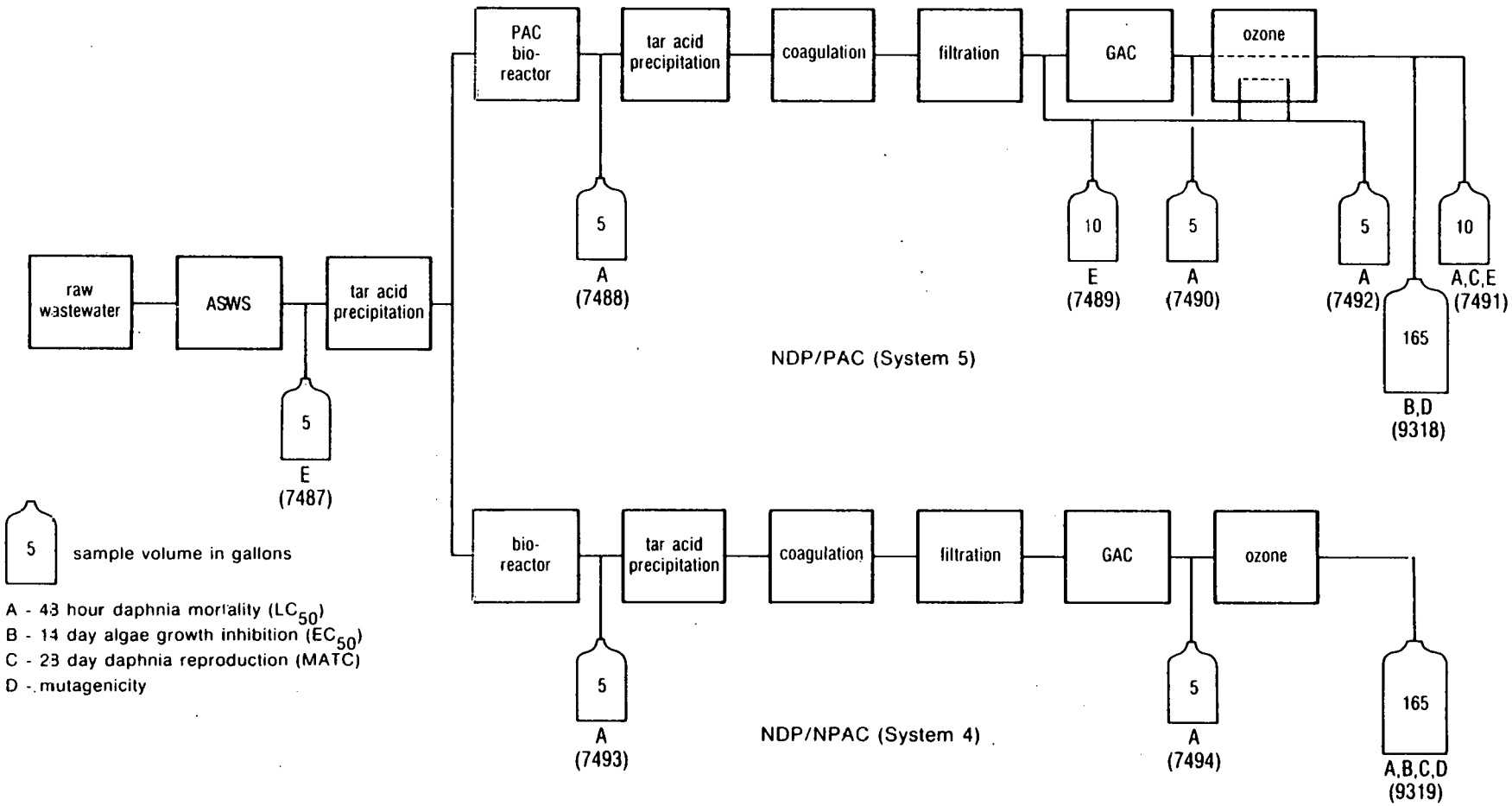


Figure 7B

Toxicology Study Sampling Points for
Aquatic Bioassay and Mutagenicity Tests: Systems 4 and 5



Note that the five systems have been denoted as DP/NPAC, DP/PAC, NDP/NPAC, or NDP/PAC depending on whether a system was treating dephenolated (DP) or nondephenolated (NDP) wastewater and whether its bioreactors were being augmented with continuous, high dosages of powdered activated carbon (PAC) or not (NPAC).

Tar Acid Removal

During the initial stage of this work, Catalytic, Inc. observed tar acids precipitating in the bioreactor effluent after acidification. Based on that, a tar acid precipitation step was thought to be necessary following biooxidation. However, when biological effluents from the system receiving dephenolated feed were sampled and the pH was lowered in increments to 2.5, no tar acid precipitation occurred in any of the samples at any of the pH values. Because of this, the tar acid unit process was eliminated from the tertiary treatment train for those systems receiving dephenolated wastewater.

Coagulation

Coagulation was evaluated on the three dephenolated bioreactor effluents using standard jar test procedures. The criteria used to evaluate the jar tests were supernatant clarity, settling characteristics, and TOC removal. The criteria were met by selecting the best combination of chemicals and dosages (ferric chloride with lime and an anionic polymer). After optimization of the chemical addition, large batches of the dephenolated bioreactor effluent were generated for the toxicology studies. One-liter graduated cylinder settling tests were conducted on these batches, which ranged in size from 65 to 134 L. The water was treated in 135-L polyethylene tanks by adding chemicals and mixing well. The floc developed was allowed to settle, and the supernatant was pumped off. At this point, no samples were taken for the toxicology studies. The resulting sludge was saved and supernatant was used in the next unit process.

Ammonia Removal

An additional treatment step was added for the toxicology samples to adjust the ammonia concentration. As discussed earlier, 200 mg of

ammonia was added per liter of feed to the bioreactors to test the possibility of biological nitrification, even though the ammonia concentration anticipated in the SRC-I Demonstration Plant will be close to zero. However, it became evident later that biological nitrification was not complete, and ammonia control must be dependent solely on steam stripping. Therefore, to lower the ammonia concentrations to the range anticipated in the demonstration plant, the toxicology samples were processed with ion exchange. The medium used was a naturally occurring resin called clinoptilolite, found in California, and used in municipal treatment systems for ammonia removal (Mindler, 1979).

Isotherms were run to estimate the amount of clinoptilolite required to remove the ammonia to the desired level. Each of two 2-in.-diameter glass columns was packed with resin to a depth of 4 ft. The coagulated effluent was pumped through the columns at a continuous rate of 125 mL/min. Before all the wastewater had been treated, the clinoptilolite had to be regenerated by pumping a 10% solution of sodium chloride at pH 12 through the column. The column was then rinsed with deionized water, and the remainder of the wastewater was treated.

Filtration

A dual media filter, run at a surface loading rate of 2 gpm/ft^2, was used prior to the carbon columns. The filter consisted of a 4-in.-diameter glass column. From top to bottom, the filter bed composition was:

Media	Depth	Effective size (mm)
Anthrafilt	18 in.	1.20-1.50
Fine sand	12 in.	0.46-0.48
Coarse sand	3 in.	0.61-0.80
Gravel	3 in.	1/4 in. x 1/8 in.

When the large batches of wastewater for toxicology testing were processed, no pressure drop was observed through the filter because of the low level of suspended solids following coagulation. Six gallons of wastewater from Unit 1B were sampled--5 gal were sent to SRI Interna-

tional for mutagenicity tests and 1 gal was submitted for complete characterization.

Activated Carbon

After coagulation and filtration, carbon adsorption isotherms were run according to ASTM Method D3860 (ASTM, 1974) on the three dephenolated systems to determine their carbon requirements. The tests indicated that much less carbon was needed to treat the dephenolated water than the control water. Although a 1-in.-carbon column breakthrough test was planned, so much TOC was removed during the coagulation step that the resulting quantity of wastewater needed to achieve breakthrough exceeded that available.

The three dephenolated system effluents were processed through carbon columns for the toxicology studies; the resulting TOC was below the limits of detection (1 ppm). Five gallons of treated effluent from Units 2B and 3 were sent to SRI International for aquatic ecotoxicity tests, and one gallon of each was characterized.

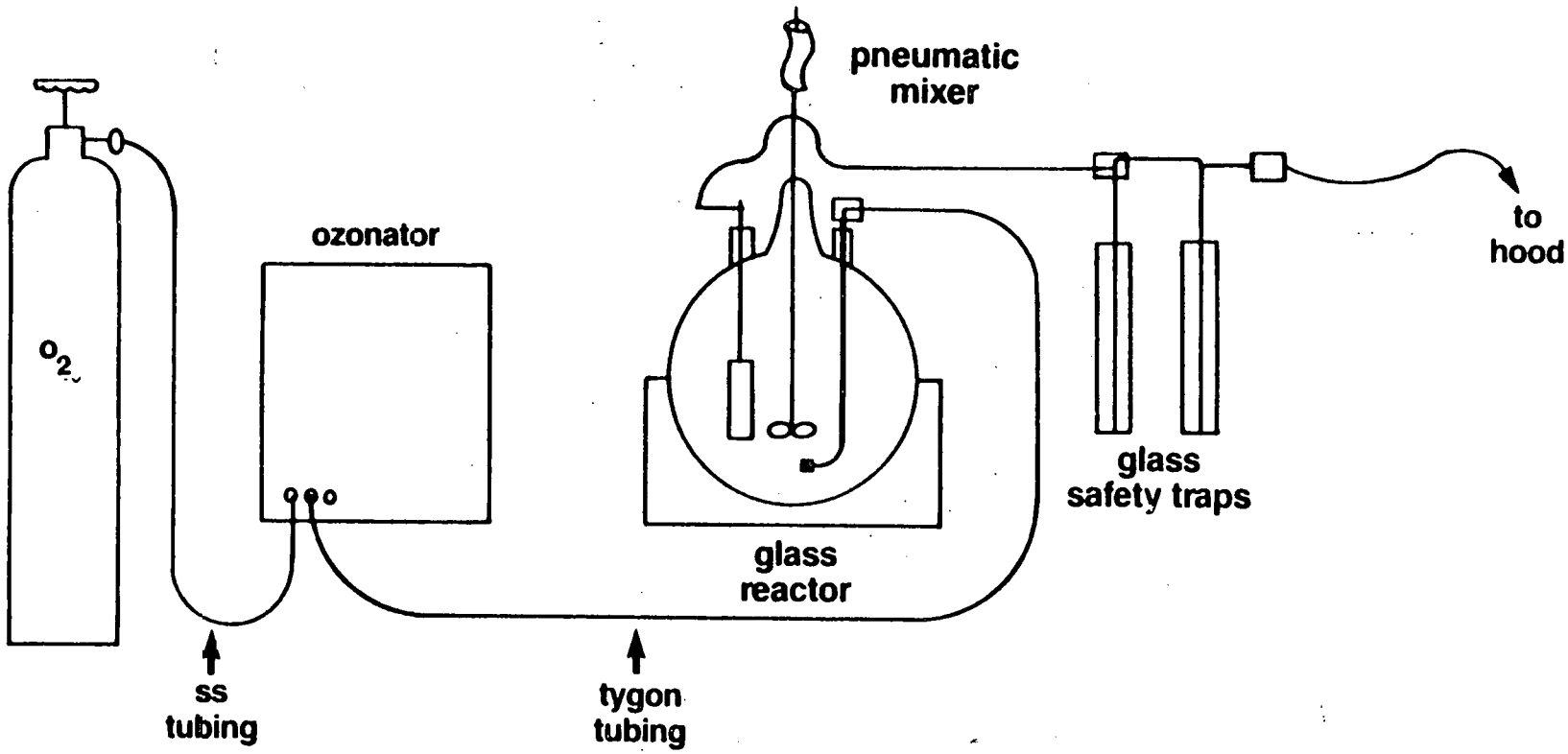
Ozonation

Equipment. The ozonation system used in the production runs for the mutagenicity and aquatic toxicity samples is diagrammed in Figure 8. A Model LOA-1 Corona generator was used to produce ozone from oxygen. The generator is designed for bench-scale operation at gas pressures from atmospheric to 15 psig, gas flows from 10 to 100 scfh, and electrical power from 0 to 200 W per corona cell (two cells). The oxygen used was extra dry grade (99.6% oxygen). All components of the system were glass, teflon, tygon, or stainless steel--all materials resistant to ozone. The glass reaction vessel had a 22-L volume, and mixing was provided by a variable-speed mixer. The ozone/oxygen mixture was introduced to the system by a coarse-grained air diffuser in the bottom of the vessel. The off-gas was passed through a solution of 5% potassium iodide (KI) to reduce the ozone concentration before venting to a hood.

Procedure. All wastewater was ozonated in batch volumes of 16 to 19 L. The ozone dosage was regulated by the inlet flow and pressure and the wattage. In general, at a given wattage, low gas flow produced a

Figure 8

Batch Ozonation System for Production Runs



high concentration and low yield, and high gas flow produced a low concentration and high yield. The glass reaction vessel had three ports that would vent open if the pressure built up because of resistance in the safety traps or high gas flow. The generator control settings varied partly because of pressure fluctuations in the reaction vessel.

The flow rates were less than 10 scfh, and wattages used were 150, 200, and 250. Ozone concentrations were determined by passing a known flow rate of gas through 400 mL of 2% KI and by titrating the solution with 0.1 N sodium thiosulfate. Ozone doses ranged from 30 to 55 mg/L (2-4% by weight in the oxygen carrier gas), and ozonation times varied from 0.5 to 3.0 hr.

After the reaction vessel was filled and control settings for gas flow were set, the mixer was started. The speed was adjusted to provide optimum dispersion of the bubbles. The vent for the off-gas was also a baffle, which further aided dispersion. The wattage was then set and ozonation began. Monitoring the system consisted of noting color, pH, and temperature changes. Ozone off-gas samples were collected periodically and analyzed immediately to prevent autodecomposition error (a half-life of 20-100 hr at room temperature can be expected). Samples were collected for each system after the batch volumes had been combined. One gallon of each effluent from systems 1B, 2B, and 3 was extensively analyzed.

V. RESULTS AND DISCUSSION

Information is presented in this section in the same sequence in which the unit processes are arranged: pretreatment (see Figure 2) followed by biooxidation and tertiary treatment (see Figure 6). However, before the unit processes are discussed, characteristics of the raw wastewater are summarized.

RAW WASTEWATER CHARACTERISTICS

During this study, the raw wastewater was not extensively characterized, because it had been done in other studies (ICRC, 1983a; Luthy and Campbell, 1984). However, the limited raw wastewater data that were generated from this study (see Table 5) are in good agreement with the other studies.

In addition to the data in Table 5, several total phenolics analyses were made using the 4AAP procedure. The average concentration was about 5,800 mg/L, which is lower than Chem-Pro's value of 6,300 mg/L, which was also measured by 4AAP. Both values were lower than the 8,000 mg/L (4AAP) reported by Luthy and Campbell. The disparity in phenolic concentrations appears to be common for raw wastewater, and becomes less significant after phenol extraction.

PHENOL EXTRACTION AND AMMONIA-SULFIDE STRIPPING

Recall that in the early phase of this study, Catalytic extracted phenols and removed ammonia and hydrogen sulfide from the wastewater. Later, Chem-Pro took over these tasks and supplied processed wastewater to Catalytic.

Phenol Extraction at Catalytic

Before processing large quantities of wastewater, Catalytic attempted to optimize operating conditions, with the goal of minimizing

Table 5

Raw Wastewater Characteristics

Sample no.	Sulfide (mg/L)	NH_3-N (mg/L)	TOC (mg/L)
1	45,000	19,200	10,000
2	50,000	17,900	10,200
3	60,000	18,450	10,400
4	45,000	17,700	10,500
5	30,000	18,500	10,500
Means	46,000	18,350	10,320
Std dev	10,840	587	216

MIBK usage rather than maximizing phenol removal. Batch extractions were performed in a 22-L round-bottomed pyrex flask, as described in Section IV. The first extraction was performed by transferring 16 L of raw wastewater to the extractor. This wastewater contained 6,000 mg/L phenolics. After the transfer, 1.3 L of MIBK was added, the extractor was mixed for 15 min, and the two phases were allowed to separate for 1 hr. The spent solvent was drawn off and 1.3 L of fresh solvent was added. The extractor was again mixed for 15 min and allowed to separate for 1 hr. Because the phenol concentration in the wastewater phase was an unacceptable 350 mg/L, a third pass was done using 1.0 L of MIBK. The phenol concentration of the wastewater phase was again checked and found to be 100 mg/L, which met the required specifications.

In the second extraction, the MIBK volume was increased to 2.0 L in each of the two steps. The wastewater phase contained 30 mg/L phenol, which was well within the specification (<125 mg/L phenolics). In the third extraction, the MIBK was reduced to 1.7 L for each of the two steps. The wastewater phase of the third extraction contained 35 mg/L phenol. The fourth extraction attempted to further minimize MIBK usage, using 1.5 L of MIBK for each pass; the wastewater extraction contained 115 mg/L phenol, less than the 125 mg/L specified. The rest of the extractions were done using 1.5 L of MIBK per step, for a total of 3 L of MIBK for each 16 L of wastewater processed.

Results after extraction, but before stripping, are shown in Table 6. Results after stripping are also summarized for a total of 56 runs in Table 7. The mean phenolic concentration after extraction and stripping was 43.2 mg/L with a standard deviation of 16.6 mg/L, which is clearly much better than the target value of 125 mg/L.

Ammonia-Sulfide Stripping at Catalytic

Stripping was performed on two kinds of wastewaters: dephenolated and nondephenolated raw Ft. Lewis PRW. The targets for stripping were 10 and 300 mg/L for H_2S and NH_3 (total), respectively. The H_2S target was met easily; the typical H_2S after the first pass of stripping was 1 mg/L. However, the ammonia concentration after the first pass was usually above 1,000 mg/L, due primarily to fixation by anions such as

Table 6

Catalytic-Prepared Extracted Wastewater
(before Stripping)

COD	NH_3-N	Phenol	TOC	Sulfide
23,500	10,300	185		
24,300	10,100	30		
23,500	9,000	35	8,230	
26,600	17,849	45.5	7,000	26,600

Table 7

Results of Catalytic's Analyses of Dephenolated, Degassed Wastewater

Run no.	NH_3 (mg/L)	Phenolics (mg/L)	Run no.	NH_3 (mg/L)	Phenolics (mg/L)	COD (mg/L)	TOC (mg/L)
1	272	130.0	29	208	32.2	5,020	1,270
2	121	30.0	30	205	31.4	3,720	1,050
3	110	30.0	31	218	30.5	5,830	1,110
4	138	75.0	32	224	34.6		
5	158	38.0	33	278	33.0		
6	133	33.0	34	260	33.1		
7	150	30.0	35	56	31.5		
8	196	41.8	36	176	40.7		
9	160	55.6	37	272	37.0		
10	123	32.9	38	212	32.0		
11	251	44.3	39	271	37.0		
12	224	25.4	40	239	34.0		
13	370	35.6	41	274	53.0		
14	480	37.5	42	470	39.3		
15	216	37.7	43	334	37.8		
16	317	30.1	44	438	54.2		
17	292	47.3	45	360	87.6		
18	343	49.1	46	87	49.0	7,300	
19	392	46.4	47	168	43.8	7,300	
20	363	40.7	48	102	66.0	7,300	
21	233	31.6	49	268	51.4	7,300	
22	164	40.0	50	283	47.0	7,300	
23	97	36.0	51	280	45.5	7,300	
24	105	37.0	52	249	57.0	7,210	
25	258	48.0	53	156	49.0	6,464	
26	179	50.0	54	210	44.0	7,584	
27	182	31.2	55	123	44.0	9,266	
28	270	34.7	56	59	12.6	9,266	2,800

chloride. Freeing the fixed ammonia typically took 7 g of $Ca(OH)_2$ per L of water processed. The lime was added before the second pass of stripping. With lime, the ammonia was reduced to 228 ± 99 mg/L for dephenolated wastewater (Table 7) and to 108 ± 64 mg/L for the nondephenolated wastewater (Table 8). The differences in concentrations between the stripped waters are insignificant, because ammonia concentrations are adjusted again before the water is fed to the bioreactors. The target concentration in the feeds was about 200 mg/L after dilution.

Phenol Extraction and Ammonia-Sulfide Stripping at Chem-Pro

Detailed results of Chem-Pro's treatment are documented elsewhere (Chem-Pro Corporation, 1983), but a summary is presented in Table 9. Compared to the Catalytic-dephenolated wastewater, the Chem-Pro-processed wastewater had a substantially lower phenolic concentration (<6 mg/L vs. 43.2 ± 16.6 mg/L). COD, TOC, and color were also lower, primarily because Chem-Pro optimized removal, whereas Catalytic minimized solvent usage. However, the difference was not significant for this study, because the organic concentration (COD) was adjusted to feed specifications by dilution.

Chem-Pro's wastewater contained more ammonia than Catalytic's (374 ± 120 vs. 228 ± 99 mg/L, respectively). Again, this was not a problem because the wastewater was diluted and the ammonia concentration was readjusted before biooxidation. Similarly, the Chem-Pro water contained more hydrogen sulfide than the Catalytic water (9.9 ± 1.8 vs. 1 mg/L), but this difference was also insignificant.

Overall, the differences between the dephenolated wastewater prepared by Catalytic and Chem-Pro were generally not significant in this study. The only exceptions are the lower color concentrations and higher sodium ion concentrations in the Chem-Pro feed, due to the use of caustic rather than lime in the steam stripping operation.

Table 8

Results of Catalytic's Analyses of Degassed, Nondephenolated Wastewater

Run no.	NH_3-N (mg/L)	COD (mg/L)	TOC (mg/L)
1	133	18,700	4,400
2	129	20,100	5,360
3	174	16,400	4,280
4	89	19,900	4,550
5	126	19,900	5,480
6	90	14,330	-
7	89	14,330	-
8	56	14,330	-
9	61	18,265	-
10	69	18,170	-
11	106	18,640	-
12	26	12,930	-
13	36	14,990	-
14	88	14,900	-
15	287	14,500	-
16	170	19,100	-

Table 9

Characteristics of Chem-Pro-Processed Wastewater[a,b]

Drum no.	pH	Phenolics (4AAP)	Cresols	Resorcinol	Solvent	H_2S	NH_3	COD	TOC	TDS	COD/TOC
1	9.1 (8.6)	<1 (0.4)	<2	<1	<1	4.9	580 (479)	(3,165)	(900)	(3,180)	3.5
2	- (9.2)	5.6	5	<1	31	9.6	290 (213)	(3,991)	(1,160)	(6,160)	3.4
3	9.1 (9.1)	<1	6	<1	9	7.9	270 (213)	(3,607)	(1,080)	(5,070)	3.3
4	9.3 (9.2)	1.4	5	<1	<1	10	510 (384)	(3,780)	(990)	(5,070)	3.8
5	9.2 (9.1)	<1	5	<1	<1	9.5	210 (127)	(3,646)	(970)	(5,500)	3.8
6	9.0 (8.9)	<1	5	<1	<1	14	320 (220)	(3,550)	(890)	(4,930)	4.0
7	- (9.3)	<1	5	<1	3	12	510 (398)	(3,684)	(970)	(4,950)	3.8
8	9.0 (9.1)	<1	5	<1	1	8.3	360 (261)	(3,607)	(960)	(4,770)	3.8
9	8.6 (9.0)	5.8	<3	<1	<1	13	340 (228)	(3,646)	(1,020)	(4,790)	3.6
10	9.1 (9.4)	5.1	48	<1	<1		350 (258)	(3,521)	(970)	(2,850)	3.6
Means	8.6 (9.1)					9.9	374 (273)	3,620	991	4,730	3.7
Std dev	1.4 (0.22)					2.8	120 (98)	208	80	995	0.22

[a]Values in parentheses are Catalytic's measurements, and the other numbers are Chem-Pro's results (Chem-Pro Corporation, 1983).

[b]Concentrations are in milligrams/liter and pH is in units.

TAR ACID REMOVAL

Following ammonia stripping, the pH of the wastewater was lowered to approximately 4.5 to precipitate tar acids. Concentrated sulfuric acid (98 wt %) was used, at a variable dose depending on the pH level of the preceding step.

Both dephenolated and nondephenolated waters were handled similarly. Both produced the same reaction, characterized by varying degrees of color loss and by formation of a precipitate. Differences were noted in acid dose and sludge production.

A number of batches were processed for special studies in which the tar acids were left in the feed to the bioreactors.

Dephenolated Wastewater

Pretreatment performed by Catalytic produced a stripped wastewater at about pH 11 and required 2.2 mL of acid/L of wastewater on the average to lower the pH to about 4.5. Chem-Pro-processed water was received at a lower pH, about 9.0, and required only 1.2 mL of acid/L of wastewater. This dose was used to lower the pH to around 4.0. Batches prepared from the first drum of Chem-Pro-processed wastewater did not precipitate until a pH of 2-3 was reached.

Freshly precipitated solids from Catalytic pretreatment normally settled rapidly and constituted 5-10% by volume, but compacted to much less after settling overnight. Chem-Pro's material did not usually produce the same heavy floc or volume, probably because considerably less calcium sulfate was precipitated. Recall that the Catalytic ammonia stripping process used lime, whereas Chem-Pro used caustic. The differences in tar acid sludge characteristics are shown by analyses of both types (all units are in mg/L):

	Catalytic	Chem-Pro
Suspended solids	50,630	2,740
Volatile suspended solids	5,940	2,740
Total solids	64,000	9,000
Total volatile solids	6,000	6,000
Calcium total	6,900	59
Calcium, soluble	2,200	51
Sodium, total	39	650
Sodium, soluble	15	600
Sulfate, total	15,000	1,700
Sulfate, soluble	1,000	1,700

Nondephenolated (Control) Wastewater

The precipitation characteristics were similar to those of Catalytic's phenol-extracted wastewater. Generally, the lower end of the pH 4-5 range was needed and sludge production appeared to be greater. On the average, 3.2 mL of acid/L of wastewater was added, which lowered the pH to about 4.1.

The quantity of acid required to induce tar acid precipitation appears to be significantly affected by dephenolization. The data tabulated below contrast the quantities of concentrated sulfuric acid required to produce the indicated pH changes for Catalytic-prepared dephenolized and nondephenolized samples:

Dephenolated, Stripped Wastewater

Initial pH	Final pH	Concn of acid required (mL of acid/L of wastewater)
11.4	4.7	1.7
11.4	4.2	2.0
10.8	4.7	2.3
11.5	4.7	2.6
		Av 2.16, std dev 0.39

Nondephenolated, Stripped Wastewater

Initial pH	Final pH	Concn of acid required (mL of acid/L of wastewater)
11.2	4.2	3.9
10.6	3.6	3.1
11.0	4.0	2.7
10.7	4.2	3.0
11.1	4.3	3.1
		Av 3.16, std dev 0.45

Although the initial and final pH values vary somewhat in the data sets, they seem close enough for comparison. Statistical hypothesis tests show that at 95% confidence levels, the difference between the acid requirements for nondephenolated and dephenolated waters is significant. On average the nondephenolated water required about 50% more acid than the dephenolated water to achieve a pH change from ~11 to ~4.

NEUTRALIZATION

Before the addition of chemical supplements, the pH was adjusted to neutral. Catalytic-processed wastewater, which contained calcium ion from stripping, was adjusted with a 50 wt % sodium hydroxide solution. For Catalytic-dephenolated wastewater, an average of 1.5 mL of the solution/L of wastewater was required to raise the pH to 7.2. In the latter stages of the study, when nitrification increased, higher pH values were required, but Chem-Pro-processed wastewater was being used at that time. An average caustic dose of about 2.5 mL/L of wastewater was needed to raise the pH from 4.0 to 8.5.

Lime [$Ca(OH)_2$] was used to neutralize Chem-Pro-processed wastewater, providing approximately the same calcium level as Catalytic water. An average dose of 1.0 g of $Ca(OH)_2$/L of wastewater was required to go from pH 3.5 to 7.3.

When the tar acid step was omitted for special feeds, Chem-Pro water was not neutralized, since the pH was in the range for chemical supplementation. Chemical supplementation changed the pH of the wastewater to varying degrees, depending on the batch. Generally, a final pH adjustment was required to reach the target value required to maintain the biosystem's mixed-liquor pH. That target pH also varied, depending on biosystem performance.

BIOLOGICAL SYSTEMS FEED PREPARATION

Final feed preparation required calculation of a dilution factor, chemical supplementation, and pH adjustment. The basis for feed preparation was discussed in Section III.

The volume of the diluted wastewater, or batch volume, was calculated by the following equation:

$$V = V_o(COD)_o/COD$$

where V = volume of the diluted wastewater (L)
V_o = volume of the pretreated wastewater (L)
$(COD)_o$ = COD concentration of the pretreated wastewater (mg/L)
COD = target COD concentration; 2,000 mg/L for the DP wastewater, and 6,000 mg/L for NDP wastewater

Targeted concentrations that were in excess of the specified concentration (after dilution for COD adjustment) were accepted anyway, without further adjustment. Parameters with concentrations below specification were added. From the constituents specified, only the following had to be added; the balance were present in the raw wastewater, amended by pretreatment:

Constituent	Added as
Ammonia-N	Ammonium hydroxide
Phosphorus	Phosphoric acid
Cyanide	Sodium cyanide
Thiocyanate	Sodium thiocyanate
Calcium	Lime (calcium hydroxide)
Iron	Ferric chloride
Magnesium	Magnesium sulfate

Table 10 shows the average feed characteristics after adjustment. Batch numbers in the table refer to different batches of diluted wastewater. The diluted dephenolated feed solution for Batches 1-12 was obtained exclusively from Catalytic-processed wastewater. Starting with Batch 13, Chem-Pro-processed water was phased in gradually. Chem-Pro and Catalytic waters were blended in 1:3 and 3:1 volume ratios in Batches 13 and 15, respectively. From Batch 16 on, all stock wastewaters were processed by Chem-Pro. The transition lasted about 3 weeks.

A summary of analyses on all feed batches, dephenolated and control, is presented in Appendices 2 and 3.

After chemicals were added, the pH was readjusted to satisfy the target pHs in the bioreactor. Systems that were nitrifying required a feed pH of up to 2.5 units higher than the normal specification, in order to neutralize the acid produced by nitrification.

Several unusual events occurred during feed preparation that later affected the experiment. These are highlighted below, and discussed later in various parts of the report.

Solids Precipitation in the Feed

Precipitation was observed in every feed batch, and was more pronounced at higher pHs. Settled solids in a freshly prepared batch normally ran about 5% by volume. Although the solids were not completely characterized, calcium phosphate and calcium sulfate were undoubtedly present. One experiment in which a feed sample was raised

Table 10

Average Feed Characteristics

Parameter (mg/L) Batch no.'s	Dephenolated feed 1-10[a]	11-14[b]	15-24 c	15-24 d	Control feed 1-6[a]	Control feed 7-11[b]
COD	2,240[f]	1,951	2,076	2,137	7,390[g]	6,050
TOC	594	480	552	594	2,034	1,374
Ammonia-N	185	162	198	205	178	188
Nitrate-N	1.8	3.8	1.4	3.3	2.2	3.7
Nitrite-N	0.2	0.3	0.12	0.1	0.2	0.3
Cyanide	6.0	6.3	2.8	1.1	4.8	8.7
Thiocyanate	199	167	200	202	198	189
Phenolics	24	12	4.9	2.3	1,345	995
Calcium	944	603	463	497	994	808
Iron	4.0	7.2	10.5	7.3	6.4	6.0
Magnesium	12	16	19	21	15	17
Phosphorus	77	69	98	67	111	145
Sodium	--	350	940	901	--	402
TDS	5,120	3,278	--	4,482	10,680	4,282[e]

[a]TOC basis for dilution; Catalytic-processed water.
[b]COD basis for dilution; Catalytic-processed water and beginning of transition to a blend with Chem-Pro water.
[c]COD basis for dilution; Chem-Pro-processed water.
[d]COD basis for dilution; Chem-Pro-processed water; no tar acid removal step.
[e]Stopped using calcium chloride salt for calcium supplement.
[f]Dephenolated feed batch 10 (high COD of 3,230 mg/L).
[g]Control feed batch 6 (high COD of 8,910 mg/L).

to pH 11.2 showed total phosphorus content to be 467 mg/L, but the soluble fraction contained only 1.2 mg/L. Among the 4,500 mg/L of total suspended solids measured, 1,200 mg/L was calcium and 1,800 mg/L was sulfate.

In another experiment, a feed batch was observed closely during makeup. The batch was at a diluted, neutralized stage ready for chemical supplementation. Starting at pH 7.4, each chemical was added; no precipitation was observed. The final addition of phosphoric acid dropped the pH to 5.7. Caustic was then added in increments to raise the pH for the full-scale batch. At pH 7.4, a slight amount of fine precipitate was formed, and at pH 8.0, a heavy floc came out of solution. Caustic was added until the pH reached 8.2. Part of this sample was then allowed to settle overnight in a glass cylinder; about 5% by volume was solids.

Originally, solids were fed to the reactors, but as higher feed pH values were required later in the study, the large quantity of sludge produced plugged the feed lines. To avoid this, each batch was then mixed well and settled overnight in the drums. Clear feed was put in individual unit feed containers.

Also, as nitrification increased in the second-stage bioreactor, the pH in that bioreactor began to drop. Thus, it became necessary to raise the first-stage effluent pH (the second-stage system feed) in order to maintain optimum pH for nitrification. When the pH was raised on these second-stage feeds, additional solids precipitated. In order to quantify the additional solids formed, an aliquot of the effluent from System 1A, at pH 8.0 and an initial suspended solids concentration of 20 mg/L, was adjusted to pH 11.0. This was the feed pH required by Unit 1B at that time. TSS concentration after adjustment was 534 mg/L. The additional solids formed were, therefore, more than 500 mg/L. In order to prevent plugging of the feed pumps, these precipitated solids were not fed to the second-stage systems. Instead, they were allowed to settle in the feed container (i.e., the suction line of the pump was raised off the bottom of the unagitated feed container).

Because of the solid precipitation problem, different pH control methods should be considered for full-scale operation. For example,

phosphoric acid could be added directly to the bioreactor when its pH is lower than that in the feed. Also, a portion of lime needed to neutralize the acid produced from nitrification could be added directly to the bioreactor where the pH is close to neutral.

Change in Sodium Concentration in the Feed

Sodium strengths in the Catalytic- and Chem-Pro-processed dephenolated wastewaters differed. The Chem-Pro water had a much higher sodium concentration (1,200 to 1,300 mg/L initially; 917 mg/L average) than Catalytic's (350 mg/L average). Although the transition from Catalytic to Chem-Pro feed was slow and gradual to avoid shock, the high sodium content apparently affected nitrification. However, nitrification did eventually recover.

COD Excursions

Two batches of feed had abnormally high COD contents: Batch 10, dephenolated water and Batch 6, nondephenolated water. Both excursions occurred about the same time and adversely impacted effluent quality. The unplanned excursions provided information on how the bioreactors would respond under a shock load, which in effect eliminated the need to conduct planned excursions scheduled for the last stage of this study.

Termination of Tar Acid Precipitation of Dephenolated Wastewater

Because tar acid precipitation required a large quantity of acid and increased the dissolved solids considerably, there was incentive to eliminate it. Accordingly, studies with dephenolated feed without tar acid precipitation were initiated with Batch 17. Following the switch, the measured parameters did not differ discernibly.

BIOOXIDATION

The reader is referred to Figure 6, which shows the five biological treatment systems studied. The five systems are as follows:

System no.	Feed	PAC	Bioreactor (target HRT)		System notation
1	DP	No	1A (2 days)	1B (2 days)	DP/NPAC
2	DP	No	2A (1 day)	2B (1 day)	DP/NPAC
3	DP	Yes	3 (2 days)	-	DP/PAC
4	NDP	No	4A (3 days)	4B (3 days)	NDP/NPAC
5	NDP	Yes	5 (3.5 days)	-	NDP/PAC

The most important characteristics distinguishing one system from another are: (1) feed type--dephenolated (DP) vs. nondephenolated (NDP); (2) addition of powdered activated carbon (PAC) to the mixed liquor (no carbon addition denoted as NPAC); (3) hydraulic retention time (HRT).

Systems 1, 2, and 3 were dephenolated and Systems 4 and 5, which served as the controls, were nondephenolated. Carbon was added to Systems 3 and 5 (PAC), but not to 1, 2, and 4 (NPAC). The NPAC systems were two stage, while the PAC systems were single stage.

Systems 1 and 2 were almost identical, except for their HRTs. System 1 had a 2-day HRT in each of the two stages and System 2 had an HRT of 1 day in each stage. The HRTs tabulated above are final target values after initial adjustments. More details about HRT selection will follow.

The most important objective of the biooxidation studies was to evaluate the impacts of phenol extraction on biological treatment. The evaluation focused on the following areas:

- Bioreactor effluent quality, primarily in terms of COD, BOD, TOC, color, phenolics, ammonia, cyanides, and thiocyanate
- System stability (resistance to shock loadings and ability to recover)
- The need for continuous, high-dose PAC addition to the bioreactors
- The need for pre- and post-biooxidation tar acid precipitation with phenol extraction
- The minimum hydraulic residence time needed for each system

The biooxidation studies lasted for more than 7 months, and an enormous quantity of data was generated. The data are summarized in subsequent tables.

The following sections compare the performances, or efficiencies, of the various systems. Emphasis is on the effects of carbon addition, two-stage treatment, and dephenolation of the feed.

Bioreactor Operating Parameters

Table 11 summarizes the key operating parameters for all bioreactors. The key operating parameters are SRT (solid residence time), F/M_{COD} (food-to-microorganism ratio on a COD basis), fraction of COD remaining, HRT (hydraulic residence time), MLSS (mixed-liquor suspended solids), MLVSS (mixed-liquor volatile suspended soldis), basic pH, OUR (oxygen uptake rate), and PAC inventory. The MLVSS includes PAC and MLVSS-PAC corrected does not.

For the dephenolated systems, the data are divided into several time periods which are characterized by different kinds of feed. In the first period, the systems were fed with the Catalytic-processed feed. For Systems 1 and 2, the feed was gradually switched to the Chem-Pro feed in the second period. The Chem-Pro-prepared feed was used exclusively in the third period. In the fourth period, Systems 1 and 2 treated the feeds with prebiological tar acid removal.

Data for System 4 are also divided into different time periods, but for different reasons. System 4A, which was a control, began to show a marked decrease in removal efficiency as the influent COD increased. This increase in the feed strength was due to the method of preparation, which was based on maintaining a constant TOC. The COD/TOC ratio was not constant, however, causing the COD concentration to rise from 6,000 to almost 9,000 mg/L. This problem was alleviated by changing the basis of feed dilution to the COD parameter. This did not result in a corresponding improvement in Unit 4A, which continued to fail. PAC was added, and, after over 2 months, the reactor did recover, although steady state was not achieved. Note that the second-stage (System 4B) effluent COD remained relatively constant throughout the upset and recovery periods.

Table 11

System Operating Parameters

	PERIOD		DESCRIPTION	SRT		F/M COD		HRT(DAYS)		MLSS(MG/L)		MLVSS(MG/L)		MLVSS-PAC CORR		BASIN pH(units)		OUR(MG/L/HR)		PAC INV(MG/L)	
				MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
UNIT1A	DEC15-FEB26		CATALYTIC FEED	29.6	3.7	0.18		2.09	0.28	6533	1063	4254	376	4254	374	7.5	0.3	25.7	10.1		
UNIT1A	FEB27-MAR19		CHANGE TO CHEMPRO	30.0	(0.1	0.19		2.02	0.27	5120	577	3732	327	3732	327	6.9	0.2	28.7	7.9		
UNIT1A	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.1	0.31		2.05	0.39	3034	441	2377	289	2377	289	7.7	0.4	26.1	9.5		
UNIT1A	MAY24-JUL25	*	CP FEED(NO TA REM)	30.0	1.8	0.28		2.03	0.20	2944	265	2653	269	2653	269	78.3		34.1	8.6		
UNIT1B	DEC15-FEB26		CATALYTIC FEED	29.6	6.0	0.04		2.20	0.52	2873	623	2244	543	1921	588	7.0	0.5	12.2	4.3	499	
UNIT1B	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	3.4	0.04		2.30	0.41	2663	817	2046	658	1896	693	7.4	0.3	11.2	3.6	500	
UNIT1B	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	2.5	0.05		2.12	0.34	3274	744	2561	523	2276	527	7.6	0.5	7.3	3.5	500	
UNIT1B	MAY24-JUL25	*	CP FEED(NO TA REM)	29.8	5.1	0.09		2.08	0.23	2027	383	1650	277	1348	350	7.6	0.4	8.6	5.6	500	
UNIT2A	DEC15-FEB26		CATALYTIC FEED	28.8	11.2	0.30		1.08	0.17	8362	1937	4828	1224	4828	1224	7.6	0.2	35.6	12.8		
UNIT2A	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	3.3	0.25		1.06	0.08	8514	841	5469	622	5469	622	7.3	0.3	36.7	11.3		
UNIT2A	MAR20-MAY16	*	CP FEED(NO TA REM)	30.0	1.4	0.25		1.06	0.31	9176	2121	5705	1153	5705	1153	7.9	0.2	48.9	10.8		
UNIT2B	DEC15-FEB26		CATALYTIC FEED	27.1	14.7	0.09		1.05	0.12	3700	1244	2656	801	2316	837	7.2	0.7	18.0	10.3	492	
UNIT2B	FEB27-MAR19		CHANGE TO CHEMPRO	25.9	8.3	0.06		1.00	0.06	3672	767	3143	670	2978	718	6.7	0.6	30.0	7.1	489	
UNIT2B	MAR20-MAY16	*	CP FEED(NO TA REM)	30.1	3.2	0.09		1.02	0.14	2752	483	2365	385	2077	430	7.1	0.6	32.4	8.5	500	
UNIT3	DEC15-FEB25		CATALYTIC FEED	39.8	7.2	0.14		2.04	0.20	13885	3396	9795	3425	5607		7.3	0.8	29.7	12.5	7086	
UNIT3	FEB26-MAY04	*	CHEMPRO (CP) FEED	39.8	2.8	0.27		2.29	0.30	10161	1770	8779	1441	2443		7.1	0.3	19.1	4.2	7415	
UNIT3	MAY05-JUN20		CP FEED(PAC REDUCT	39.8		0.25		2.53	0.33	8458	797	7322	923	2283		7.1	0.3	23.5	6.3	5620	
UNIT4A	NOV18-JAN17	*		31.5	9.2	0.37		3.87	1.19	4900	1060	3315	754	3315	754	7.3	0.3	27.6	11.7		
UNIT4A	FEB18-MAR24		SYSTEM FAILING	25.9	8.7	0.50		3.28	0.58	4885	1419	2698	783	2684	800	7.7	0.3	27.8	18.7		
UNIT4A	MAR25-APR15		PAC ADD-SYS RECOV.	30.8	7.9	0.48		3.26	0.25	3619	938	2542	667	2457	667	7.5	0.3	15.4	21.5	250	
UNIT4A	APR16-MAY06		SYS RECOVERED	30.1	0.7	0.43		3.80	1.34	2855	768	2393	598	2320	575	7.3	0.2	25.0	17.7	184	
UNIT4B	NOV18-JAN17	*		30.5		0.09		3.67	1.33	4013	861	3250	793	3014	787	6.8	1.7	11.4	5.7	461	
UNIT4B	FEB18-MAR24			29.4	4.6	0.23		3.29	0.41	5178	1386	4001	1183	3798	1150	7.2	0.3	51.0	31.1	500	
UNIT4B	MAR25-APR15			31.2	4.9	0.20		3.20	0.32	6363	982	5241	833	5087	833	7.4	0.4	62.5	21.4	500	
UNIT4B	APR16-MAY06			30.8	.0	0.07		3.50	0.36	5261	486	2997	580	2849	688	7.1	0.4	17.1	9.8	500	
UNIT5	DEC15-FEB08			41.4	24.3	0.28		3.60	0.53	16503	2994	13199	2559	5240		7.2		34.1	16.7	10253	
UNIT5	FEB09-APR15	*		45.1	24.2	0.16		3.52	0.48	18878	2209	15638	1757	7415		6.9	0.2	36.6	16.1	9906	

* STEADY STEATE

Table 11 also indicates those time periods that are considered as steady state for each system. Steady state is defined as a period of at least 3 weeks in which the first-stage COD removal approached a consistent percentage of the COD applied; that is, the percent removal was not affected by changes in feed concentration (see Figures 9-13). An additional requirement was that the SRT remain relatively constant. Also, for systems in which nitrification produced a consistent NH_3-N removal efficiency, the stable COD and NH_3-N removal periods should coincide. If no such constant NH_3-N removal occurred in the second-stage reactor, then steady state was based solely on COD. The period during which PAC was added to System 4A is not considered representative of steady state, because it did not rely solely on biological activity.

Organic Removal (COD, TOC, and BOD)

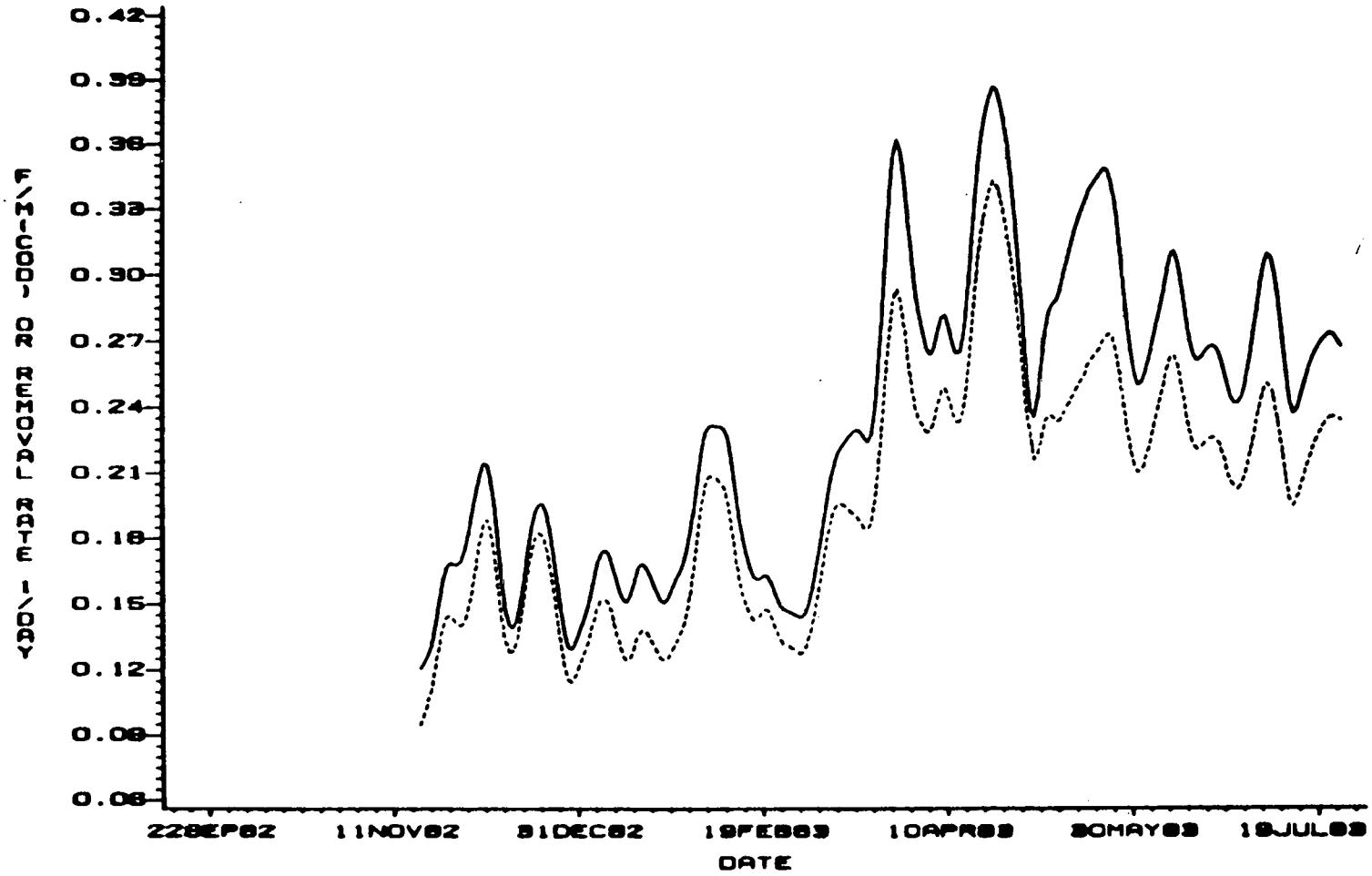
Table 12 presents the data for each reactor in the five biological treatment systems. Time series plots for COD concentration data are presented in Figure 14-18. These graphs indicate that all systems can generally remove a substantial quantity of COD despite fluctuations in feed strength. Even so, a close examination of the COD data reveals significant differences between systems. The following discussions highlight these differences.

Dephenolated vs. Nondephenolated. The dephenolated systems provided more complete organic removal than the nondephenolated. This is evident from a comparison of the effluent concentrations of COD, TOC, and BOD_5 from the last-stage bioreactors of all five biological systems. During steady-state operation, the effluent COD from the DP systems ranged from 170 to 221 mg/L, vs. 262 and 648 mg/L for the NDP systems. Even with PAC the NDP system could not match any of the effluents of the NPAC systems treating a dephenolated feed, on an average basis. The NDP/PAC system performance did vary widely (SD = 101 mg/L for COD). The DP systems were much more stable, and the effluent COD data showed standard deviations of 34 to 63 mg/L.

The limited BOD_5 data also indicated that the DP systems produced a better effluent than the NDP systems, although the differences are not as dramatic as those for COD. First-stage effluent BOD_5 concentrations

Figure 9

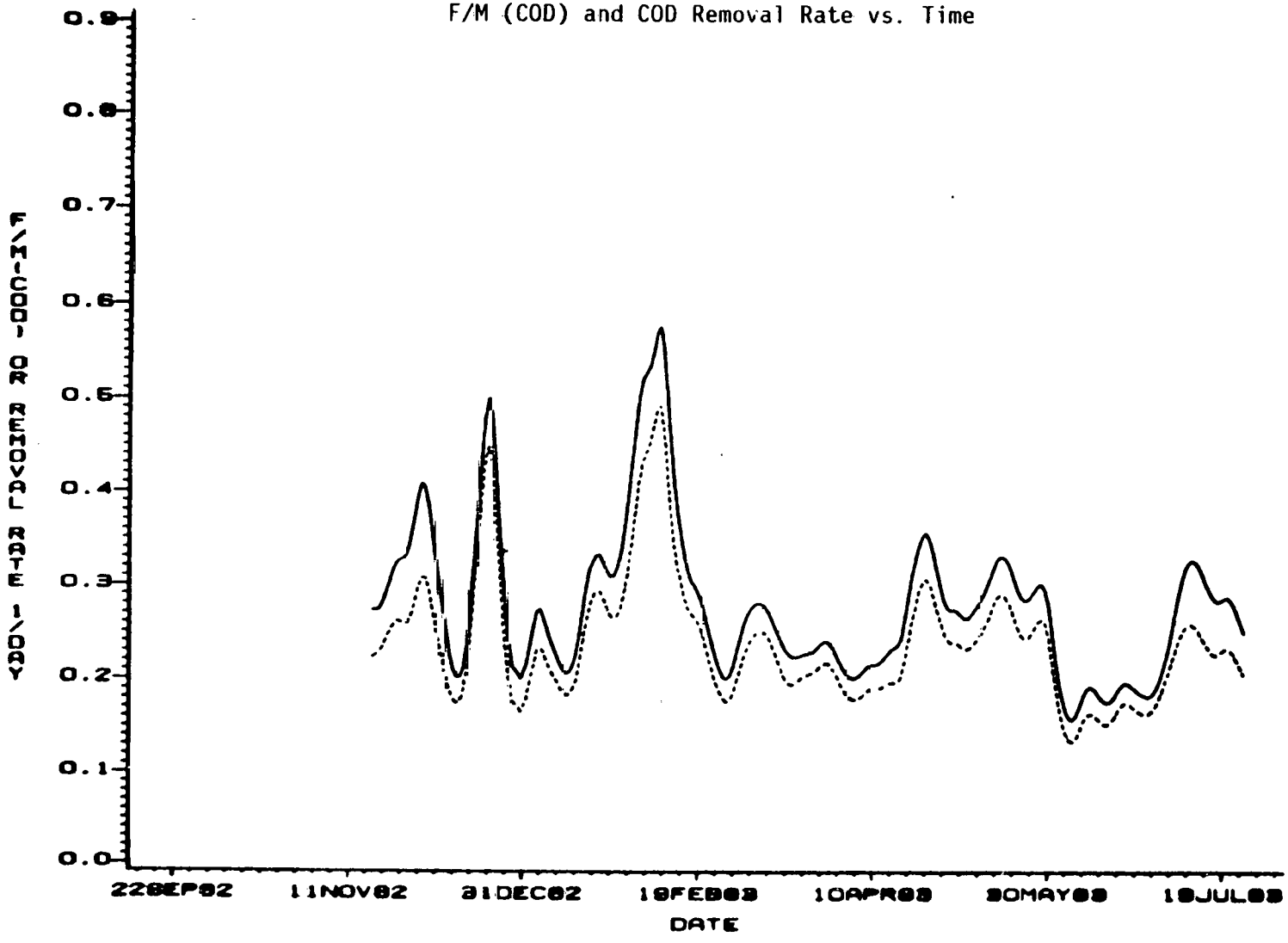
SRC-I Biotreatment Data for Unit 1A:
F/M (COD) and COD Removal Rate vs. Time



—F/M (COD) - - -COD Removal Rate

Figure 10

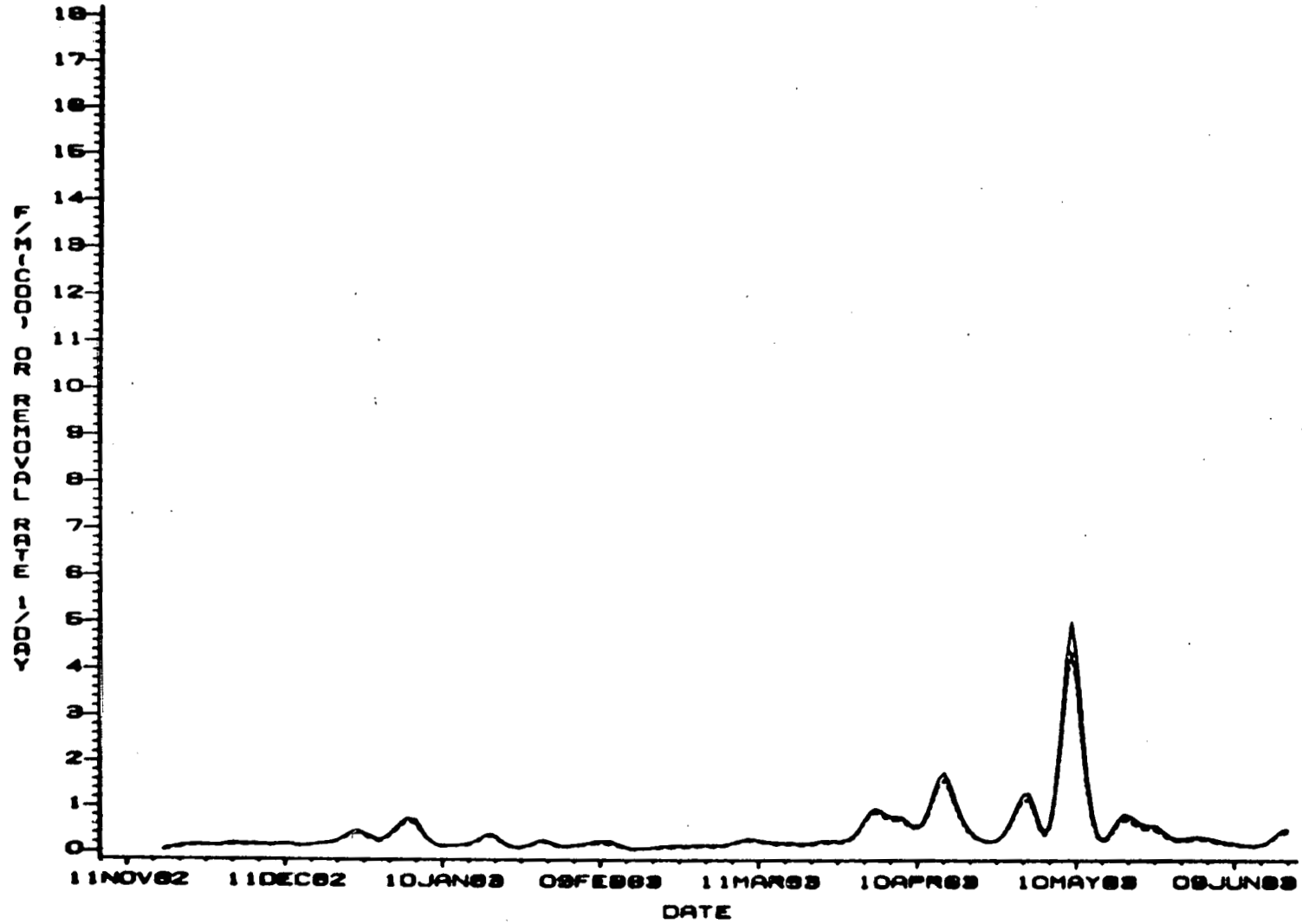
SRC-I Biotreatment Data for Unit 2A:
F/M (COD) and COD Removal Rate vs. Time



—F/M (COD) - - -COD Renoval Rate

Figure 11

SRC-I Biotreatment Data for Unit 3:
F/M (COD) and COD Removal Rate vs. Time



—F/M (COD) - - -COD Removal Rate

Figure 12

SRC-I Biotreatment Data for Unit 4A:
F/M (COD) and COD Removal Rate vs. Time

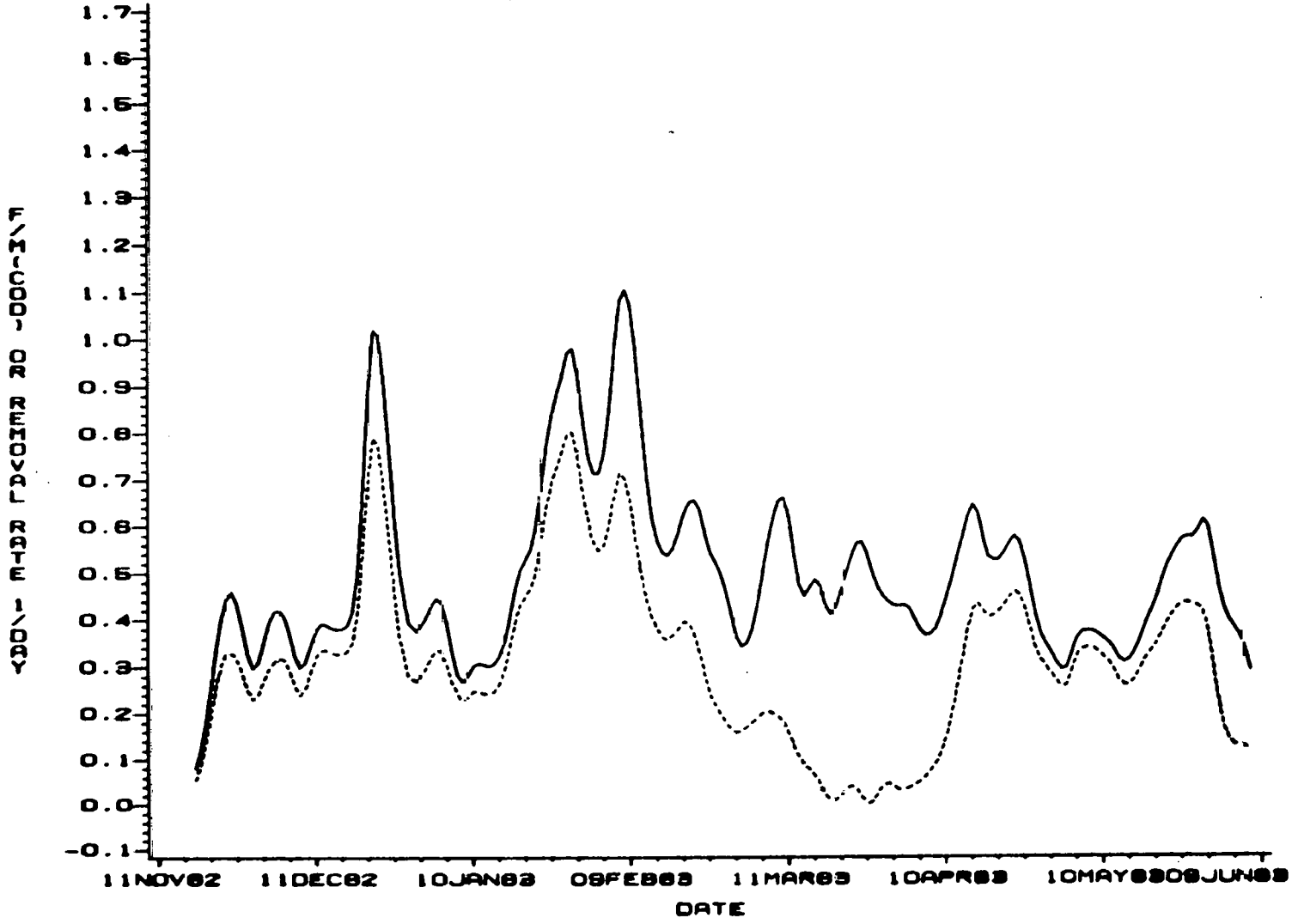
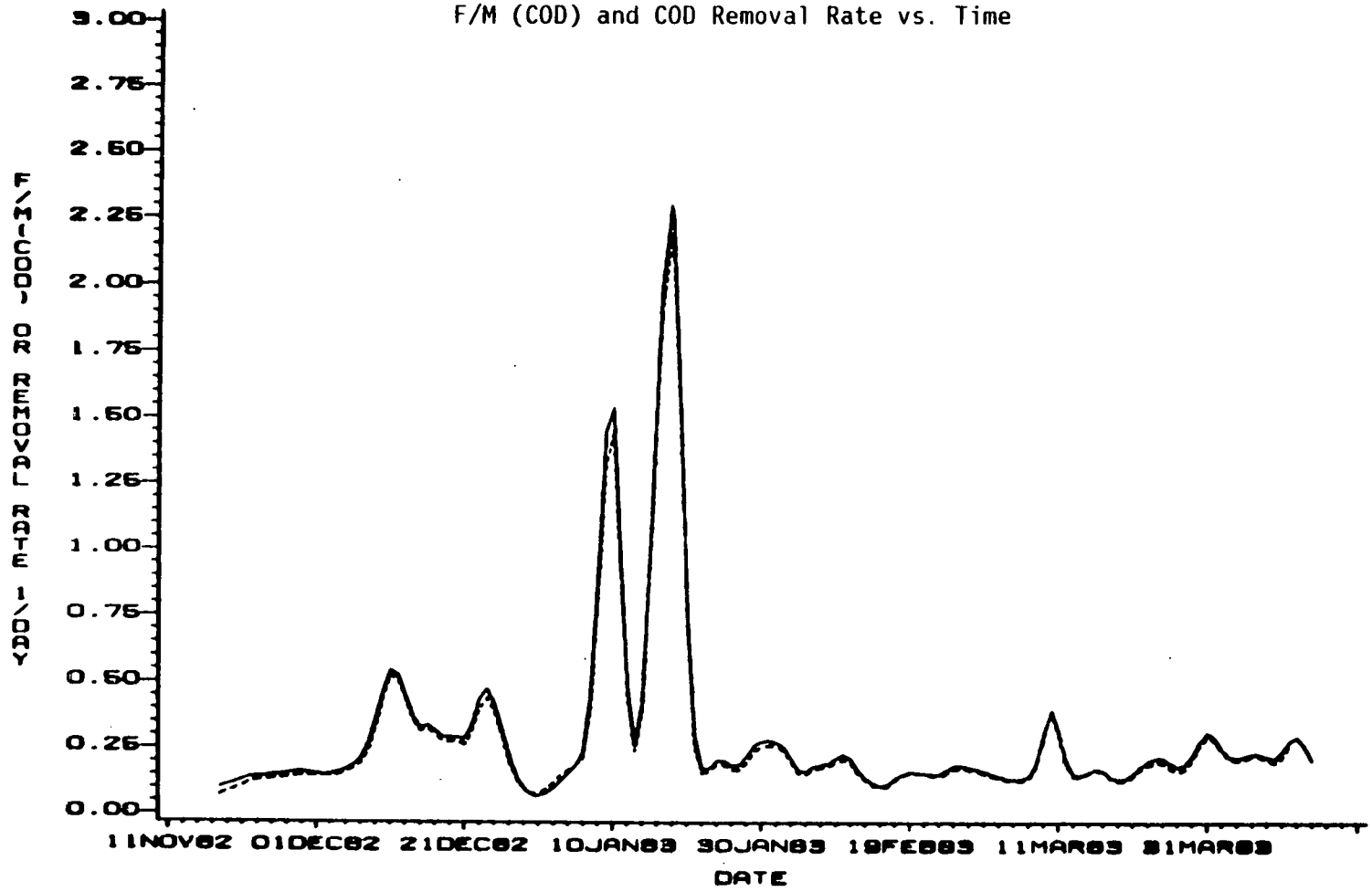


Figure 13

SRC-I Biotreatment Data for Unit 5:
F/M (COD) and COD Removal Rate vs. Time



—F/M (COD) - - -COD Removal Rate

Table 12

Organic Parameters

	PERIOD		DESCRIPTION	SRT	F/M COD	HRT	MLVSS PAC COR	FEED COD MEAN	FEED COD STD DEV	EFF COD MEAN	EFF COD STD DEV	FEED TOC MEAN	FEED TOC STD DEV	EFF TOC MEAN	EFF TOC STD DEV	FEED BOD5 MEAN	FEED BOD5 STD DEV	EFF BOD5 MEAN	EFF BOD5 STD DEV	FEED PHENOL MEAN	FEED PHENOL STD DEV	EFF PHENOL MEAN	EFF PHENOL STD DEV
UNIT1A	DEC15-FEB26		CATALYTIC FEED	29.6	0.18	2.09	4254	2037	345	250	66.7	643	138	80		1118	210.0	9.6	6.1	31.50	15.50	0.20	0.10
UNIT1A	FEB27-MAR19		CHANGE TO CHEMPRO	30.0	0.19	2.02	3732	1830	126	252	69.2	587	45	70		1173	92.0	8.3	3.9	8.60	1.50	0.10	0.10
UNIT1A	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.31	2.05	2377	1975	105	296	80.5	526	52	73						3.50		(0.1	
UNIT1A	MAY24-JUL25	•	CP FEED(NO TA REM)	30.0	0.28	2.03	2653	1957	56	319	40.1	523	74	63						0.50	0.30	(0.025	
UNIT1B	DEC15-FEB26		CATALYTIC FEED	29.6	0.04	2.20	1921	243	69	179	66.4	80	22	58		9	6.0	6.3	2.4	0.40	0.30	0.1	(0.1
UNIT1B	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.04	2.30	1896	246	67	159	58.0	61	3	45		8	3.9	5.9	1.3	0.14	0.05	(0.1	
UNIT1B	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.05	2.12	2276	292	79	210	50.7	73	23	53						(0.1		(0.1	
UNIT1B	MAY24-JUL25	•	CP FEED(NO TA REM)	29.8	0.09	2.08	1348	322	40	221	62.5	64	14	55						(.025		(0.025	
UNIT2A	DEC15-FEB26		CATALYTIC FEED	21.8	0.30	1.08	4828	2038	346	279	84.3	643	130	69		1606	210.0	24.8	10.5	31.53	15.55	0.15	0.05
UNIT2A	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.25	1.06	5469	1891	124	230	38.8	587	45	62		1173	91.8	7.7	4.0	8.55	1.48	0.24	0.05
UNIT2A	MAR20-MAY16	•	CP FEED(NO TA REM)	30.0	0.25	1.06	5705	1995	123	244	41.5	521	54	70		1009	24.1	7.0	1.9	3.50	0.18	(0.1	
UNIT2B	DEC15-FEB26		CATALYTIC FEED	27.1	0.09	1.05	2316	271	81	210	72.2	89	31	43		23	11.6	7.4	2.3	0.42	0.31	0.03	0.01
UNIT2B	FEB27-MAR19		CHANGE TO CHEMPRO	25.9	0.06	1.00	2978	229	48	132	28.5	62	4	39		8	4.0	3.7	0.5	0.24	0.05	0.10	
UNIT2B	MAR20-MAY16	•	CP FEED(NO TA REM)	30.1	0.09	1.02	2077	243	42	170	34.0	78	33	49		7	2.0	3.4	0.5	(0.1		(0.1	
UNIT3	DEC15-FEB25		CATALYTIC FEED	35.8	0.14	2.04	5607	2038	346	224	100.7	643	130	53		1606	209.7	4.6	0.5	31.53	15.54	(0.05	(0.01
UNIT3	FEB26-MAY04	•	CHEMPRO (CP) FEED	35.8	0.27	2.29	2443	1968	115	204	51.9	526	56	43		1173	91.8	9.3	3.9	8.55	1.48	(0.05	(0.01
UNIT3	MAY05-JUN20		CP FEED(PAC REDUCT	35.2	0.25	2.53	2283	1879	78	199	40.8	514	76	42						1.30	0.29	(0.025	
UNIT4A	NOV18-JAN17	•		31.5	0.37	3.87	3315	6209	492	1339	351.0	1560		345		3665	473.0	197.0		1037.00	28.00	4.4	
UNIT4A	FEB18-MAR24		SYSTEM FAILING	25.9	0.50	3.28	2684	5720	269	3894	1123.0	1265	143			3294	192.8			1004.00	47.20		
UNIT4A	MAR25-APR15		PAC ADD-SYS RECOV.	30.8	0.48	3.26	2457	5043	406	4014	1171.0	1275	118	820		3500				1075.00			
UNIT4A	APR16-MAY06		SYS RECOVERED	30.1	0.43	3.88	2320	4941	229	879	269.0	1197	201	324									
UNIT4B	NOV18-JAN17	•		30.5	0.09	3.67	3015	1318	325	648	163	345		230		137		33.0					
UNIT4B	FEB18-MAR24			29.4	0.23	3.29	3790	3740	1263	747.0	99.4												
UNIT4B	MAR25-APR15			31.2	0.20	3.20	5087	5175	1078	624.0	184.0	820	416	213									
UNIT4B	APR16-MAY06			30.0	0.07	3.50	2849	931	301	571	69.5	324	107	193									
UNIT5	DEC15-FEB08			41.4	0.28	3.60	5240	6964	810	540	169.0	2100		177		5400				1486.00		0.10	
UNIT5	FEB09-APR15	•		45.1	0.16	3.52	7415	5469	613	262	101.0	1314	253	103		3492	776.0	9.7	5.4	1019.00	169.00	0.07	0.02

• STEADY STATE

Figure 14

SRC-I Biotreatment Data for System 1:

COD vs. Time

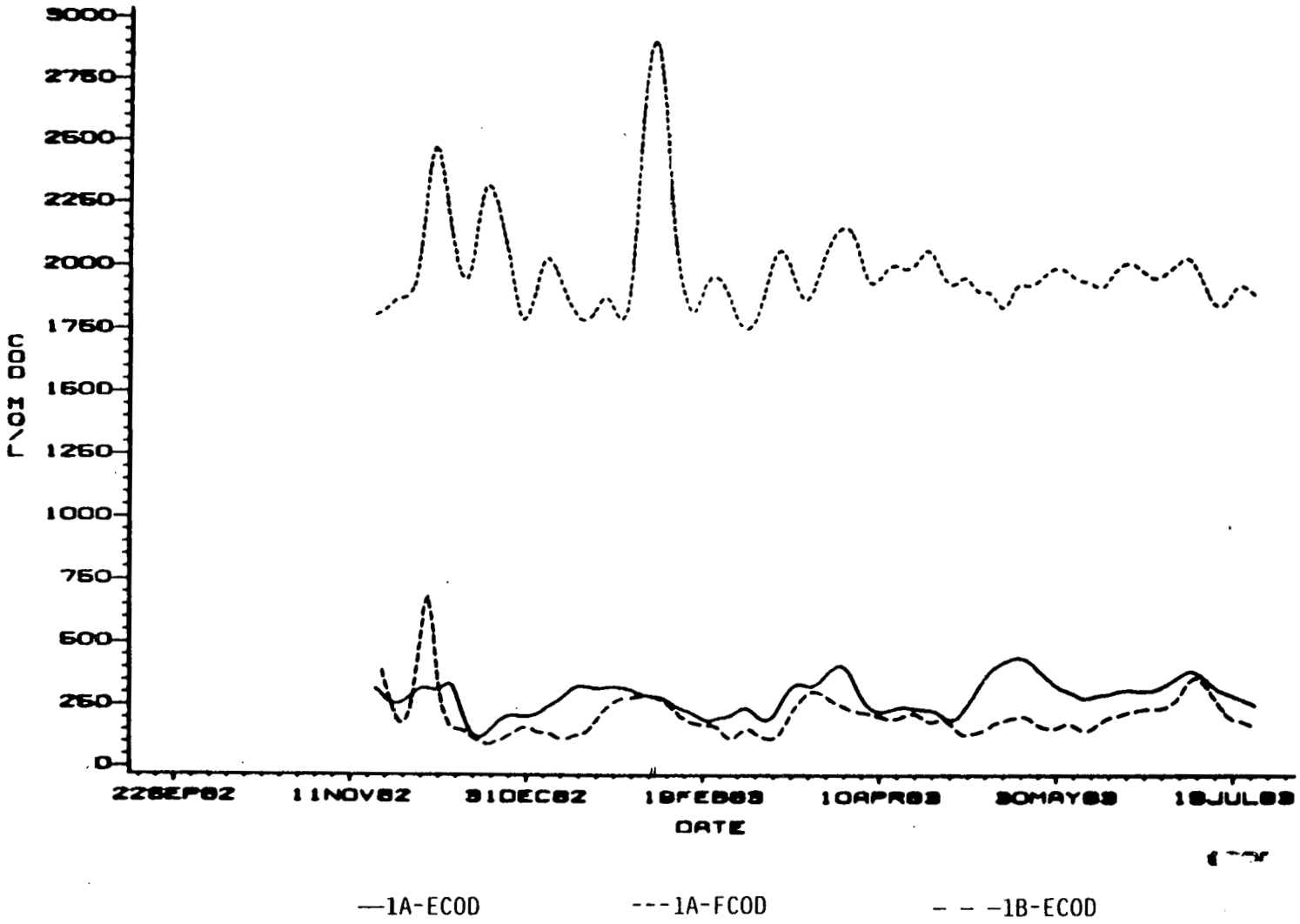


Figure 15

SRC-I Biotreatment Data for System 2:
COD vs. Time

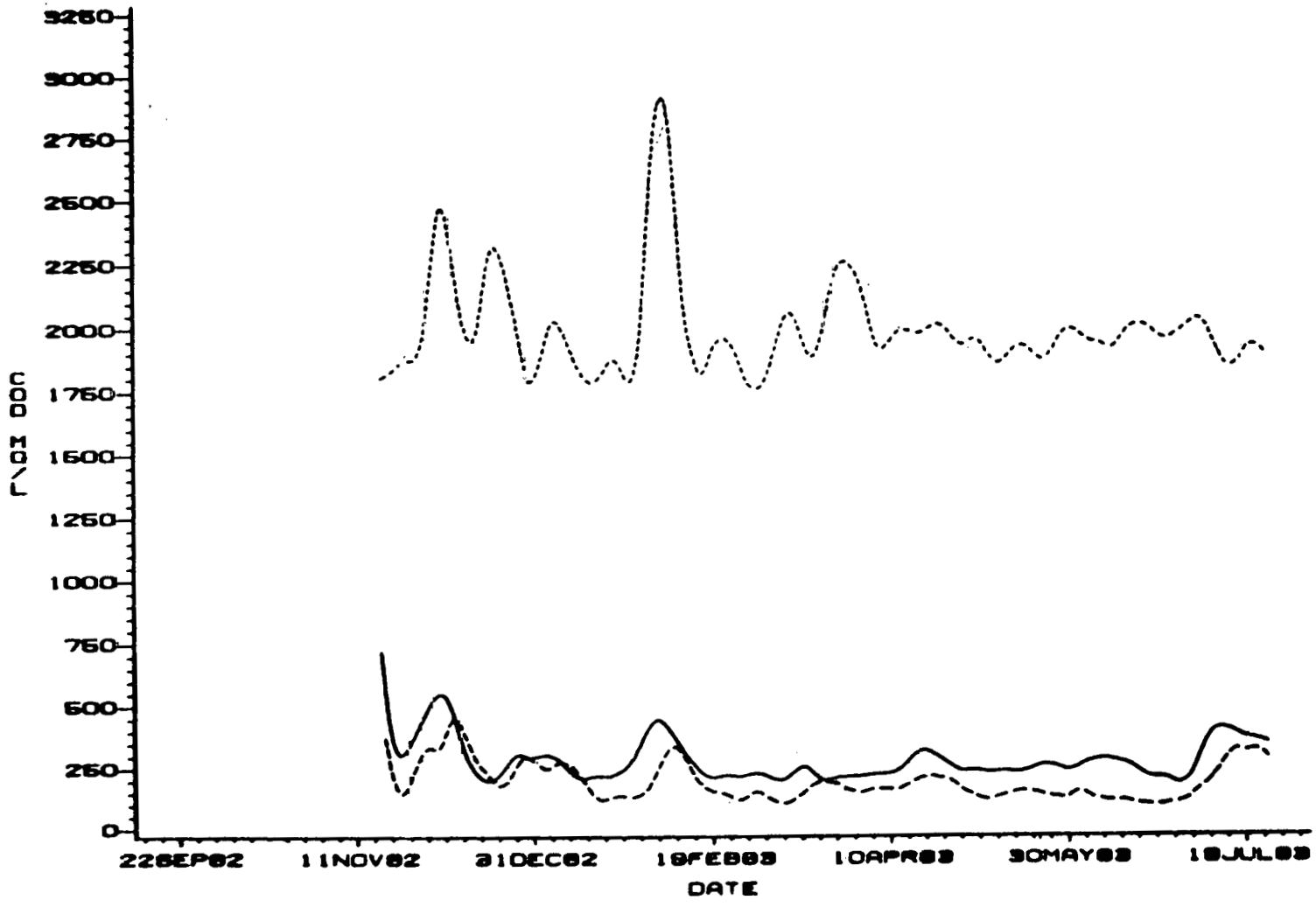
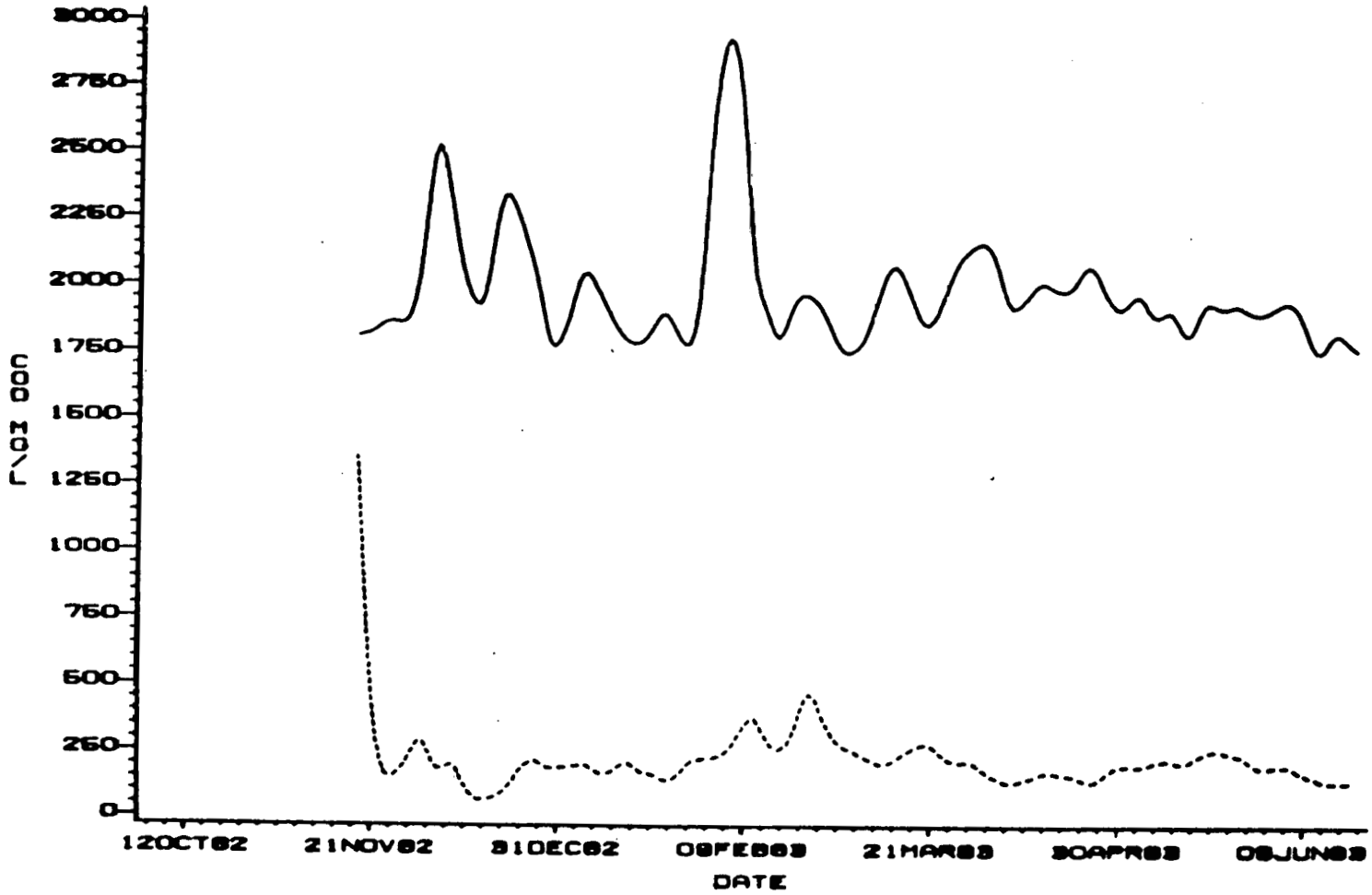


Figure 16

SRC-I Biotreatment Data for System 3:

COD vs. Time



__3-ECOD ---3-FCOD

Figure 17

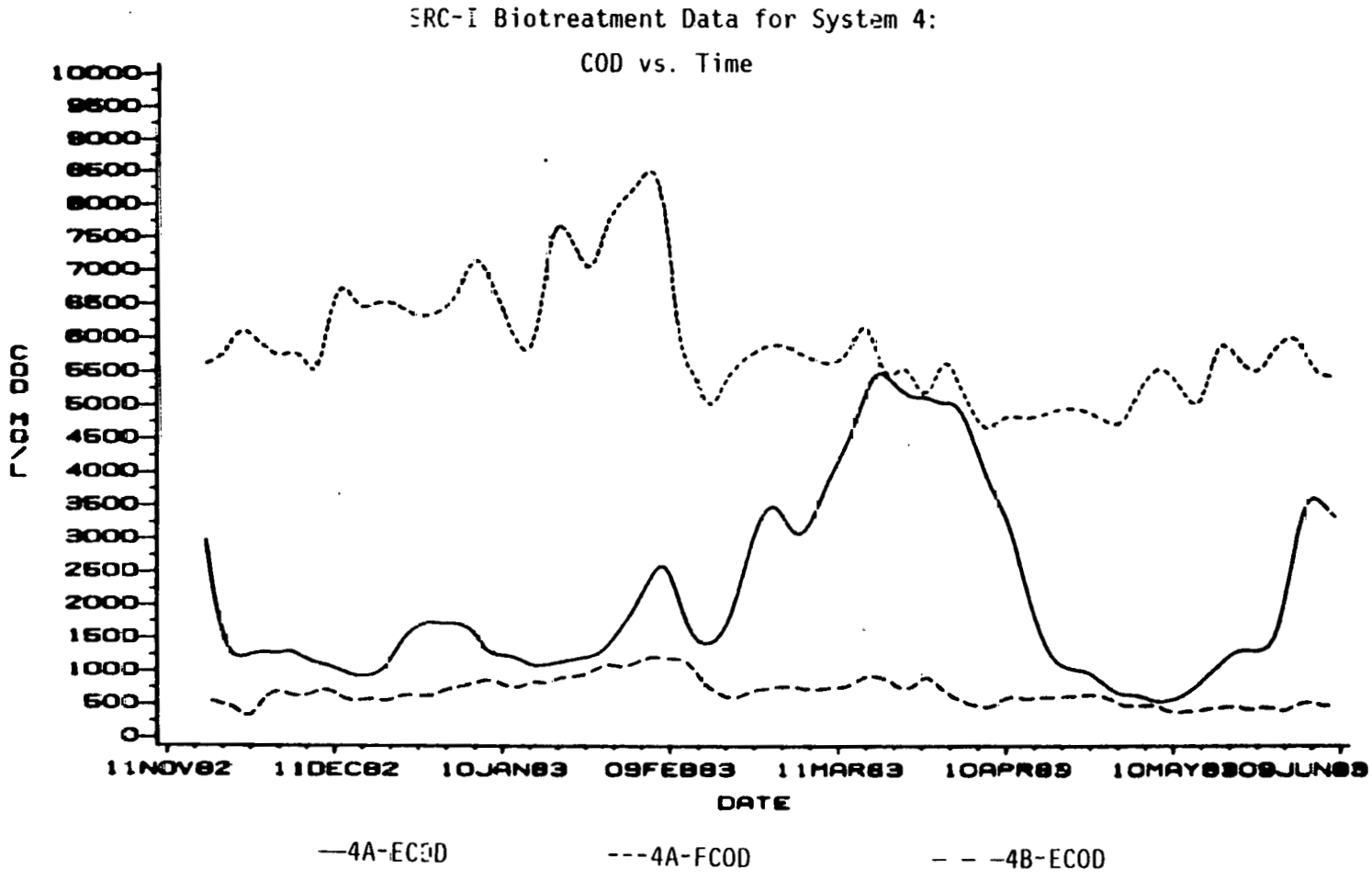
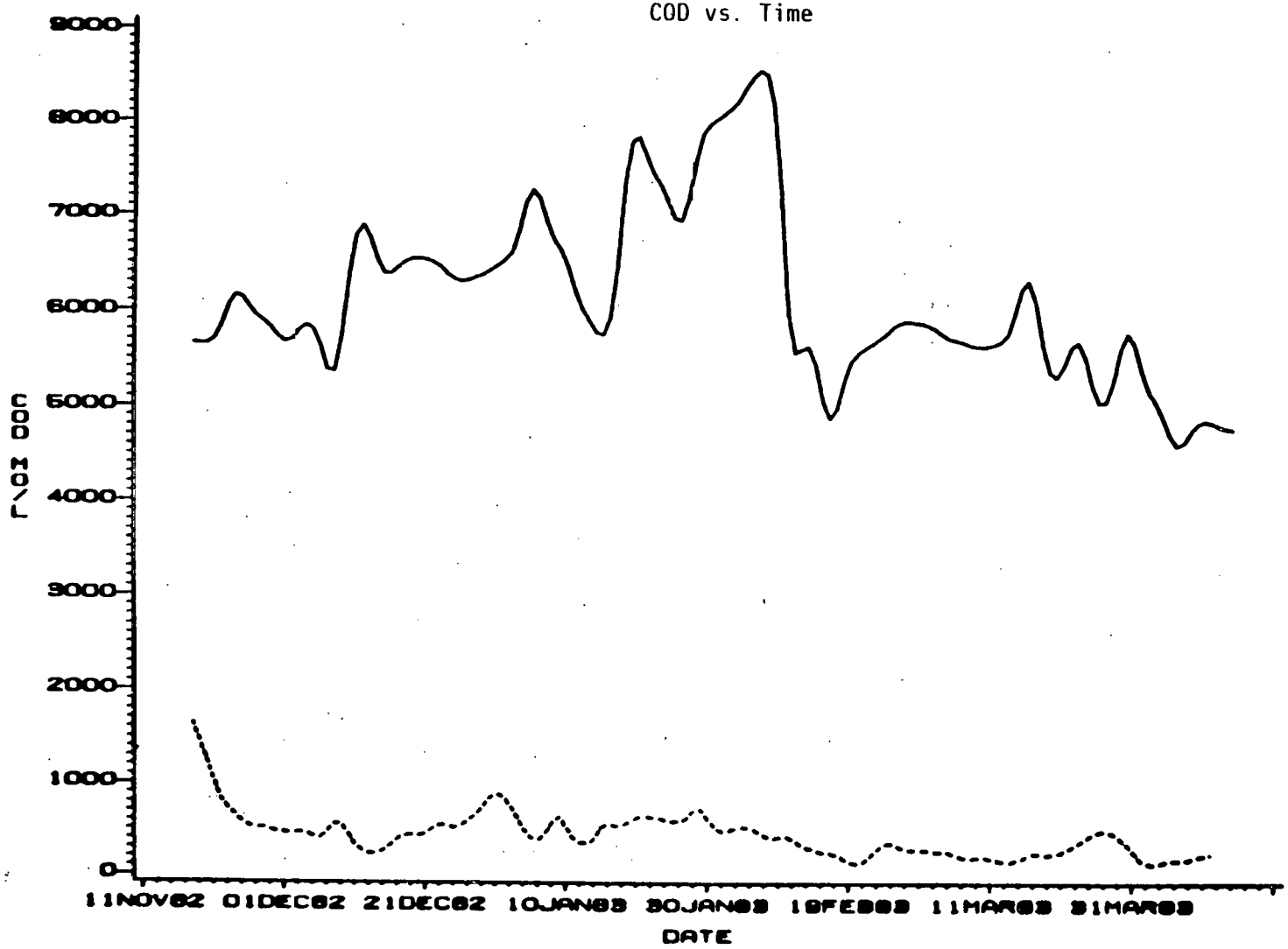

SRC-I Biotreatment Data for System 4:
COD vs. Time
COD MG/L
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
11NOV82
11DEC82
10JAN83
09FEB83
11MAR83
10APR83
10MAY83
09JUN83
DATE
—4A-ECOD
---4A-FCOD
– – –4B-ECOD

Figure 18

SRC-I Biotreatment Data for System 5:
COD vs. Time



of less than 10 mg/L were typical for the DP systems. In contrast, the BOD_5 for the NDP/NPAC system was 33 mg/L, and that for the NDP/PAC system was about 10 mg/L.

The residual TOC concentrations in the effluents of the DP systems were definitely lower than those of the NDP systems. Effluent TOC concentrations of the DP systems ranged from 42 to 58 mg/L throughout all periods of operation, whereas those for the nondephenolated NPAC and PAC units were 230 and 103 mg/L, respectively.

Single-Stage vs. Two-Stage NPAC Systems. For a dephenolated non-PAC (NDP/NPAC) system, a two-stage configuration performed better than a single-stage bioreactor with the same HRT. This can be seen by comparing the effluents from Units 1A and 2B. Unit 1A has a 2-day HRT, as does the combination of Units 2A and 2B. The effluent COD for Unit 1A was 319 ± 40 mg/L (mean ± 1 std. dev.), and that for Unit 2B was 170 ± 34 mg/L.

The need for a second-stage bioreactor in a non-PAC system is also evidenced by comparing the effluent COD for that bioreactor and for the first stage within the same system. For System 1, the effluent COD concentration from the first stage was 319 ± 40 mg/L, while the second-stage effluent was 221 ± 63 mg/L. The reduction of the mean COD concentration in the second-stage bioreactor was 98 mg/L, or about 31%. Similarly, for System 2 the effluent COD values were 244 ± 42 and 170 ± 34 mg/L for Units 2A and 2B, respectively. This is a reduction of 74 mg/L, or 30%.

The same pattern holds for NDP System 4. The effluent from Unit 4A contained 1,339 ± 351 mg/L of COD, which was lowered to 648 ± 163 mg/L in Unit 4B. Thus, the second-stage bioreactor not only reduced the mean COD by 691 mg/L (52%), but also more than halved the standard deviation. These results demonstrate the benefit of the second-stage bioreactors for the NPAC systems, both with or without dephenolation.

The BOD_5 reductions in the second stage were not as obvious. For example, Systems 1B and 2B each lowered the BOD_5 by only 3 mg/L. System 4B was somewhat more effective, reducing the concentration from 197 to 33 mg/L. In all three of these systems, almost all of the apparent BOD_5 reduction took place in the first-stage reactors. Apparent BOD_5 removal in the second stages is so low simply because the BOD is

removed as it is produced. That is, biological activity breaks down organics that are not measured in the BOD test. In this way, organics (COD) are reduced, even though BOD_5 concentrations do not appear to change.

PAC vs. NPAC Systems. Comparing the DP systems shows that the single-stage PAC system produced an effluent of comparable quality to that of the two-stage NPAC systems. The mean effluent COD concentrations for NPAC Systems 1 and 2 were 221 ± 63 and 170 ± 34 mg/L, respectively. The effluent from System 3 (PAC) contained 204 ± 52 mg/L. All three effluents are, therefore, in the same general range. This is also true for TOC and BOD_5 levels. Most of the organic removal in Systems 1 and 2 occurred in the first stages, which lowered the COD concentrations to 319 ± 40 and 244 ± 42 mg/L, respectively. Although the additional removals in the second-stage reactors were not dramatic, they were necessary to produce effluents comparable to the PAC system.

For the NDP systems, the difference between PAC (System 5) and NPAC (System 4) was more pronounced. The mean effluent COD from the second-stage reactor in System 4 was 648 ± 163 mg/L, while the System 5 effluent was only 262 ± 101 mg/L. This is a considerable difference, and clearly indicates PAC to be a superior treatment method for NDP systems.

Ammonia Removal and Nitrification

Ammonia removal and nitrification for the DP systems were slow to occur and difficult to maintain. Steady-state conditions were established for both of the two-stage systems, but not until late in the study. The single-stage PAC treatment (System 3) never achieved consistent nitrification. For the NDP systems, the reverse was true. The two-stage biological system did not achieve steady-state nitrification, while the PAC system did. System 5 was, in fact, the only system that can be termed a successful operation.

Except for System 5, the effluent ammonia concentrations fluctuated widely (and unacceptably) during non-steady-state conditions. Low levels (5 to 10 mg/L) were achieved for Systems 1 and 2 when stable operation could be maintained. However, even during these periods the concentration would intermittently rise to over 25 mg/L. Overall, the

data indicate that biological ammonia removal and nitrification are not dependable processes to achieve the Final Environmental Impact Statement goal of 20 mg/L for NH_3-N (DOE, 1981). Consequently, steam-stripping should continue to be the method of choice for ammonia control. Consistent operation of the stripping process should be recognized as a critical factor; biological systems are not adequate back-ups.

Table 13 summarizes the results for ammonia removal and nitrification for each system. The data are grouped according to time periods corresponding to different feed or operating conditions, and also show the performance of individual reactors. Steady-state periods are noted.

Influent and effluent ammonia concentrations for each system are plotted vs. time in Figures 19-23 and Figures 24-28 show the relation between ammonia applied and removed. As the figures show, the ammonia feed concentrations fluctuated significantly. This occurred even though an exact amount was added during feed preparation aiming at the target concentration of 200 mg/L. Analyses of freshly prepared batches show ranges of 123 to 221 mg/L for DP feeds, and 147 to 215 mg/L for NDP feeds. These concentrations varied further before and during actual use of the feeds, covering a 2-10-day period. However, the magnitude of these variations is not that critical because 200 mg/L does not represent a design condition.

In addition to ammonia levels, Table 13 lists nitrite and nitrate concentrations, which are indicators of the occurrence of nitrification, since they are end products of the process. Their presence can be reduced by subsequent denitrification, but this requires anoxic conditions, which should not occur in the aerobic bioreactors. Overall nitrogen balances for the individual reactors were good, and gave no indication of denitrification.

Some erratic ammonia removal performance can be partially explained by the difficulty in maintaining optimum pH conditions for nitrification. The alkalinity was not sufficient to buffer hydrogen ion produced in the reaction, and the pH occasionally dropped to less than 7. The laboratory apparatus did not permit continuous on-line pH control, which would be a recommendation for plant design.

The second-stage bioreactor of System 1 appeared to be underloaded at times. Unit 1A was operating well, most of the ammonia (and COD) was

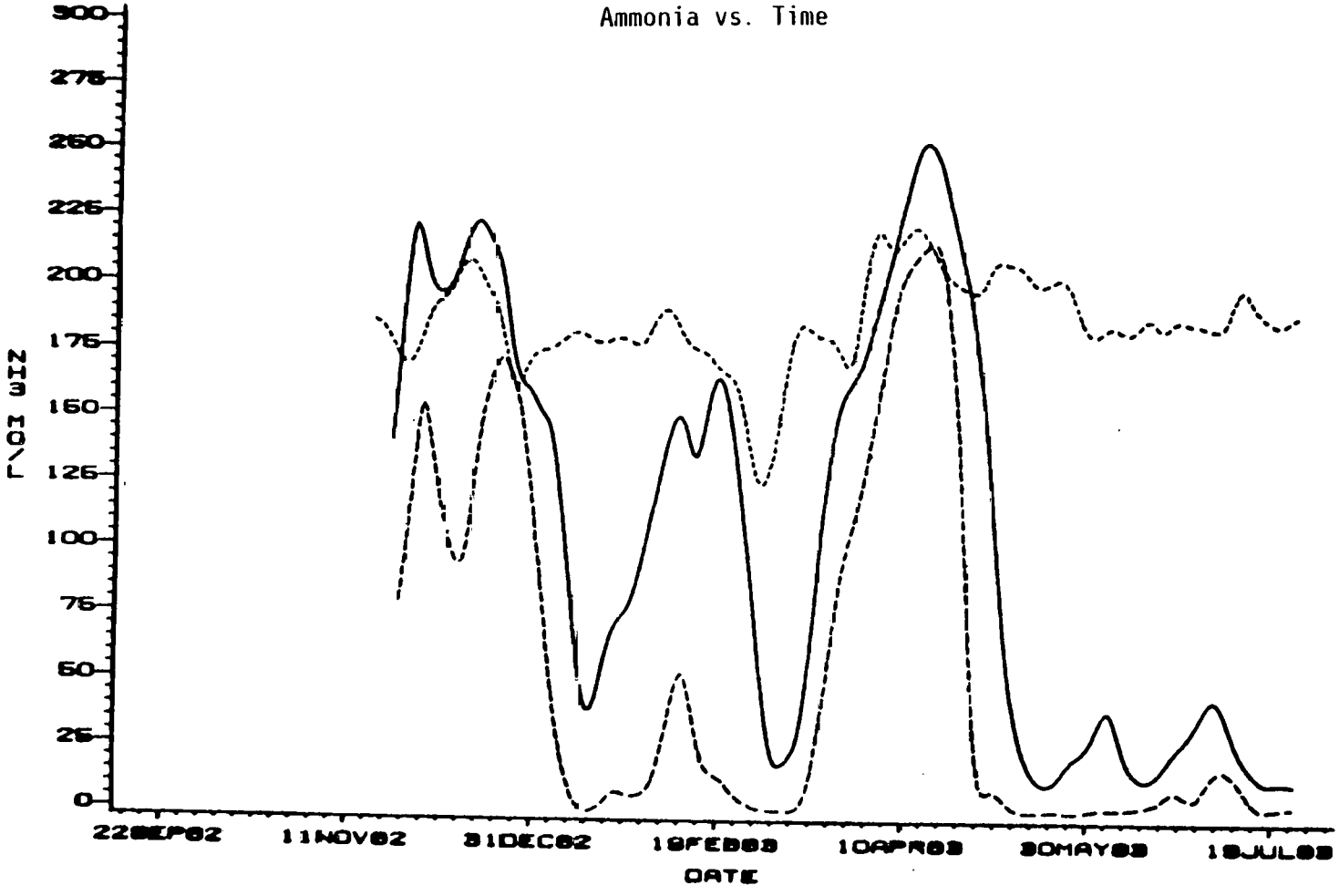
Table 13

Inorganic Nitrogen Parameters

	PERIOD		DESCRIPTION	SRT	F/M COD	HRT	MLVSS-PAC CORR	FEED NH3		EFF NH3		FEED NO2		EFF NO2		FEED NO3		EFF NO3	
								MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
UNIT1A	DEC15-FEB26		CATALYTIC FEED	29.6	0.18	2.09	4254	177	11.6	128.0	53.5			53.4	47.1			16.5	8.0
UNIT1A	FEB27-MAR19		CHANGE TO CHEMPRO	30.0	0.19	2.02	3732	158	26.0	50.0	37.3			53.0	33.6			71.6	30.6
UNIT1A	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.31	2.05	2377	203	15.8	164.0	75.3			36.6	51.3			16.1	20.0
UNIT1A	MAY24-JUL25	•	CP FEED(NO TA REM)	30.0	0.28	2.03	2653	188	6.2	24.0	11.6			114.5	25.7			66.7	34.8
UNIT1B	DEC15-FEB26		CATALYTIC FEED	29.6	0.04	2.20	1921	133	55.1	51.0	60.2	49	51	32.7	40.1	15	9	111.7	45.9
UNIT1B	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.04	2.30	1896	49	34.3	6.6	12.4	53	34	28.0	40.0	72	30	89.6	69.9
UNIT1B	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.05	2.12	2276	166	72.8	107.9	82.5	35	50	40.0	23.9	15	19	65.5	67.9
UNIT1B	MAY24-JUL25	•	CP FEED(NO TA REM)	29.8	0.09	2.08	1348	24	11.6	5.5	5.2	116	26	73.4	89.5	64	34	147.3	38.4
UNIT2A	DEC15-FEB26		CATALYTIC FEED	28.8	0.30	1.08	4828	178	11.6	155.2	57.5			13.1	21.3			4.7	4.5
UNIT2A	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.25	1.06	5469	159	25.2	101.9	32.8			41.2	24.3			12.5	6.6
UNIT2A	MAR20-MAY16	•	CP FEED(NO TA REM)	30.0	0.25	1.06	5705	205	10.9	175.3	12.5			20.7	9.5			13.9	7.9
UNIT2B	DEC15-FEB26		CATALYTIC FEED	27.1	0.09	1.05	2316	162	44.8	78.1	80.6	20	31	14.4	17.9	4	4	96.3	72.7
UNIT2B	FEB27-MAR19		CHANGE TO CHEMPRO	25.9	0.06	1.00	2978	102	32.8	12.1	9.9	41	25	2.3	6.1	12	7	134.4	16.9
UNIT2B	MAR20-MAY16	•	CP FEED(NO TA REM)	30.1	0.09	1.02	2077	175	13.1	27.9	23.5	21	10	5.8	6.0	14	8	170.7	38.7
UNIT3	DEC15-FEB25		CATALYTIC FEED	39.8	0.14	2.04	5607	178	11.6	98.5	55.6			70.8	41.9			30.7	19.1
UNIT3	FEB26-MAY04	•	CHEMPRO (CP) FEED	39.8	0.27	2.29	2443	189	29.0	119.4	47.8			69.4	18.6			39.7	30.1
UNIT3	MAY05-JUN20		CP FEED(PAC REDUCT	39.2	0.25	2.53	2283	196	16.3	49.1	29.1			67.7	35.5			106.3	24.7
UNIT4A	NOV18-JAN17	•		31.5	0.37	3.87	3315	163	16.9	97.7	22.6			0.6	0.5			16.1	30.1
UNIT4A	FEB18-MAR24		SYSTEM FAILING	25.9	0.50	3.28	2684	134	15.6	89.4	35.1							1.7	0.7
UNIT4A	MAR25-APR15		PAC ADD-SYS RECOV.	30.8	0.48	3.26	2457	175	20.0	144.2	11.2			0.7	0.4			3.8	1.6
UNIT4A	APR16-MAY06		SYS RECOVERED	30.1	0.43	3.80	2320	182	14.3	116.5	30.0			1.9	2.3			3.8	3.3
UNIT4B	NOV18-JAN17	•		30.5	0.09	3.67	3015	97	22.4	65.2	22.1	0.4	0.25	1.3	1.1	15.7	29.7	73.4	30.7
UNIT4B	FEB18-MAR24			29.4	0.23	3.29	3790	84	38.6	66.4	13.7			1.3	619	2	1	2.1	1.2
UNIT4B	MAR25-APR15			31.2	0.20	3.20	5087	145	8.8	83.4	13.8	1	(1	10.9	15.2	4	2	20.3	13.1
UNIT4B	APR16-MAY06			30.0	0.07	3.50	2849	114	28.3	38.1	29.0	2	2	54.5	38.6	3	3	56.0	34.1
UNIT5	DEC15-FEB08			41.4	0.28	3.60	5240	162	20.5	31.9	41.1			0.8	0.9			48.8	19.3
UNIT5	FEB09-APR15	•		45.1	0.16	3.52	7415	144	29.8	6.5	5.1			3.7	7.2			70.5	52.6

Figure 19

SRC-I Biotreatment Data for System 1:
Ammonia vs. Time



—1A-ENH_3 ---1A-FNH_3 - - -1B-ENH_3

Figure 20

SRC-I Biotreatment Data for System 2:
Ammonia vs. Time

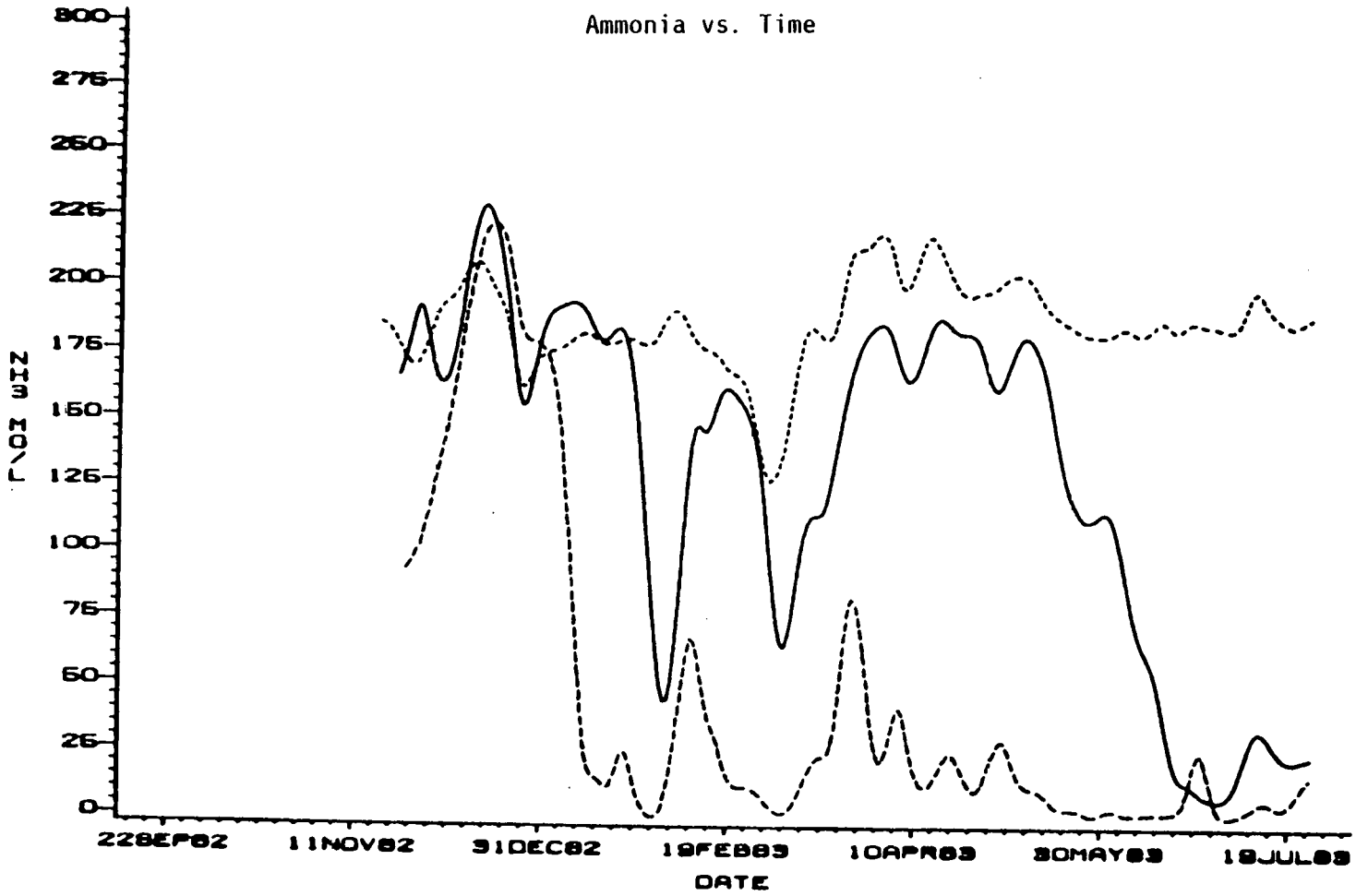
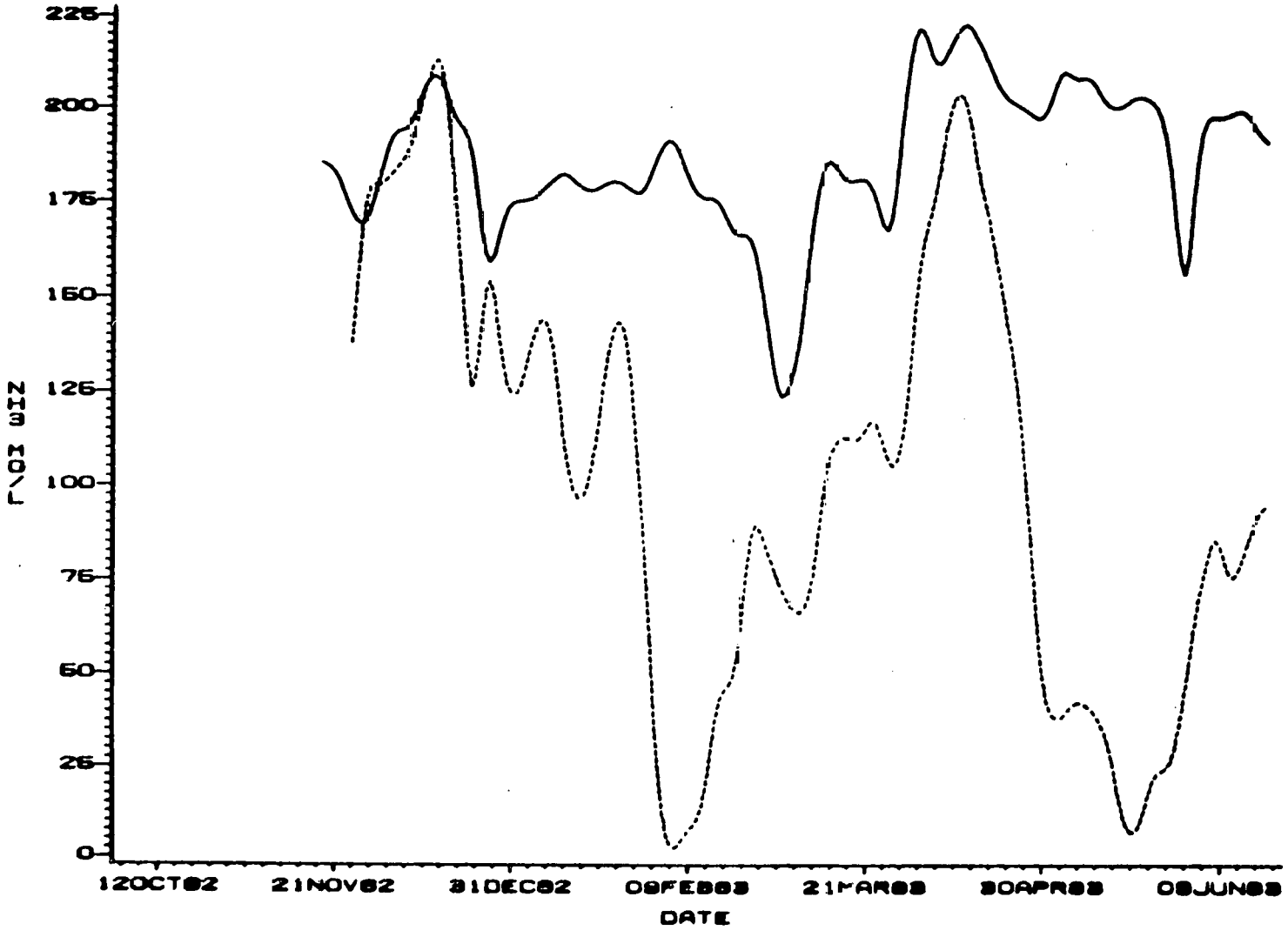


Figure 21

SRC-I Biotreatment Data for System 3:

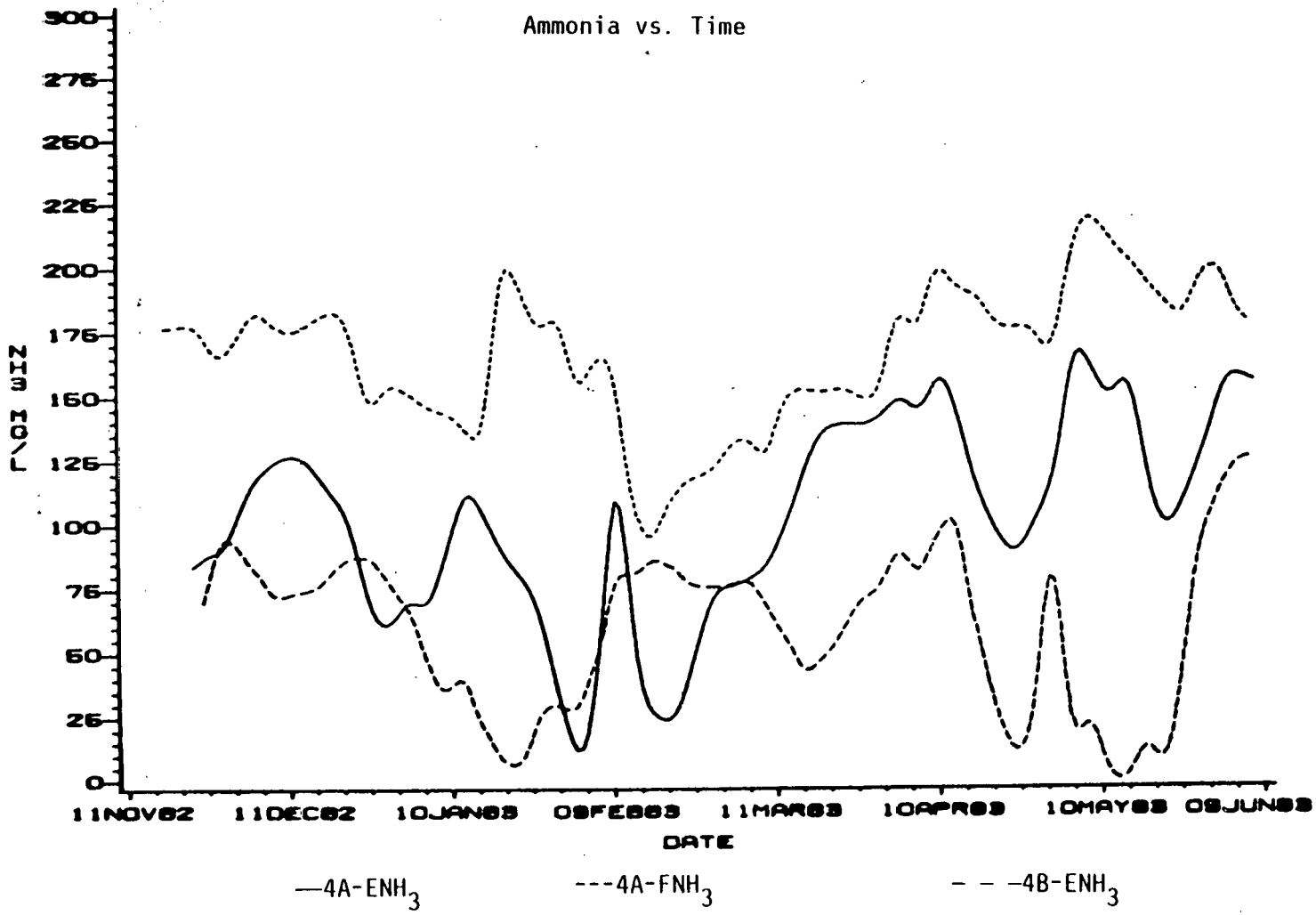
Ammonia vs. Time



—3-ENH$_3$ ---3-FNH$_3$

Figure 22

SRC-I Biotreatment Data for System 4:
Ammonia vs. Time



—4A-ENH_3 ---4A-FNH_3 - - -4B-ENH_3

Figure 23

SRC-I Biotreatment Data for System 5:

Ammonia vs. Time

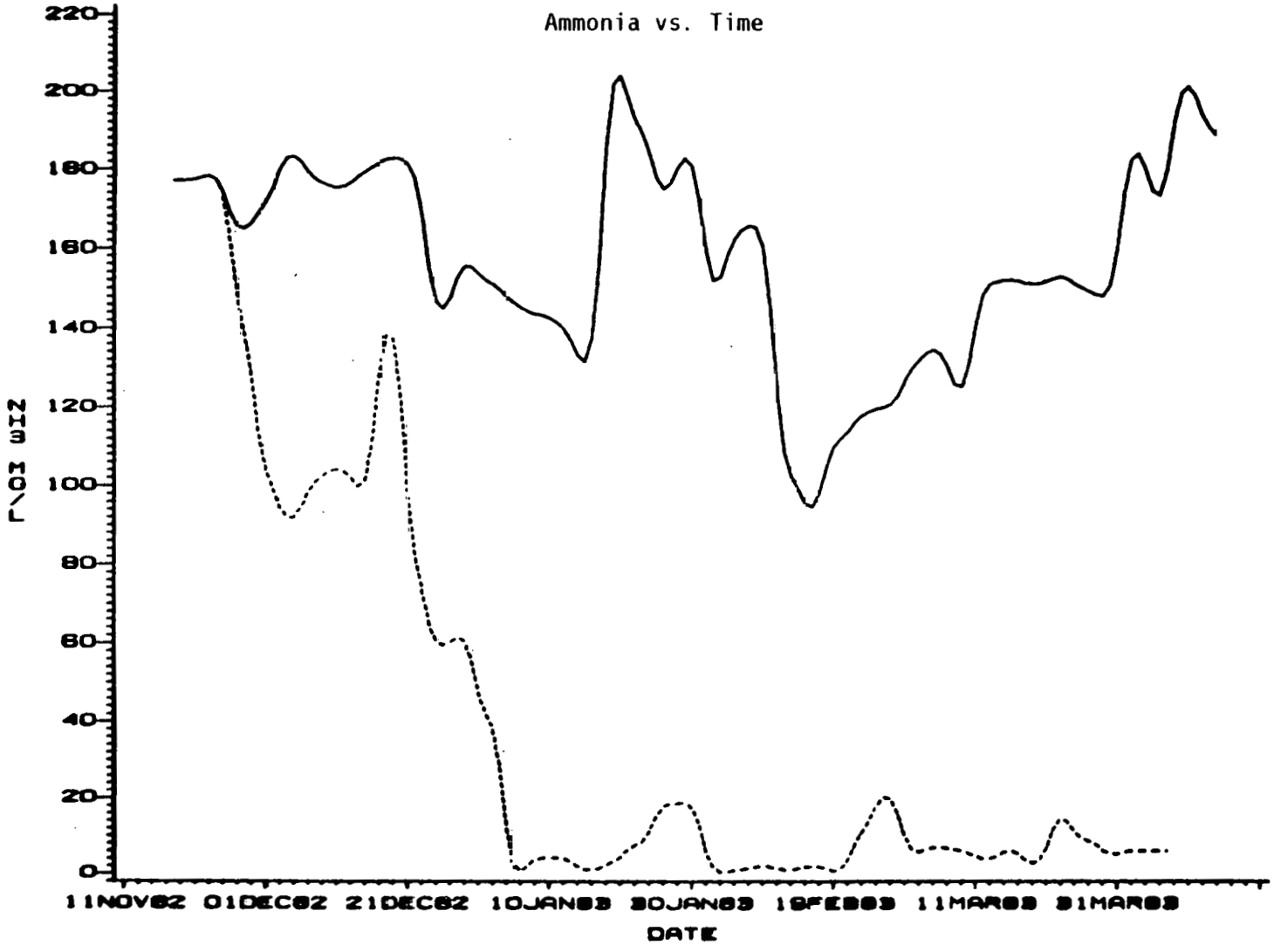
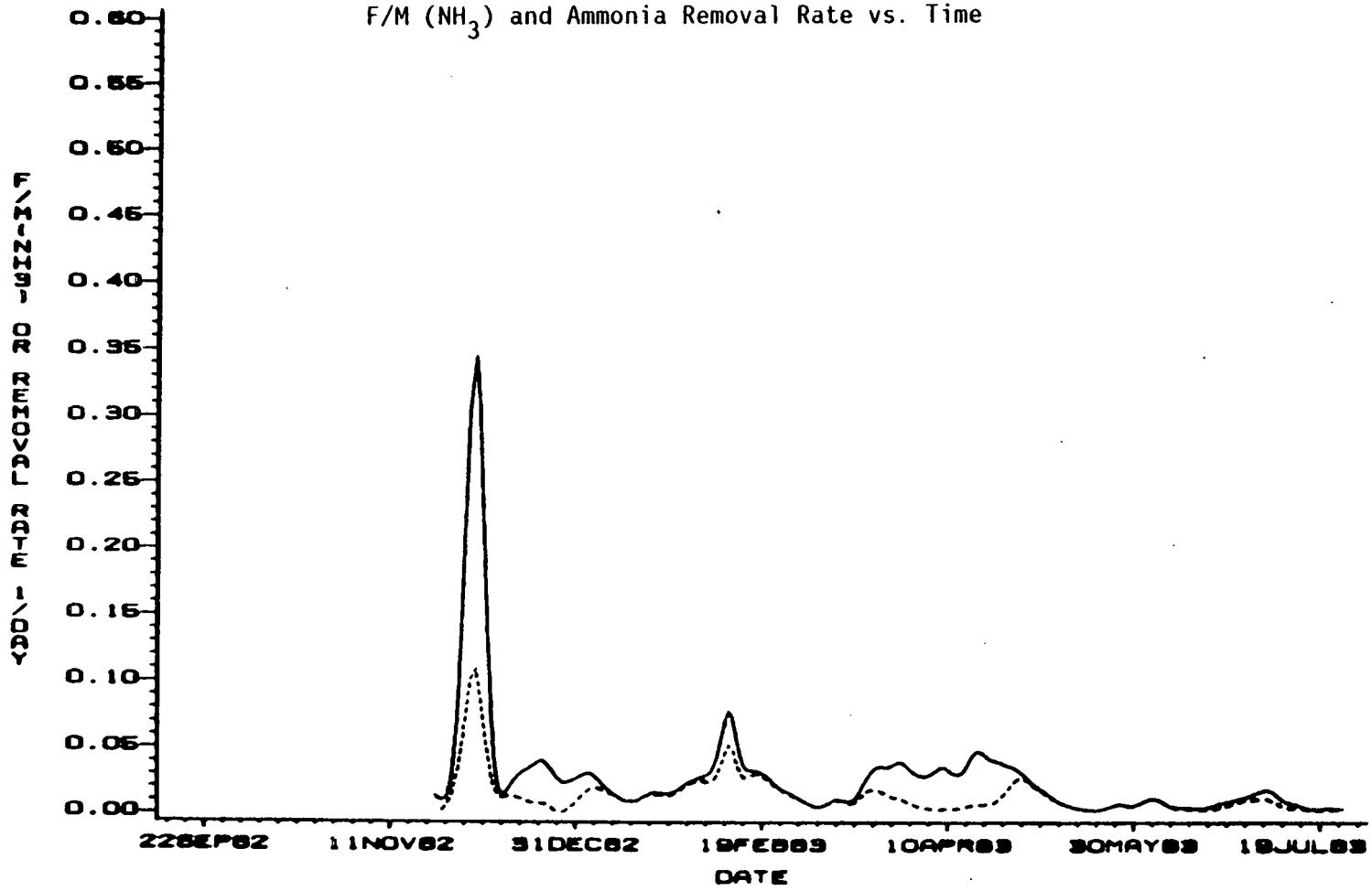


Figure 24

SRC-I Biotreatment Data for Unit 1B:
F/M (NH_3) and Ammonia Removal Rate vs. Time



—F/M (NH_3) ---NH_3 Removal Rate

Figure 25

SRC-I Biotreatment Data for Unit 2B:
F/M (NH_3) and Ammonia Removal Rate vs. Time

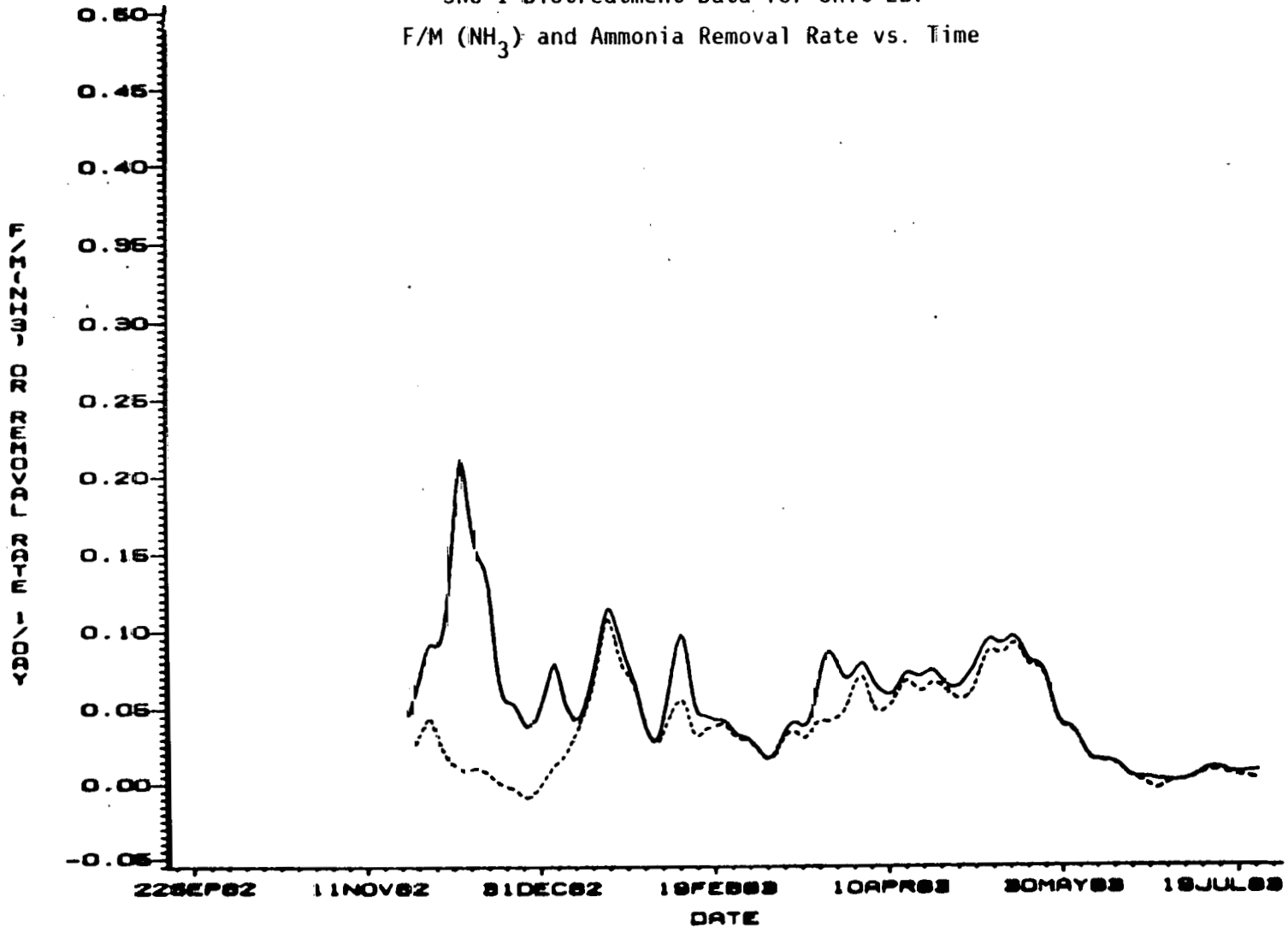
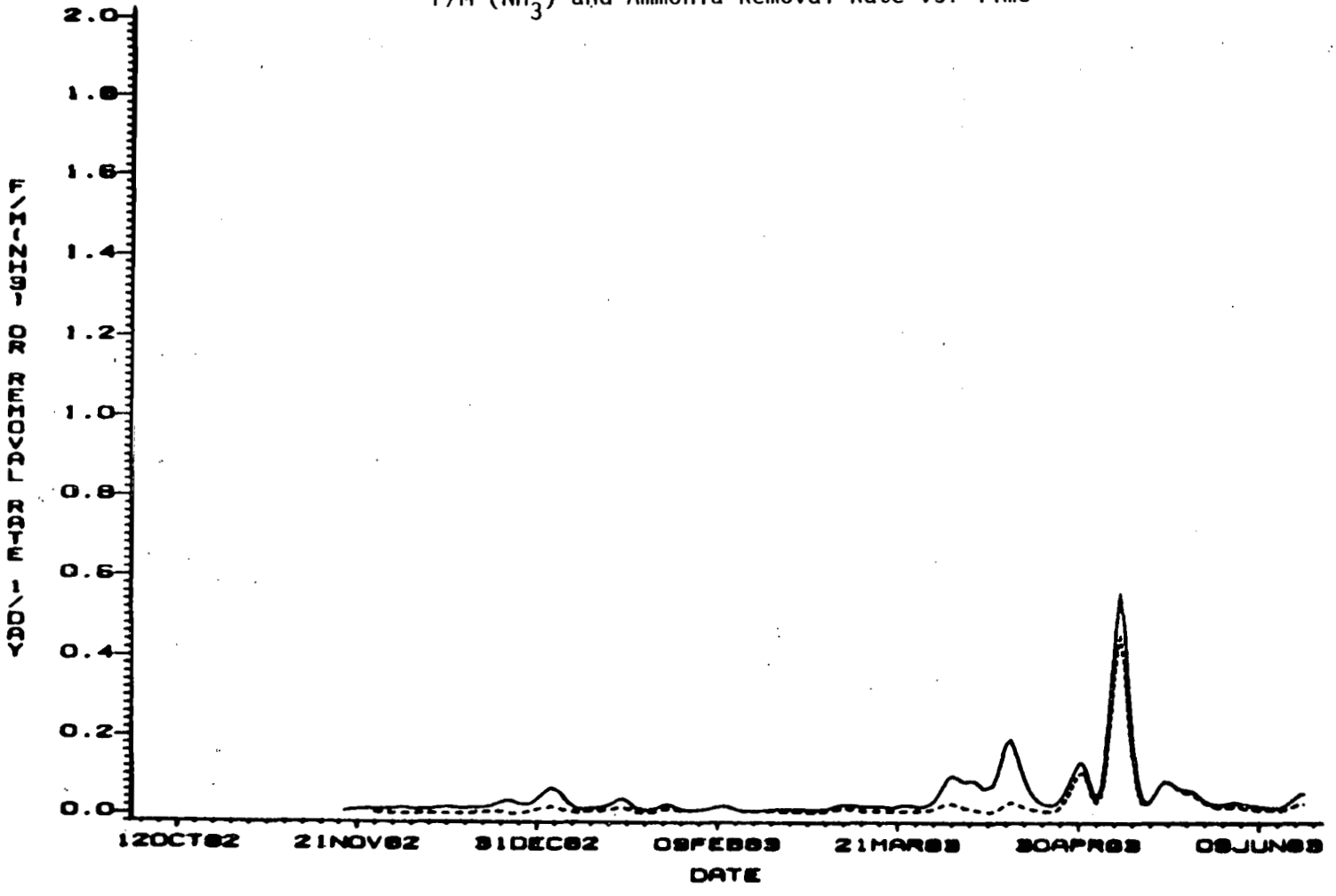


Figure 26

SRC-I Biotreatment Data for Unit 3:
F/M (NH_3) and Ammonia Removal Rate vs. Time



—F/M (NH_3) ---NH_3 Removal Rate

Figure 27

SRC-I Biotreatment Data for Unit 4B:
F/M (NH_3) and Ammonia Removal Rate vs. Time

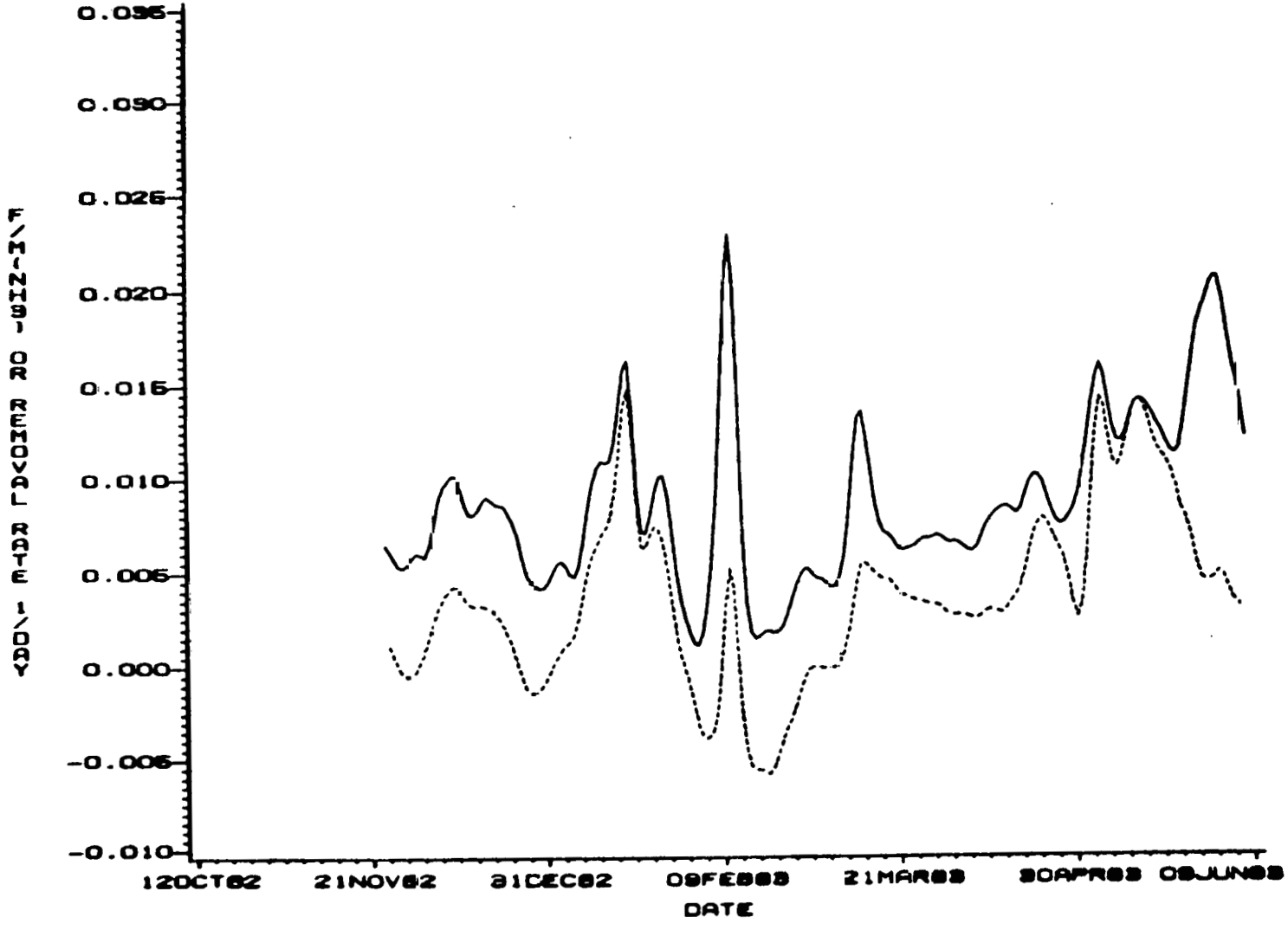
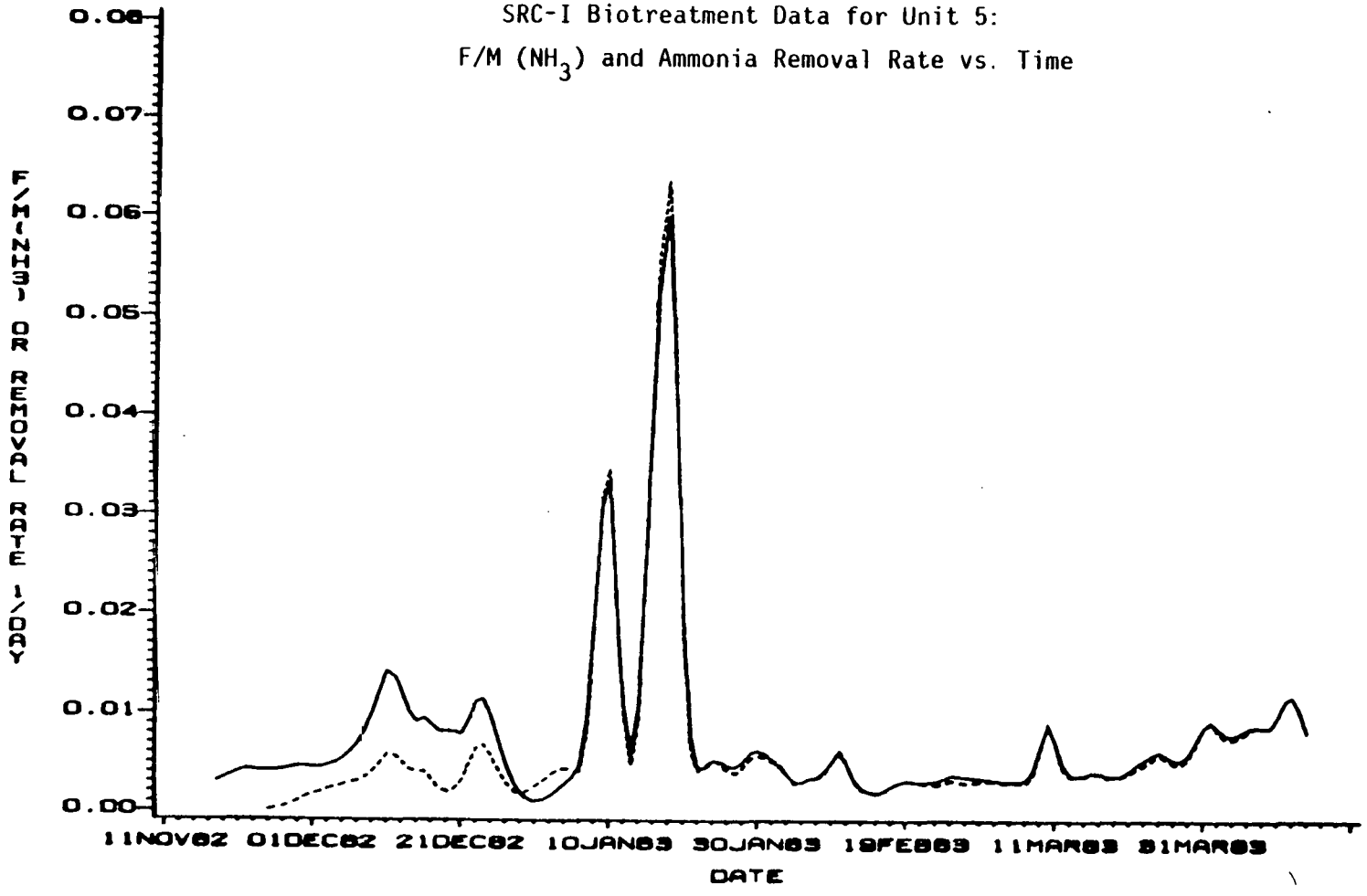


Figure 28

SRC-I Biotreatment Data for Unit 5:
F/M (NH_3) and Ammonia Removal Rate vs. Time



—F/M (NH_3) ---NH_3 Removal Rate

removed in the first stage, and the oxygen uptake rates in Unit 1B dropped below 10 mg/L per hr. The microbial population in Unit 1B at these times would be almost completely in the endogenous mode and have very few viable nitrifiers. At this time, Chem-Pro feed was introduced, which apparently inhibited the nitrification in Unit 1A, and Unit 1B did not have sufficient nitrifiers to respond to the change. By contrast, in System 2 the first-stage effluent ammonia level was greater than 50 mg/L, and the oxygen uptake rates in the second stage were averaging 25-30 mg/L per hr. The system was actively nitrifying and recovered quickly from the feed change, even though ammonia removal was initially affected.

System Comparisons. Without the addition of powdered activated carbon, the DP systems (No.'s 1 and 2) were both superior to the NDP system (No. 4) in terms of nitrification. Although nitrification proved difficult to establish, the DP system attained consistent removal toward the end of the study. In contrast, the NDP/NPAC system (No. 4) never achieved steady nitrification.

Adding carbon to the bioreactors did not increase ammonia removal for the DP systems. In fact, DP System 3 (PAC) could not be brought to steady state. The reverse was true for the NDP systems; System 5 (NDP/PAC) performed the best of all systems tested. This improvement in performance is in good agreement with an earlier study (ICRC, 1983a). The reason for the increased efficiency is not certain, but the high PAC concentration (about 10,000 mg/L) probably played a role.

Data for the two-stage bioreactors (Systems 1, 2, and 4) show that the second-stage reactors improved ammonia removal substantially. In System 1, the mean ammonia effluent concentration was 24 mg/L from Unit 1A, and only 6 mg/L from Unit 1B. This represents a 75% reduction through the second-stage reactor. System 2 exhibited a similar pattern (175 mg/L reduced to 28 mg/L, or an 83% efficiency). Even System 4 showed a definite reduction, although removal was not consistent.

As noted previously, biological treatment cannot be expected to provide adequate (20 mg/L) effluent ammonia concentrations without prior treatment by steam-stripping. The biological systems did, however, clearly demonstrate that ammonia removal will occur in the second stage.

Therefore, two-stage systems are essential to achieve the lowest effluent concentrations.

Color Removal

Both the SRC-I wastewater and Ft. Lewis PRW have high color intensities. Typical color values for the DP feeds (after pretreatment and dilution) were in the range of 7,200 ± 3,500 APHA units for the Catalytic-prepared feeds, and 1,200 ± 120 for the Chem-Pro-prepared feeds. The NPD feeds averaged 6,000 APHA units.

Table 14 summarizes the color data for all treatment systems, as well as individual bioreactors. The discussions below compare the effectiveness of the various systems. Note that color data were limited and highly variable, and were influenced by changes in pH.

Dephenolated vs. Nondephenolated. The DP systems (No.'s 1 and 2) without PAC yielded an average residual color concentration of about 1,600 and 900 units for Catalytic- and Chem-Pro-pretreated wastewater, respectively. Without PAC, the NDP system (No. 4) did not appreciably reduce color. Even with PAC, the NDP system (No. 5) residual color was in the range of 2,000 to 3,000 units. Clearly, the DP systems were superior to the NDP systems.

PAC vs. Non-PAC. With PAC, the DP system (No. 3) on Chem-Pro feed produced an effluent with residual color of about 400 units, about half that of the DP/NPAC systems (No.'s 1 and 2). This same ratio is noted for the darker Catalytic feed. Comparison of the NDP systems shows that, again, the system is superior to the non-PAC system (No. 5 vs. No. 4). The residual color for the PAC system was 2,000-3,000 units, much lower than the 5,000 units for the non-PAC system.

The fact that the DP/PAC system (No. 3) produced an effluent with lower color than the DP/NPAC systems (No.'s 1 and 2) does not necessarily justify the use of PAC. The residual color in a bioreactor effluent can be removed by granular activated carbon (GAC) adsorption downstream.

Single Stage vs. Two Stage. The effluents from the first- and second-stage bioreactors differed very litte in color. pH adjustments probably affected apparent color more than the number of stages.

Table 14

Miscellaneous Parameters

	PERIOD	DESCRIPTION	SRT	F/M COD	HRT	MLVSS-PAC CORR	FEED COLOR		EFF COLOR		EFF POA		EFF TDS		EFF SS	
							MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
UNIT1A	DEC15-FEB26	CATALYTIC FEED	29.6	0.18	2.09	4254	7200		3460	818	2.1	1.3	4599	18	165	297
UNIT1A	FEB27-MAR19	CHANGE TO CHEMPRO	30.0	0.19	2.02	3732	1175	121	1000		3.9	2.7	3420		140	74
UNIT1A	MAR20-MAY16	CHEMPRO(CP) FEED	30.0	0.31	2.05	2377	1000		607	228	6.4	3.7	3740		73	42
UNIT1A	MAY24-JUL25 *	CP FEED(NO TA REM)	30.0	0.28	2.03	2653			589	221	3.7	3.1			78	67
UNIT1B	DEC15-FEB26	CATALYTIC FEED	29.6	0.04	2.20	1921	3146	1299	1425	578	1.8	1.2	5040	337	164	113
UNIT1B	FEB27-MAR19	CHANGE TO CHEMPRO	30.1	0.04	2.30	1896	1000		1000		3.3	2.2	3650		127	132
UNIT1B	MAR20-MAY16	CHEMPRO(CP) FEED	30.0	0.05	2.12	2276	614	224	832	378	5.8	2.3	4850		104	59
UNIT1B	MAY24-JUL25 *	CP FEED(NO TA REM)	29.8	0.09	2.08	1348	591	219	964	414	3.1	2.9			113	65
UNIT2A	DEC15-FEB26	CATALYTIC FEED	28.8	0.30	1.08	4828	7200		1516	2484	23.2	45.3	4590		374	598
UNIT2A	FEB27-MAR19	CHANGE TO CHEMPRO	30.1	0.25	1.06	5469	1175	121	1000		5.4	5.6	2610		127	143
UNIT2A	MAR20-MAY16 *	CP FEED(NO TA REM)	30.0	0.25	1.06	5705	1500		1096	206	2.6	1.6	4175	150	100	64
UNIT2B	DEC15-FEB26	CATALYTIC FEED	27.1	0.09	1.05	2316	3823	1174	1800	638	2.4	2.1	4627	498	244	162
UNIT2B	FEB27-MAR19	CHANGE TO CHEMPRO	25.9	0.06	1.00	2978	1000		914	107	3.5	2.5	3230		175	122
UNIT2B	MAR20-MAY16 *	CP FEED(NO TA REM)	30.1	0.09	1.02	2077	1092	206	893	228	5.8	4.9	5224	5	81	35
UNIT3	DEC15-FEB25	CATALYTIC FEED	39.8	0.14	2.04	5607	7200		870	461	1.9	1.9	5001	311	362	549
UNIT3	FEB26-MAY04 *	CHEMPRO (CP) FEED	39.8	0.27	2.29	2443	1175	121	347	311	6.4	2.2	2860		164	197
UNIT3	MAY05-JUN20	CP FEED(PAC REDUCT)	39.2	0.25	2.53	2283	1000		421	182	3.6	3.5			131	72
UNIT4A	NOV18-JAN17 *		31.5	0.37	3.87	3315							10663	354	699	742
UNIT4A	FEB18-MAR24	SYSTEM FAILING	25.9	0.50	3.28	2684							4312		836	397
UNIT4A	MAR25-APR15	PAC ADD-SYS RECOV.	30.8	0.48	3.26	2457	6000		6000		1.3	1.1	4040		360	486
UNIT4A	APR16-MAY06	SYS RECOVERED	30.1	0.43	3.80	2320	6000		5238	374					150	121
UNIT4B	NOV18-JAN17 *		30.5	0.09	3.67	3015							11484	141	582	395
UNIT4B	FEB18-MAR24		29.4	0.23	3.29	3790									444	492
UNIT4B	MAR25-APR15		31.2	0.20	3.20	5087			5000	907	3.8	0.8			385	352
UNIT4B	APR16-MAY06		30.0	0.07	3.50	2849	5261	406	5095	201	4.9	1.2			137	83
UNIT5	DEC15-FEB08		41.4	0.28	3.60	5240			3000		45.2	33.4	12881	1736	1657	1599
UNIT5	FEB09-APR15 *		45.1	0.16	3.52	7415	6000		2015	402	5.6	2.8	6516	1447	1065	826

* STEADY STATE

Residual Phenolic Concentration

Phenolics are contaminants of concern because the ambient concentrations in the Green River sometimes violate water quality standards. The bioreactors removed the phenolics to a low level. Table 15 shows the average data for the entire study period. (Table 12 also presented these data, but by individual time period.) Most of the phenolic analyses carried out in this study were for the DP systems. Therefore, data obtained from a previous study of NDP systems are also listed in Table 15 for comparison.

The data indicate that biological treatment systems receiving dephenolated wastewater produced effluent (from the last-stage bioreactor) phenolic concentrations of less than 100 µg/L, over all time periods. For steady-state conditions, phenolics were reduced to less than 25 µg/L (see Table 12). There was little difference between the PAC and NPAC systems. The NDP systems also remove phenolics effectively. As will be discussed in the Tertiary Treatment Section, the low residual phenolics will be reduced even further by granular activated carbon.

CN/SCN

Because the Ft. Lewis PRW had significantly lower CN and SCN concentrations than the conservatively targeted values for the feed to the biological systems in this study (10 and 200 mg/L, respectively), the feeds were spiked with NaCN and NaSCN. Chemical analyses showed that the SCN concentrations were generally on target after spiking, but the CN concentrations were not, even when two or three times the calculated concentrations were added. Typical concentrations of CN observed in the feeds were less than 3 mg/L for the DP systems and fluctuated between 0.6 and 12.2 mg/L for the NDP systems. It has been hypothesized that CN reacted with components in the feed or that it was converted to other species.

Table 16 presents the CN and SCN data. Based on the data, no discernible differences existed between the influent and effluent CN concentrations, and thus no definitive conclusions can be drawn. However, measurable effluent CN^- concentrations were generally less than 2 mg/L for all systems.

Table 15

Residual Phenolic Concentrations (All Periods)

Systems (bioreactors)	SRT (days)	HRT (days)	Feed phenolics (mg/L)	Effluent phenolics (µg/L)
This study				
DP/NPAC (1A)	30	2	12.7	<112
(1B)	30	2	--	<78
DP/NPAC (2A)	30	1	17.8	<144
(2B)	30	1	--	<66
DP/PAC (3)	40	2	15.8	<44
NDP/NPAC (4A)	30	3	1,034	28,050
(4B)	30	3	--	<50
NDP/PAC (5)	45	3.5	1,233	84
Previous study[a]				
NDP/NPAC (1st stage)	23	4.55	896 ± 116	103 ± 35
	18	3.05	1,137 ± 38	64 ± 63
(2nd stage)	30	6.26	114 ± 133	110 ± 30
	18.1	5.5	149 ± 18	68 ± 10
	20	4.6	108	42
	27.5	4.22	151 ± 10	17
NDP/PAC (single stage)	32	4.75	850 ± 99	25 ± 26
	40	4.5	798 ± 50	72 ± 1.4
	52	4.45	944 ± 113	39 ± 33

[a]ICRC (1983a).

Table 16

Organic Nitrogen Parameters

	PERIOD		DESCRIPTION	SRT	F/M COD	HRT	MLVSS-PAC CORR	FEED ORG-N		EFF ORG-N		FEED CN		EFF CN		FEED SCN		EFF SCN	
								MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
UNIT1A	DEC15-FEB26		CATALYTIC FEED	29.6	0.18	2.09	4254	80.7	9.9	15.9	4.5	1.05	2.01	1.34		204	31	4.1	1.4
UNIT1A	FEB27-MAR19		CHANGE TO CHEMPRO	30.0	0.19	2.02	3732	107.2	26.4	69.7	1.6	2.71	1.94	1.75	0.67	190	8	3.7	1.2
UNIT1A	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.31	2.05	2377					1.72	2.19	0.79	0.53	193	10	32.0	47.1
UNIT1A	MAY24-JUL25	*	CP FEED(NO TA REM)	30.0	0.28	2.03	2653			15.9	5.3	0.33	0.16	2.20	0.48	176	3	5.7	0.9
UNIT1B	DEC15-FEB26		CATALYTIC FEED	29.6	0.04	2.20	1921	14.0	2.3	16.5	2.7	1.29	0.89	1.10	0.40	4	1	2.1	1.0
UNIT1B	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.04	2.30	1896	70.0	1.6	42.7	27.8	1.72	0.68	1.80	0.45	4	1	2.1	0.2
UNIT1B	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.05	2.12	2276					0.80	0.55	1.01	0.34	31	47	3.1	0.8
UNIT1B	MAY24-JUL25	*	CP FEED(NO TA REM)	29.8	0.09	2.08	1348	16.2	5.2	8.4	2.8	2.21	0.49	1.75	0.45	6	1	4.2	0.9
UNIT2A	DEC15-FEB26		CATALYTIC FEED	28.8	0.30	1.08	4828	80.7	9.9	10.5	8.4	2.26	3.81	1.13		208	29	4.2	2.3
UNIT2A	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.25	1.06	5469	107.2	26.4	16.9	4.8	2.71	1.94	1.46	0.56	190	8	3.8	1.4
UNIT2A	MAR20-MAY16	*	CP FEED(NO TA REM)	30.0	0.25	1.06	5705	59.7	5.3	10.3		0.57	1.27	1.12	0.49	197	9	5.5	1.8
UNIT2B	DEC15-FEB26		CATALYTIC FEED	27.1	0.09	1.05	2316	18.0	10.5	16.9	7.5	1.13	1.18	1.05	0.43	4	4	2.4	0.7
UNIT2B	FEB27-MAR19		CHANGE TO CHEMPRO	25.9	0.06	1.00	2978	13.0		11.0	27.3	1.40	0.58	0.76	0.42	4	1	2.2	0.2
UNIT2B	MAR20-MAY16	*	CP FEED(NO TA REM)	30.1	0.09	1.02	2077	10.3		(1		1.13	0.49	1.03	0.41	6	2	4.6	1.2
UNIT3	DEC15-FEB25		CATALYTIC FEED	39.8	0.14	2.04	5687	80.7	9.9	18.7	10.4	1.98	3.16	1.30		216	20	1.8	0.9
UNIT3	FEB26-MAY04	*	CHEMPRO (CP) FEED	39.8	0.27	2.29	2443	107.2	26.4	44.6	30.5	2.42	2.31	0.60	0.40	191	10	2.2	0.5
UNIT3	MAY05-JUN20		CP FEED(PAC REDUCT)	39.2	0.25	2.53	2283					0.52	0.26	1.16	0.57	181	14	2.9	0.4
UNIT4A	NOV18-JAN17	*		31.5	0.37	3.87	3315					0.79	0.44	1.04	0.52	166	11	44.3	29.8
UNIT4A	FEB18-MAR24		SYSTEM FAILING	25.9	0.50	3.28	2684	69.7	1.6			11.31	12.51	1.50		146	20	143.0	11.0
UNIT4A	MAR25-APR15		PAC ADD-SYS RECOV.	30.8	0.48	3.26	2457					9.03	6.06	1.16	0.36	155	23	144.2	19.9
UNIT4A	APR16-MAY06		SYS RECOVERED	30.1	0.43	3.00	2320					2.98	1.00	0.50	0.21	181	10	112.0	
UNIT4B	NOV18-JAN17	*		30.5	0.09	3.67	3015					0.80	0.50	0.75	0.38	42	32	6.3	1.5
UNIT4B	FEB18-MAR24			29.4	0.23	3.29	3790					1.50		1.20		139	17	23.4	6.4
UNIT4B	MAR25-APR15			31.2	0.20	3.20	5087					1.19	0.36	1.36	0.87	142	19	8.8	3.1
UNIT4B	APR16-MAY06			30.0	0.07	3.50	2849					0.51	0.23	2.64	1.25	92	91	8.1	0.7
UNIT5	DEC15-FEB08			41.4	0.28	3.60	5240	76.0				0.90	0.65	0.79	0.35	180	22	4.6	2.3
UNIT5	FEB09-APR15	*		45.1	0.16	3.52	7415	64.6	10.0	17.3	7.1	12.27	9.67	1.30	0.76	147	29	7.2	7.1

* STEADY STATE

In contrast, SCN concentrations were significantly reduced. The average SCN concentration in the feeds to the DP systems was about 190 mg/L, while the typical concentration in the effluents was below 5 mg/L. For the NDP systems, the effluent SCN concentrations were slightly higher than those for the DP systems but still typically below 10 mg/L. Therefore, the DP systems were slightly more effective than the NDP systems, but the differences were not significant. Among the DP systems, PAC addition did not affect SCN removal appreciably, but of the two NDP systems (No.'s 4 and 5), that with PAC seemed to improve SCN removal slightly.

Need for Prebiological Tar Acid Precipitation

As discussed earlier, tar acid precipitation was considered a necessity in a treatment scheme without phenol extraction (ICRC, 1983a). However, tar acid precipitation consumes a large quantity of acids and bases, creates additional sludges, and adds a large amount of dissolved solids to the wastewater. Therefore, there was an incentive to eliminate this process, and the need to retain it was investigated.

It had been anticipated that phenol extraction might eliminate the need for tar acid precipitation. To test this assumption, the tar acid precipitation step was eliminated from the pretreatment sequence in the later stages of this study. Only the two DP/NPAC systems were evaluated, since these were of prime concern at this point in the study. Table 17 compares the removal of COD, color, and SCN before and after the elimination of tar acid removal.

Comparison of the COD concentrations in the effluents of the second-stage bioreactors with and without tar acid precipitation suggests that there were slight differences. For Unit 1B, the CODs with and without tar acid precipitation were 210 ± 51 and 221 ± 62 mg/L, respectively. Likewise, Unit 2B had a COD of 132 ± 29 mg/L with tar acid precipitation, and 170 ± 34 mg/L without it. Thus, the CODs in the effluents from both systems were lower with tar acid precipitation than without it. The difference in color removal is not evident. For Unit 1B, the color was lower with tar acid precipitation, but the converse is true for Unit 2B. The difference, if any, was probably

Table 17

Comparison of Performance of Biooxidation with
and without Tar Acid Precipitation

System/bioreactor		Period	Tar acid precipitation	Effluent COD (mg/L)	Effluent color (APHA units)	Effluent SCN (mg/L)
1 (DP/NPAC)	1A	3/20 - 5/16	Yes	296 ± 81	607 ± 228	32 ± 47
		5/24 - 7/25	No	319 ± 40	589 ± 221	5.65 ± 0.91
	1B	3/20 - 5/16	Yes	210 ± 51	832 ± 378	3.05 ± 0.824
		5/24 - 7/25	No	221 ± 62	964 ± 414	4.21 ± 0.91
2 (DP/NPAC)	2A	2/27 - 3/19	Yes	230 ± 39	1,000	3.84 ± 1.35
		3/20 - 5/16	No	244 ± 42	1,096 ± 206	5.5 ± 1.0
	2B	2/27 - 3/19	Yes	132 ± 29	914 ± 107	2.2 ± 0.2
		3/20 - 5/16	No	170 ± 34	893 ± 228	4.6 ± 1.2

obscured by the typical large scatter of color measurements. The difference in SCN removal appears to be clearer. Again, comparing the SCN concentrations in the second-stage effluent, with and without tar acid precipitation, shows that the SCN concentrations were slightly lower with tar acid precipitation.

The slight differences in COD and SCN are probably not significant. The post-biological tertiary treatment processes downstream provide additional removal. This will be evident by examining the fully treated wastewater composition. As will be discussed later, the fully treated wastewater can meet all targeted effluent limits. For this reason, prebiological tar acid precipitation does not appear to be necessary based on the laboratory results obtained in this study. However, because "tar acids" are not well understood, more research in areas such as origin and identification of the major constituents is recommended.

Operational Stability

During operation of the bioreactors, there were several changes in the feed compositions, some by design and some unplanned. The most significant changes were a COD excursion and a switch from Catalytic-pretreated to Chem-Pro feed, which had a much higher sodium content. These changes triggered responses in the bioreactors and provided insight into their stability and resilience.

COD Excursion. The COD excursion in the feeds to the DP systems occurred on 1 February and lasted for about a week. Before the excursion, the typical feed COD was about 1,800 to 2,000 mg/L, and the shock load increased the concentration to about 2,900 mg/L.

Table 18 shows the weekly average COD concentrations from a week before the excursion to 9 weeks after. Week 0 denotes the week when the excursion took place, week -1 represents 1 week before, week +1 represents 1 week after, and so on.

System 1 (DP/NPAC), consisting of two bioreactors in series, each having an HRT of 2 days, did not show any adverse effects whatsoever. In fact, the COD concentrations in the effluent from the first-stage

Table 18

Response to COD/Sodium Excursions (DP Systems)

	Feed	System 1		System 2		System 3
		1A	1B	2A	2B	3
HRT (days)		2	2	1	1	3.5
Weekly av COD (mg/L)						
Week -1 (2/2)[a]	2,074 ± 470	305 ± 25	280 ± 7	360 ± 68	149 ± 21	218 ± 36
Week 0 (2/9)[b]	2,863 ± 45	293 ± 13	280 ± 14	422 ± 78	304 ± 51	272 ± 45
Week +1 (2/16)	1,854 ± 231	262 ± 34	204 ± 27	309 ± 82	241 ± 65	324 ± 93
Week +2 (2/23)	1,922 ± 89	200 ± 46	178 ± 26	224 ± 32	159 ± 21	371 ± 173
Week +3 (3/2)[c]	1,840 ± 90	209 ± 32	125 ± 34	212 ± 22	125 ± 27	337 ± 65
Week +4 (3/9)	1,814 ± 80	200 ± 36	141 ± 47	220 ± 38	135 ± 34	243 ± 26
Week +5 (3/16)	2,029 ± 70	271 ± 67	154 ± 52	231 ± 43	121 ± 22	223 ± 23
Week +6 (3/23)	1,886 ± 56	326 ± 29	285 ± 31	214 ± 53	183 ± 38	272 ± 22
Week +7 (3/30)	2,083 ± 69	398 ± 34	274 ± 22	218 ± 15	177 ± 20	215 ± 18
Week +8 (4/6)	2,073 ± 128	318 ± 79	230 ± 16	223 ± 11	156 ± 16	163 ± 25
Week +9 (4/13)	1,962 ± 49	231 ± 15	208 ± 21	232 ± 12	162 ± 15	149 ± 22

[a]Date of week ending (1983).
[b]COD excursion.
[c]Began gradual change to high sodium feed on 27 February 1983 (completed 17 March 1983).

bioreactor steadily decreased over the period from a week before to a week after the shock. They then stabilized at about 200-210 mg/L during weeks 3 and 4 (weekly average). The COD from the second-stage bioreactor decreased for three consecutive weeks after the excursion.

System 2 was similar to System 1 except for a 1-day HRT in each stage. The first-stage bioreactor exhibited an initial drop in performance in week 0, but stabilized rather quickly. In the week preceding the shock loading, the effluent COD from the first-stage reactor averaged 360 mg/L. In week 0, it increased to 422 mg/L, it dropped to 309 mg/L in week +1, and then finally tapered to the low 200-mg/L range thereafter. The second-stage bioreactor exhibited a similar response. The bioreactor recovered fully within 2 weeks after the excursion.

System 3 was operated with a high inventory of PAC and an HRT of 3.5 days. Neither the PAC nor the longer HRT of System 3 provided a better buffer to upset than System 1 or 2. In fact, its performance was affected to a greater degree. The effluent COD in week 0 increased 24% over week -1, and went up further in the next 2 weeks. Only in week +4 did the concentration return to approximately the pre-excursion level.

In summary, none of the three DP systems were drastically affected by the COD excursion. System 1 exhibited no loss of efficiency. System 2 apparently was affected slightly, but recovered quickly. System 3 was also affected and recovered in 4 weeks. The reasons for these differing responses are not clear. The longer HRT in System 1 did provide a lower F/M than System 2 (0.23 vs. 0.59). However, System 3, with an even lower F/M (0.18), was the most affected. The increase in COD during the stabilizing period should not affect the final plant effluent quality significantly, because the tertiary treatment provided downstream of the bioreactors would dampen the increase.

Also note that the COD excursion for the DP systems affected nitrification and ammonia removal. Figures 19 and 20 showed that the excursion on February 3 was accompanied by a temporary increase in effluent ammonia concentration for Systems 1 and 2. The recovery trend was similar to that for COD. In System 3 (DP/PAC), however, ammonia removal recovery was not as rapid and did not improve to former levels.

The nondephenolated systems (No.'s 4 and 5) were subject to a COD surge of longer duration. The pattern is shown in Figures 17 and 18, the time-series plots of COD. Before February 9, the feed COD concentration to each system initially fluctuated because of variations in the TOC/COD ratio. (The feed was originally made up using TOC as the target concentration.) During this time, the effluent COD concentration from each system seemed to be relatively stable, although System 4 does show a slight, gradual rise.

Following the excursion, both system effluents decreased slightly, but, again, were very stable. The most noteworthy aspect of their performance was the dampening effect provided by Unit 4B. Unit 4A, following the excursion, began to perform very poorly, at one point providing virtually no removal. During this time, Unit 4B achieved effluent concentrations that were actually lower than before the excursion (when Unit 4A was operating well).

Regardless of whether the decreased efficiency of Unit 4A was due to the loading excursion or to some other cause, the data certainly illustrate the advantage of a two-stage system. The second stage provided both polishing (normally) and sustained effluent quality (during the excursion, or upset condition). A further example of the effectiveness of two-stage treatment is evident from a comparison of DP Systems 1 and 2. The HRT for Unit 1A equals the sum of Units 2A and 2B. However, the effluent from System 2 was consistently superior to that of Unit 1A (except for week 0, when the two effluents were about equal).

Response to High Sodium Concentration. When the DP system feeds were changed from Catalytic-pretreated to Chem-Pro-processed wastewaters, the concentration of sodium in the feeds to the bioreactors increased from 230 to 1,300 mg/L.

Table 18 shows that, starting from week +3, the feeds to the DP systems were gradually switched to the Chem-Pro feed, and the switch was completed in week +6. In week +3, the feed was a mixture of 3 parts of Catalytic wastewater and 1 part Chem-Pro wastewater (i.e., 3:1). In week +4, the ratio was 2:2, in week +5, 1:3, and in week +6, 100% Chem-Pro.

The effluent CODs showed little change during the transitional period (from week +3 through +5), but did show a more perceptible increase in week +6, when the feed batch was prepared from 100% Chem-Pro-processed wastewater, which had a Na concentration of 1,300 mg/L. Fortunately, the resulting COD excursions subsided quickly, within 2 to 3 weeks. Analysis of the effluent from System 1 (i.e., from Bioreactor 1B) showed that the COD was in the 125-150-mg/L range immediately before and during the transition, and increased to 285 mg/L in week +6. It returned to the low 200-mg/L level in week +9.

System 2 was even less affected. Effluent COD from Bioreactor 2B was about 130 mg/L during the transition, and increased to only 183 mg/L in week +6. The concentration decreased to about 160 mg/L in weeks +8 and 9. System 3 was virtually unaffected by the change in sodium concentration.

The change in sodium concentration had a much more dramatic impact on ammonia removal and nitrification. Figures 19-21, the time-series plots of ammonia for the DP systems, show that System 1 (Bioreactor 1B) produced effluents having relatively low ammonia concentrations during the transition (between February 27 and March 17). However, the ammonia concentrations increased drastically on and after March 17, when the feed became 100% Chem-Pro. A similar pattern existed for System 2, but the increase was not nearly as drastic. System 3 (DP/PAC) effluent ammonia concentrations steadily increased following a COD excursion around February 9 and continued to increase after the higher sodium concentrations appeared in the feed. The data again demonstrate the sensitivity of ammonia removal and nitrification to the feed conditions.

Hydraulic Residence Time Study

Hydraulic residence times (HRTs) required for the bioreactors will affect system economics. One objective of this study was to evaluate various hydraulic retention times with different feeds and operating conditions.

Dephenolated Systems. For DP/NPAC systems, the laboratory data indicate that 1-day HRTs are adequate for the first- and second-stage bioreactors. The COD and NH_3 concentrations in the effluents from

System 1, which had 2-day HRTs in each stage, and System 2, which had 1-day HRTs in each stage, were compared statistically to determine whether the two reactor systems performed differently.

Based on the mean difference of paired observations, the average difference in CODs for both reactor systems was not statistically significant. However, at the 5% level of significance, System 2 removes more ammonia than System 1.

The feed to both systems was the same each day, but the daily feed COD and NH_3 levels varied considerably. For this reason, the statistic used to compare performance was the average daily difference in effluent concentration, rather than the difference between the daily averages. This approach was taken in order to take into account some of the effluent variation due to the time-varying concentration of the feed.

Ammonia. The statistics for the differences in the daily effluent ammonia concentration for Systems 1 and 2 are as follows:

Average ammonia level Unit 1B effluent:	52.0 mg/L
Average ammonia level Unit 2B effluent:	43.2 mg/L
Average of daily differences:	8.78 mg/L
Standard deviation of differences:	63.6 mg/L
Standard error of the mean:	4.11 mg/L

At the 95% confidence level, where there is no difference between the systems (i.e., the average difference is equal to zero), the acceptance range of the mean difference in ammonia levels is ±8.06 mg/L. Since the computed mean difference lies outside this region, the average ammonia in System 1 effluent is concluded to be significantly different (and higher) than that in System 2 effluent.

COD. COD statistics are as follows:

Average COD level Unit 1B effluent:	200 mg/L
Average COD level Unit 2B effluent:	193 mg/L
Average of daily differences:	7.88 mg/L
Standard deviation of differences:	103 mg/L
Standard error of the mean:	6.6 mg/L

In this case, at the 95% confidence level, the mean would have to lie in the range of -12.9 to 12.9 mg/L to conclude that there is no difference in the COD levels in the reactor effluents. Since the mean is only 7.9 mg/L, there is no difference in the COD concentrations at the 95% confidence level.

Of concern in the use of the differences in daily values is which pairs to select to use in forming the differences. Because the reactor dynamics differ, simultaneous changes in feeds may not be fully reflected in the effluents at the same time.

The possible effects of different reactor dynamics on the mean difference and standard error of the mean calculated for CODs were examined briefly. The equations and calculations are included in Appendix 4.

As the calculations show, a typical change in COD influent from 2,000 to 1,500 mg/L for System 1 requires about 3 days to be fully reflected in the effluent. To examine the effect of time shifting on the mean difference and standard error of the mean, difference pairs were formed at from -3 to +3 days with reference to System 1. The mean differences generated ranged between 5.9 and 9.7 mg/L, while the standard errors were in the range of 6.3 to 7.2 mg/L. Thus, the conclusion remains that COD performance of the two reactors does not differ significantly.

Nondephenolated Systems. Without PAC, the two bioreactors operating on nondephenolated water were inferior to the dephenolated systems even at an HRT of 3.5 days each. With PAC, the minimum HRT of 3.5 days was adequate, and only one stage was required.

To determine the minimum HRT required for the NDP/NPAC system, the HRTs for both stages of System 4 were gradually decreased (starting in May 1983), while the solid residence time of 30 days was maintained. Results are displayed in Table 19.

Although the data indicate that effluent COD in the two-stage system was stable, the first stage did not respond well to additional loading. Also, previously the unit was not able to maintain high mixed-liquor levels (6,000-8,000 mg/L MLSS). Solids settleability deteriorated, resulting in washout. Further losses were caused by excessive foaming at the higher organic loadings.

Table 19

System 4 Performance--HRT Reduction Study

Day	HRT (days)		F/M (COD)		MLSS (mg/L)		Eff COD (mg/L)		Eff NH_3 (mg/L)	
	4A	4B	4A	4B	4A	4B	4A	4B	4A	4B
1[a]	3.60	4.07	0.35	0.04	5,100	4,110	500	460	159	26
3	3.05	3.11	0.42	0.05	4,810	4,120	590	310	159	26
6	2.84	2.72	0.45	0.07	4,500	3,480	645	400	143	2
10	2.82	2.78	0.34	0.09	5,690	4,210	1,030	455	163	1
13	2.51	2.59	0.47	0.13	5,390	3,580	1,265	495	110	17
17	2.30	--				3,890	1,320	410	100	8
20	2.00	2.30				3,470	1,500	525	114	48
24[b]	2.20	2.10				3,200	2,360	385	130	97
27	1.90	2.00	0.41	0.59	8,250	3,350	3,950	495	161	115
31	2.10	2.10	0.37	0.40	7,850	4,360	3,370	450	156	125

[a]Day 1 was 7 May 1983, 24 hr into the study.
[b]Stopped reducing HRT.

Therefore, although a 2-day HRT is apparently feasible for each stage of the NDP/NPAC system, it is not recommended. It is definitely not feasible for nitrification.

PAC Dose Study

High doses of PAC were added to the DP/PAC and NDP/PAC systems (3 and 5, respectively). The program was intended to evaluate whether a single-stage PAC-augmented system could produce an effluent equivalent to a two-stage system without PAC. Previous discussions clearly showed that PAC system effluents were equivalent to, and in some cases superior to, non-PAC two-stage systems for some parameters. Anticipated operational problems and costs associated with handling the high concentrations of mixed liquor and large quantities of carbon and sludge in a full-size plant made the option less desirable, and a study to evaluate reduced PAC concentration was conducted.

During the basic program, PAC was added on the basis of wastewater feed volume after an initial high dose. The PAC inventories ranged between 6,500 and 8,000 mg/L and 8,000 and 11,000 mg/L for Systems 3 and 5, respectively. The PAC dose study was designed to decrease the daily dose by 3% of the prior day's dose, for 40 days.

System 3 was chosen for the study because by then it was obvious that a DP system should be recommended for the plant design. Over the 40 days, the dose was reduced from 500 to 150 mg/L of feed to the bioreactor and the PAC inventory dropped from 7,020 to 4,840 mg/L in the bioreactor. Data for this period were shown in Tables 11 through 16 (period: May 5 to June 20). The reduction of PAC dose was stopped on June 12, and the PAC dose held constant for an additional week until the study was terminated.

Effluent COD during the study was 199 ± 41 mg/L, compared to 204 ± 52 mg/L in the prior period, also using Chem-Pro feed. Effluent COD was at its best, about 150 mg/L, toward the end of the study when the PAC inventory was lowest. Similarly, TOC in the effluent averaged 42 mg/L compared to 43 mg/L in the prior period. BOD was not measured during the study.

Phenolics, cyanide, and thiocyanate in the effluent also showed essentially no change between the two periods. Color rose about 20%, from 347 ± 311 to 421 ± 182 APHA units during the study.

Effluent ammonia appeared to be lower during the study, 49 ± 29 vs. 119 ± 48 mg/L, but in fact rose from a low of 7 mg/L in the middle of the period to a high of 94 mg/L at the end.

There was little change in performance down to a dosage of about 250 mg/L, at which time the basin inventory was 5,800-6,000 mg/L. Further reduction of the PAC dose appeared to affect ammonia removal, and a gradual increase in effluent ammonia was measured through the end of the study.

Based on the brief PAC dose study, it would appear that the PAC dose for System 3 could be reduced to about 250 mg/L of feed without an adverse effect on COD, TOC, ammonia, phenolics, cyanide, and thiocyanate removal.

Biokinetics

Developing biokinetic coefficients was not an objective of this study. However, semiquantitative estimates of the coefficients using the data generated from this study and the previous study (ICRC, 1983a) are possible.

Apparent Yield Coefficients. The apparent yield (Y_{COD}) is defined as grams of biomass wasted per gram of COD removed from a biological system. The estimates are as follows:

System no. and notation	ΔCOD/Δt (g/day)	ΔVSS/Δt (g/day)	Y_{COD}
1. DP/NPAC	7.84	1.46	0.186
2. DP/NPAC	15.9	2.89	0.182
3. DP/PAC	7.16	0.74	0.103
4. NDP/NPAC	13.1	2.26	0.173
5. NDP/PAC	13.8	1.99	0.144

The term ΔCOD/Δt represents the COD removed per day by each system, and ΔVSS/Δt is the sludge waste per day. The sludge wastage also includes non-COD-removing biomass such as nitrifying bacteria, but that is negligibly small. As the table above shows, the apparent yield

coefficients for COD are generally consistent for the five systems, even though the feeds were different.

Ammonia Removal. Ammonia removal can be described as a first-order reaction (Adams and Eckenfelder, 1977):

$$C/C_o = e^{-k_N X\Theta}$$

where C = effluent concentration of ammonia (mg/L)
C_o = influent concentration of ammonia (mg/L)
k_N = rate constant of ammonia removal (L/mg-day)
X = MLVSS (mg/L)
Θ = hydraulic residence time (days)

The data for the steady-state period for Units 1B and 2B were chosen for the analysis. The calculated values for k_N were 5.3×10^{-4} and 8.7×10^{-4} L/mg-day for Units 1B and 2B, respectively. These values are close to the values ranging from 3.9×10^{-4} to 5.0×10^{-4} L/mg-day reported in the literature (Adams and Eckenfelder, 1977). Ammonia removals, expressed as the ratio C/C_o, are shown in Table 20.

Oxygen Utilization. Oxygen utilization was correlated with COD removal rates in Units 1A and 2A according to the following expression:

$$R_r/VSS = a' \text{ (COD removal rate)} + b'$$

where R_r = oxygen utilization per day, a' = fraction of COD used for oxidation, and b' = fraction of MLVSS oxidized (COD basis). When the steady-state data for Units 1A and 2A are used, $a' = 0.917$ mg of O_2/mg of COD removed and $b' = 0.017$ mg of O_2/mg of VSS per day. These values are comparable to corresponding values of 0.77 and 0.01, respectively, as reported by Luthy et al. (1983).

Biomass Separation

Batch settling tests were run on mixed-liquor samples from all five bioreactor units. These tests were conducted throughout the course of the study, and the average results are shown in Table 21. The MLSS values are the measured concentrations for the test samples. They differ slightly from the steady-state concentrations, but are in the

Table 20

Ammonia Removal

	PERIOD		DESCRIPTION	SRT	F/M COD	HRT	MLVSS-PAC CORR	C/Co	LN C/Co	
UNIT1A	DEC15-FEB26		CATALYTIC FEED	29.6	0.10	2.09	4254	0.723163	-0.32411	-7.6E-05
UNIT1A	FEB27-MAR19		CHANGE TO CHEMPRO	30.0	0.19	2.02	3732	0.316455	-1.15057	-1.5E-04
UNIT1A	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.31	2.05	2377	0.807081	-0.21333	-4.4E-05
UNIT1A	MAY24-JUL25	*	CP FEED(NO TA REM)	30.0	0.28	2.03	2653	0.127659	-2.05838	-3.8E-04
UNIT1B	DEC15-FEB26		CATALYTIC FEED	29.6	0.04	2.20	1921	0.303458	-0.95052	-2.3E-04
UNIT1B	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.04	2.30	1896	0.134969	-2.00270	-4.6E-04
UNIT1B	MAR20-MAY16		CHEMPRO(CP) FEED	30.0	0.05	2.12	2276	0.65	-0.43078	-8.9E-05
UNIT1B	MAY24-JUL25	*	CP FEED(NO TA REM)	29.0	0.03	2.00	1340	0.225859	-1.48704	-5.3E-04
UNIT2A	DEC15-FEB26		CATALYTIC FEED	28.8	0.30	1.08	4828	0.871741	-0.13726	-2.6E-05
UNIT2A	FEB27-MAR19		CHANGE TO CHEMPRO	30.1	0.25	1.06	5469	0.640880	-0.44491	-7.7E-05
UNIT2A	MAR20-MAY16	*	CP FEED(NO TA REM)	30.0	0.25	1.06	5705	0.855121	-0.15651	-2.6E-05
UNIT2B	DEC15-FEB26		CATALYTIC FEED	27.1	0.09	1.05	2316	0.482941	-0.72785	-3.0E-04
UNIT2D	FEB27-MAR19		CHANGE TO CHEMPRO	25.9	0.06	1.00	2978	0.119019	-2.12846	-7.1E-04
UNIT2D	MAR20-MAY16	*	CP FEED(NO TA REM)	30.1	0.09	1.02	2077	0.159405	-1.83630	-8.7E-04
UNIT3	DEC15-FEB25		CATALYTIC FEED	39.8	0.14	2.04	5607	0.553370	-0.59172	-5.2E-05
UNIT3	FEB26-MAY04	*	CHEMPRO (CP) FEED	39.8	0.27	2.29	2443	0.631746	-0.45926	-0.2E-05
UNIT3	MAY05-JUN20		CP FEED(PAC REDUCT	39.2	0.25	2.53	2283	0.250510	-1.38425	-2.4E-04
UNIT4A	NOV18-JAN17	*		31.5	0.37	3.87	3315	0.599386	-0.51184	-4.0E-05
UNIT4A	FEB18-MAR24		SYSTEM FAILING	25.9	0.50	3.28	2684	0.667164	-0.40471	-4.6E-05
UNIT4A	MAR25-APR15		PAC ADD-SYS RECOV.	30.8	0.48	3.26	2457	0.823028	-0.19379	-2.4E-05
UNIT4A	APR16-MAY06		SYS RECOVERED	30.1	0.43	3.80	2320	0.639945	-0.44637	-5.1E-05
UNIT4B	NOV18-JAN17	*		30.5	0.09	3.67	3015	0.672164	-0.39725	-3.6E-05
UNIT4B	FEB18-MAR24			29.4	0.23	3.29	3790	0.792362	-0.23273	-1.9E-05
UNIT4B	MAR25-APR15			31.2	0.20	3.20	5087	0.573984	-0.55515	-3.4E-05
UNIT4B	APR16-MAY06			30.0	0.07	3.50	2849	0.334210	-1.09598	-1.1E-04
UNIT5	DEC15-FEB08			41.4	0.28	3.60	5240	0.196913	-1.62499	-8.6E-05
UNIT5	FEB09-APR15	*		45.1	0.16	3.52	7415	0.045138	-3.09801	-1.2E-04

same general range. The HRT and SRT values represent steady-state conditions. The solids flux rates are based on the underflow concentrations shown (2% for NPAC; 3% for PAC). The numbers shown in Table 21 are direct measurements without scale-up factors, which should be included to derive the design basis.

Settling data were difficult to generate for Units 1B and 2B. As noted previously, there was limited microbial growth in the second-stage bioreactors and, because of this, flocculent settling did not occur. That is, a distinct water/solids interface did not appear near the top of the graduated cylinder, and gradually descend. Rather, a bottom interface, due mostly to the powdered carbon added to the second-stage reactors, developed almost immediately. Zone settling velocities (ZSV) and solids loading rates (flux) could not be established for Unit 2B during steady-state conditions, and the values shown for Unit 1B are based on a single test. However, during non-steady-state periods, it was possible to calculate settling data for Unit 2B, which are shown in Table 21. Flocculent settling did not occur during these settling tests because the mixed liquor solids were much higher than during the steady-state period (4,930 vs. 2,752 mg/L).

The data show that the solids loading rate is higher for Unit 2A than 1A, despite a substantially lower initial settling rate. This is due to the much higher (almost three times) solid concentration of the mixed liquor. The high MLSS levels in Unit 2A may be misleading. While the total MLSS was 9,176 mg/L, the volatile solids concentration was only 5,705 mg/L, or 62% of the total. By contrast, Unit 1A had total and volatile suspended solids levels of 2,944 and 2,653 mg/L, respectively (volatile fraction 90%). This ratio of volatiles between Units 1A and 2A is expected. Unit 1A had about half as many volatiles, but twice the hydraulic retention time (SRTs were equal). However, the large portion of nonvolatile solids in Unit 2A was unexpected, and is not completely understood. It is apparently due to the precipitation of inorganic solids, which may have been caused by a higher pH in System 1 than 2 (8.3 vs. 7.6). Whatever the cause, these higher solids caused a lower ZSV in 1A than 2A. When the MLSS in Unit 2A dropped to the 7,000

Table 21

Results from Batch Settling Tests

System	Bio-reactor	HRT (days)	SRT (days)	MLSS (mg/L)	ZSV[a] (ft/min)	Underflow (% solids)	SOR[b] (gpd/ft^2)	Flux (lb/ft^2-day)
DP/NPAC	1A	2.03	30.0	3,204	0.268	2	948	25.0
DP/NPAC	1B	2.08	29.8	2,350	0.389	2	1,233	24.2
DP/NPAC	2A	1.06	30.0	7,050	0.190	2	1,214	71.3
DP/NPAC	2B	1.02	30.1	4,930	0.200	2	992	41.6
DP/PAC	3	2.53	39.8	11,920	0.233	3	2,130	211
NDP/NPAC	4A	3.87	31.5	5,450	0.272	2	1,577	70.9
NDP/NPAC	4B	3.67	30.5	4,013	0.220	2	1,328	54.2
NDP/PAC	5	3.52	45.1	17,587	0.090	3	901	134

[a]Zone settling velocities.
[b]Surface overflow rates.

range, the ZSV increased. In actual plant operation, it is possible that pH adjustments could reduce the size of the nonvolatile fraction.

System 4 (NDP/NPAC) reactors exhibited higher average loading rates than Systems 1 and 2. Its mixed-liquor concentrations (5,500 mg/L in 4A; 4,000 mg/L in 4B) were higher than Unit 1A but lower than 2A. The initial settling velocities in both of the System 4 reactors were comparable to those of Unit 2A, and about three times higher than 2A. The surface overflow rates for Units 4A and 4B were both about 50% higher than Unit 1A.

The PAC systems, because of extremely high mixed-liquor concentrations, produced the highest solids loading rates. System 3, at almost 12,000 mg/L, still settled very quickly, resulting in a solids loading of 211 lb/ft^2-day. System 5, at over 17,000 mg/L, exhibited hindered settling, and the solids loading rate was only 134 lb/ft^2-day. The surface overflow rate of System 3 was also the highest of all systems. This did not hold for System 5, however, where the hindered settling dropped the surface overflow rate (SOR) down to the level of Unit 1A.

Other Operating Problems Observed

Foaming. Dephenolization reduced foaming. A "normal" amount of basin foaming produced by aeration was observed in DP systems, and no control measures were necessary. In NDP systems, however, significantly greater foam levels were almost always present and, for several extended time periods, foaming presented serious operational difficulties.

PAC partially alleviated foaming problems for the nondephenolated systems. The NDP/PAC system (Unit 5) was less a problem than the NDP/NPAC system (Unit 4), and was satisfactorily controlled by periodically applying an antifoam spray. However, antifoam was less effective in System 4, particularly the first-stage unit, and applications provided only temporary control. A more effective solution was found to be decreasing the air rate through the diffusers, while maintaining a D.O. level of at least 2 mg/L.

Reasons for inordinate foaming in the NDP systems were never determined. There is no correlation between any measured parameter and the sporadic occurrence of severe foaming. Because foaming was absent in the DP systems, the only explanation is the intermittent introduction of some constituent in NDP feeds that is removed by phenol extraction in the DP feeds.

Solids Precipitation vs. pH. Before good nitrification rates were established in the bioreactors, feed batches were prepared to a pH of about 8. This was adequate to maintain the pH of the bioreactor within the specified range of 7 to 8. As the study progressed, nitrification began to occur extensively in the bioreactors. Nitrification generates acid which removes alkalinity. This decrease in alkalinity caused the pH of the bioreactors to drop. Because all reactors were the complete-mix type, such a problem could be countered simply by raising the pH of the feed. These pH adjustments were originally required for the feeds to the second-stage systems (where nitrification began), but nitrifiers were later developed in the first-stage units. Eventually, the entire feed batch required adjustment to a higher pH, and individual adjustment of second-stage feeds was still necessary.

Several experiments conducted during batch preparation showed slight precipitation at about pH 7.4, and larger quantities (5%, by volume) at pH 8.0. These solids were determined to consist largely of sulfate, phosphate, and calcium species. Another experiment raised a first-stage effluent from pH 8.0 to 11.0, which was required for second-stage feed at that time. The TSS rose from 20 to over 530 mg/L.

These observations are indicative of potential problems in an operating plant. System design should prevent solids precipitation in the equalization tank.

Nitrification vs. pH. Concurrent with a discussion of the effects of high pH on a system are the effects of low pH on nitrification. Published information generally indicates that nitrifying bacteria require a higher pH environment than carbon-utilizing bacteria. Metcalf & Eddy, Inc. (1979) states that maximum nitrification rates occur between about pH 7.2 and 9.0.

During the program, minor pH excursions below 7.0 for even 1 day were almost always accompanied by a small rise in effluent ammonia. The difficulty in controlling pH in the experimental systems has been discussed and is reiterated in this section to emphasize the importance of good control for ammonia removal through nitrification.

Effluent Solids. The effluent solids levels from the bioreactors varied significantly between the systems. For the dephenolated feeds, the average effluent suspended solids during steady-state conditions was 93 mg/L for the NPAC bioreactors, and 151 mg/L for the PAC system. The NDP feed systems exhibited much higher effluent solids, averaging 551 and 1,067 mg/L for NPAC and PAC, respectively. This last figure is extremely high, but it should be remembered that the mixed liquor for System 5 (NDP/PAC) exceeded 18,000 mg/L. The NDP-NPAC average of 551 mg/L is indicative of the continual upset conditions for that system.

Laboratory bench-scale bioreactors are used to model the biological treatment process, not to establish design criteria for clarifiers. For the lab units used in this study, the so-called "clarifiers" were simply baffled sections in the aeration vessels. This configuration is designed to retain most of a unit's biomass, but not to indicate design solids levels. Nevertheless, the solids values were somewhat higher than expected. As a further check, the data were compared to the suspended solids concentration in the supernatant from 1-L batch settling tests. Such tests do not necessarily predict the effluent solids that will be obtained under field conditions. However, they are run under quiescent conditions, eliminating possible interference caused by agitation in the bench-scale bioreactors. The supernatants exhibited solids levels in rather good agreement with the daily effluent values. The DP feeds averaged 153 mg/L for NPAC systems, and 141 mg/L for the PAC system. For NDP feeds, the values were 477 and 577 mg/L for NPAC and PAC, respectively.

These data indicate that effluent suspended solids levels over 100 mg/L would be likely to occur, and could be considerably higher under upset conditions. As was discussed in Section III of this report, solids precipitated due to pH adjustments to the feed. This precipitate could have contributed to the high effluent solids. It is also noteworthy that all two-stage systems were operated with a PAC inventory of

500 mg/L in the second-stage mixed liquor. The stated purpose of this carbon addition was to aid in solids settling. However, when the effluent solids for first- and second-stage units are compared, the values are roughly comparable. While this does not mean the carbon was ineffective, its value is not conclusively demonstrated by the results.

Desired effluent solids levels need to be evaluated in terms of downstream tertiary treatment processes. In this case, the bioreactor effluent is treated by coagulation and another clarification step, thereby removing most solids escaping the secondary system. The impact on this tertiary coagulation/clarification process would be minimal for the solids quantities noted above for all three DP systems. For the NDP feeds, such solids would still be removed. However, because of the larger quantity of sludge, the size of the underflow pumps would have to be greater.

Comparison with Other Studies

In this section, results from the biooxidation study are compared with results from investigations of treatment of wastes produced by other coal liquefaction processes, coal gasification, and coal coking. The principal objective of this comparison is to detect any common patterns shared by the coal-conversion wastewater treatment systems.

Two recent studies, which investigated activated-sludge and/or powdered-activated-carbon/activated-sludge (PACT) treatment of coal liquefaction wastewaters, provide an especially relevant data base for comparison with results of the current study. Exxon Research and Engineering Company evaluated a zero-discharge treatment scheme for wastewaters produced by the Exxon Donor Solvent (EDS) coal liqeufaction process (Robertaccio and Kaczmarek, 1983), while Zimpro, Inc. performed studies with H-coal pilot plant water to evaluate wastewater treatability and to assess effects of process impacts on wastewater treatment system performance (Berndt et al., 1982). Results of these two studies are compared below. This is followed by discussion of other investigations on treatment of coal conversion and coal coking wastewaters.

Treatment of EDS Wastewater. The wastewater treatment scheme proposed for the EDS coal liquefaction process included two-stage sour

water stripping, solvent extraction, and biological treatment. Because biologically treated wastewater was to be used as makeup to a cooling tower, additional treatment was included for this purpose: filtration, granular activated carbon (GAC) adsorption, and weak acid cation exchange. The objective of Exxon's treatability study was to verify the proposed wastewater treatment scheme, and to compare the effectiveness of PACT with the sequential steps of biological treatment and GAC adsorption.

Stripping and solvent extraction reduced TOC by approximately 85%, to approximately 400 mg/L. Most of the organic material remaining after stripping and extracting was believed to consist of organic acids. Steam-stripping reduced ammonia to an average level of about 2 mg/L. The bioreactors were operated with a hydraulic residence time of 1 day and a sludge age of 20 days. The PACT bioreactor maintained 8,000 mg/L of PAC in the mixed liquor (400 mg/L of feed).

Conventional activated-sludge biological treatment removed 75% of the 400-mg/L TOC and approximately 96% of the 500-mg/L BOD that was present in the wastewater after pretreatment. The PACT process reduced organic material even further: over 90% reduction of TOC to 37 mg/L, and more than 98% reduction of BOD to 8 mg/L. The PACT process also controlled foaming, assisted settling, and aided color removal. The study concluded that the PACT process removed approximately twice as much TOC as predicted by a powdered carbon adsorption isotherm, due to biodegradation of adsorbed material.

The Exxon study was similar in several respects to the current investigation with SRC condensate water. However, note that the EDS wastewater contains residual organic acids that are not anticipated in the SRC-I wastewater.

The Exxon wastewater contained approximately one-half the BOD and two-thirds the COD or TOC of the extracted and stripped SRC-I bioreactor influent. Nevertheless, the effluent BOD and TOC for similar bioreactors were comparable for the two studies. This is evident by comparing the effluent BOD and TOC from the EDS biological treatment system with that of bioreactor Unit 2A; both had 1-hr HRTs. Unit 2A gave an effluent BOD_5 of 20 mg/L, which is comparable to a value of 24 mg/L for

EDS wastewater. Unit 2A also removed approximately 85% of influent TOC, which is the same as with the EDS wastewater.

There is insufficient information from which to compare nitrification efficiencies between treatment of EDS and SRC-I wastewaters, since the EDS water contained very low levels of ammonia (~2 mg/L) and thiocyanate (15 mg/L), whereas the concentrations selected for this SRC-I study were both 200 mg/L. The reason for selecting a higher concentration for the laboratory studies than that expected in the full-scale demonstration plant was to test the capability of the biological treatment systems to remove these contaminants.

The objectives of the PACT study with extracted-stripped SRC-I condensate were to assess single-stage organic removal as well as nitrification, whereas the principal objective of the EDS study was to evaluate removal of organic contaminants with single-stage PACT only. Hence, the Exxon study employed shorter hydraulic residence times in the single-stage PACT process compared to System 3 in this study. Nonetheless, as shown below, several comparisons can be made regarding treatment of EDS and SRC-I coal-liquefaction process waters.

The apparent loading of organic carbon for treatment of wastewater by the PACT process may be defined as the difference between PACT and conventional activated sludge effluent TOC divided by the carbon dose. Apparent loading for treatment of EDS wastewater was 180 mg/L of TOC per g of carbon; a comparable value for treatment of SRC-I wastewater was 66 mg/L of TOC per g of carbon, based on the difference in effluent TOC for bioreactor 2A and bioreactor 3, with a nominal PAC dose of 500 mg/L of feed for bioreactor 3. This apparent loading is lower than that obtained in the EDS study, suggesting that the PAC dose could have been lower in bioreactor 3 in order to achieve a higher utilization of powdered carbon. This has been confirmed by the PAC-dose study discussed earlier. However, as discussed below with reference to the H-coal study, a lower PAC dose may adversely impact single-stage nitrification efficiency.

As will be discussed in a subsequent section, tertiary treatment studies with SRC-I wastewater showed that effluents from bioreactors 1B, 2B, or 3, which are then processed by coagulation, filtration, and PAC,

result in no detectable value of TOC (<1 mg/L). This is different from results with EDS, which showed a residual TOC of 24 mg/L after GAC and weak acid cation exchange.

A conclusion from the EDS study was that either use of PACT or a combination of PACT and GAC are the best ways to employ activated carbon in treating EDS wastewater. This study has shown that, with dephenolization, PAC did not significantly improve organic removal over a two-stage non-PAC system.

Treatment of H-Coal Water. Berndt et al. (1982) studied the treatment of process wastewater from the H-coal liquefaction pilot plant. The purpose of the study was to evaluate PACT treatment of stripped-extracted wastewater, with pretreated feed to the biological treatment system having the following characteristics: TOC, 520 mg/L; COD, 1,780 mg/L; NH_3-N, /150 mg/L; and BOD, 700 mg/L. These concentrations are similar to those for the biological reactors receiving dephenolated-stripped wastewater in this study.

The H-coal treatability study evaluated single- and two-stage PACT treatment. No studies were performed to evaluate biological treatment without PAC. Operating conditions for the PACT reactors with H-coal water are summarized below:

	Single stage	Two stage	
		1st stage	2nd stage
HRT (hr)	25	9	22
SRT (days)	25	5	24
MLSS (g/L)	26.4	14.5	20.0
Mixed-liquor volatile carbon (g/L)	16.7	8.2	15.1
Mixed-liquor biomass (g/L)	5.2	4.4	1.2
Nonvolatile mixed-liquor solids (g/L)	4.5	1.9	3.7

These data show that in comparison with the SRC wastewater treatment investigation, the H-coal study employed wastewater treatment under

conditions of shorter hydraulic residence time with significantly increased concentrations of PAC.

Treatment of H-coal wastewater removed BOD to less than 7 mg/L; nitrification was essentially complete for either single- or two-stage treatment. The results also showed that a residual COD of 186 mg/L and TOC of 43 mg/L remained after treatment. These effluent values of TOC, BOD, and COD are not significantly different from those obtained during steady-state treatment of SRC-I wastewater.

The results of the H-coal study show that by operating at high PAC doses, low effluent levels of ammonia may be achieved. Hence, an important conclusion regarding comparison between treatment of SRC-I and H-coal waters is that, if nitrification is a treatment goal, the PAC dose may be a variable offering flexibility in wastewater treatment process design. Tradeoffs can be made between HRT and PAC dose to achieve various levels of nitrification efficiency. Currently, there is insufficient data from which to define an explicit functional relationship between HRT, PAC dose, and nitrification efficiency. However, the following preliminary analysis suggests an approach for assessment of a relationship between these parameters, which can provide a basis for design of future experiments and interpretation of experimental data.

The rate of nitrification in the second-stage bioreactor can be expressed as $C/C_o = \exp[-k_N X\Theta]$. Application of this equation to the H-coal results shows that exceptionally high nitrification rates occur due to the high level of PAC in the bioreactor. By comparison, in the SRC-I study, the second-stage bioreactor 2B, with a hydraulic residence time of 1 day and a biomass concentration of 2,077 mg/L, achieved a k_N of about 0.0009 L/mg-day. This rate was approximately one-fifth of that obtained with the H-coal water, at a similar HRT and a biomass concentration of 1,200 mg/L.

However, the differences in the rates of nitrification tend to disappear if total mixed-liquor volatile suspended solids, i.e., volatile carbon plus biomass, are used in calculating the estimated rate coefficient. For the H-coal study, second-stage volatile carbon and biomass total 16,300 mg/L, resulting in a rate coefficient of 0.0003 L/mg-day. This rate is similar to that observed in the SRC-I study for bioreactors 1B (0.0004 L/mg-day) and 2B (0.0007 L/mg-day), using the

same basis of computation, with MLVSS equaling the sum of biomass plus powdered carbon concentration.

This comparison of nitrification rate efficiency shows somewhat surprisingly that the rates of nitrification for the two studies are more similar if the rate is expressed in terms of total volatile solids in the second-stage reactor. Of course, since this result may be fortuitous, we suggest that future studies be performed to validate this observation. Additional study is warranted because it suggests an especially convenient method for engineering analysis and design of second-stage PACT nitrification systems.

The H-coal studies also evaluated the effect of failure of the ammonia stripper and solvent extraction process on performance of the PACT process. Berndt et al. showed that a short-term (i.e., several days) decrease in PACT performance resulted from upset of the pretreatment units, but no long-term operating problems were encountered. Both bench-scale and pilot-plant testing showed that, overall, the two-stage PACT process demonstrated good, consistent performance for removal of organics and ammonia. If consistent biological nitrification of a high concentration of ammonia is a treatment goal, a two-stage PACT system is a very viable alternative.

Other Coal Liquefaction Wastewater Studies. Reap et al. (1978) and Drummond et al. (1981) both reported results of single-stage activated-sludge treatment of coal liquefaction process wastewater. Pretreatment included stripping for removal of acid gases and ammonia, followed by dilution with tap water to approximately 20% strength. Neither study employed solvent extraction to reduce phenol and other organic constituents.

Reap et al. (1978) studied H-coal water with the following influent characteristics: COD, 3,070 to 4,180 mg/L; BOD, 1,890 to 2,600 mg/L; and NH_3-N, 68 to 140 mg/L. Food-to-microorganism (F/M) ratios, on a BOD basis, were in the range 0.06 to 0.22 day^{-1}, and effluent characteristics were: COD, 310 to 380 mg/L; BOD, 24 to 36 mg/L; and NH_3-N, 40 to 140 mg/L. In the current investigation with SRC-I water, bioreactors 1A and 2A were operated at F/M ratios of 0.22 and 0.16 day^{-1}. Under steady-state conditions, these bioreactors were able to achieve lower effluent BOD and ammonia values than reported by Reap et al.

Drummond et al. (1981) conducted tests on Ft. Lewis SRC-I wastewater that had been processed for tar acid removal and diluted to 10-35% strength. Nominal wastewater characteristics for 20% strength influent were 1,400 mg/L TOC and 4,500 mg/L COD. When this water was treated at an SRT of 22 days and an HRT of 3.7 days, the effluent characteristics were: BOD, 5 mg/L; TOC, 90 mg/L; and COD, 250 mg/L.

The studies of Reap et al. (1978) and Drummond et al. (1981) show that coal liquefaction water can be treated successfully, without pretreatment by solvent extraction, if sufficiently diluted and if biological reactor influent characteristics are held constant. Neither study reported results on nitrification. The effluent characteristics reported by Drummond et al. are similar to those obtained in this study with treatment of solvent-extracted wastewater at hydraulic retention times of 1 or 2 days. Drummond et al. concluded that in order to achieve stable biological treatment, either dilution or pretreatment to remove most of the organic contaminants would be required. They also concluded that about 12-13% wastewater TOC and COD is not biodegradable in activated-sludge treatment. Both of these conclusions are generally consistent with results of the current investigation.

Treatment of Coal Gasification and Coal Coking Wastewaters. Luthy et al. (1983) evaluated biological treatment of solvent-extracted ammonia-stripped coal gasification wastewater. The study compared conventional activated sludge and PACT. Raw wastewater, after solvent extraction and ammonia stripping, without dilution, had 1,380 mg/L TOC and 2,980 mg/L COD. These values are approximately one-third to one-half those observed in the current study with SRC-I water, probably because the organic content of the coal gasification wastewater consists of a larger fraction of phenolic material. The influent to the bioreactors employed by Luthy et al. (1983) was not diluted; consequently, the influent TOC was approximately twice as great and the influent COD approximately one and one-half times as great as that employed in the current study.

Luthy et al. (1983) operated the bioreactors under extended aeration conditions, wtih SRT values of 20 and 30 days and corresponding low BOD and COD removal rates. The bioreactor operated at $(F/M)_{COD}$ = 0.15

day^{-1}, while the PACT system operated at $(F/M)_{COD}$ = 0.23 day^{-1}, expressed in terms of biomass corrected for the presence of PAC. The COD loadings for bioreactors 1A and 2A in the current study were 0.28 and 0.25 day^{-1}, respectively, while bioreactor 3 operated at $(F/M)_{COD}$ = 0.27 day^{-1}, expressed in terms of biomass corrected for the presence of PAC. Thus, in comparison with Luthy et al., the current study employed a somewhat higher loading.

Although there are some differences between feed composition and loading to the bioreactors, the results of Luthy et al. are comparable to those of the present study. Both investigations found that either non-PAC activated sludge or PACT could successfully remove organic contaminants and produce an effluent with low BOD. Both studies also showed that it was possible to achieve nitrification, with an effluent ammonia being in the range of 20 mg/L. (However, the current study found that nitrification was sensitive to environmental changes.) Luthy et al. showed that PACT treatment would produce a colorless effluent, in contrast to the performance of bioreactor 3A in the SRC-I study, which gave an effluent color in the range of 1,000 APHA units. However, both studies showed that treatment of bioreactor effluent by GAC removed color essentially completely. Also, the SRC-I wastewater study showed that GAC treatment of bioreactor effluent could remove TOC to detection limits, while Luthy et al. showed that a residual of approximately 100 mg/L TOC was not readily adsorbable on activated carbon.

In summary, there is generally good agreement between the study of biological treatment of extracted and stripped coal gasification wastewater and this study with extracted and stripped coal liquefaction water. Both investigations show that solvent extraction offers various advantages.

Another study by Luthy (1981) summarized results of various investigations of biological treatment of coal gasification wastewaters that have not been pretreated by solvent extraction to reduce organics. These studies served as background for the investigation with SRC-I process wastewater. The studies by Reap et al. (1978) and Drummond et al. (1981) discussed previously indicated that high-strength wastewater required dilution prior to treatment and that biological oxidation resulted in relatively low microbial yields. This was believed to be a

result of inhibitory constituents in the wastewater, perhaps those formed as a result of biological treatment. It was concluded from review of these investigations with nondephenolated coal gasification wastewaters that under suitable conditions biological treatment adequately removes BOD, COD, phenolics, ammonia-nitrogen, and cyanogen-nitrogen.

Various studies on activated sludge treatment of coke plant wastewaters have been reported. Barker et al. (1973) evaluated biological removal of carbonaceous and nitrogenous compounds in a three-stage process. It was found that substantial nitrification was difficult to achieve; part of the problem was attributed to fluctuating influent composition and equipment malfunctions. Adams (1975) performed studies with an evaporative condensate containing phenol and ammonia, but little other contamination. Single-stage nitrification was feasible if $(F/M)_{COD}$ was approximately 0.2 day^{-1} or less.

Luthy and Jones (1980) reported results of treatment of coke plant wastewater by activated sludge at different values of HRT and SRT. The data showed a yield coefficient of Y = 0.13 (COD basis), which was in the range of 0.10 to 0.29 reported for treatment of nondephenolated gasification wastewater (Luthy, 1981). For both dephenolated and nondephenolated SRC-I wastewaters, the apparent yield coefficient observed by this study was between 0.10 and 0.19. The coke plant study showed that nitrification efficiency increased to 85% as $(F/M)_{COD}$ decreased from 0.75 to 0.16 day^{-1}. A first-order nitrification rate coefficient was estimated to be approximately 0.0001 L/mg per day. This nitrification rate coefficient is lower than that observed in second-stage nitrification bioreactors, because much of the MLVSS in a single-stage system consists of nonnitrifying microorganisms. Nonetheless, this value is in the range of 0.00003-0.0004 L/mg per day which is calculated for first-stage bioreactors 1A and 2A with SRC-I wastewater. The basis of comparison for these systems includes influent SCN-N as well as NH_3-N, since biological degradation of SCN^- releases NH_3.

Bhattachsyya and Middleton (1981) performed tests to evaluate single-stage nitrification of coke plant wastewater at very long SRTs (100-200 days). A slug dose of 1,500 mg/L PAC was added to the mixed

liquor in order to provide good settling characteristics that were needed to maintain exceptionally high values of SRT. They achieved essentially complete nitrification with PAC-corrected loadings of $(F/M)_{COD}$ = 0.135 day^{-1} and $(F/M)_{NH3\text{-}N,SCN\text{-}N}$ = 0.015 day^{-1}. An observed yield coefficient (COD basis) was 0.4 and decay coefficient was 0.80 day^{-1}. The current study with SRC-I wastewater showed that some nitrification occurred in the first stage; however, very low levels of effluent ammonia were not obtained by the single-stage configuration. This is due to the higher COD loading (0.29 and 0.26 day^{-1} for bioreactors 1A and 2A, respectively) and higher NH_3-N, SCN-N loading (0.048 day^{-1} for both reactors 1A and 2A) for the SRC-I study compared to the study of Bhattachsyya and Middleton.

Adams and Eckenfelder (1977) report second-stage nitrification rate constants for pulp and paper wastewater (0.0005 L/mg per day), refinery wastewater (0.00043 L/mg per day), and phenolic waste (0.0009 L/mg per day). These values are similar to values of 0.0005 and 0.0009 observed for bioreactors 1B and 2B, respectively, where the calculation did not include the mixed-liquor PAC concentration of 500 mg/L.

Ganczarazyk (1979) conducted studies to evaluate second-stage nitrification of coke plant wastewater. Laboratory and pilot plant studies showed that good ammonia removals could be achieved with $(F/M)_{NH3\text{-}N} \leq 0.02$ mg of NH_3-N/mg of MLSS per day and long SRT values. Comparison with results of two-stage treatment of dephenolated SRC-I water confirms this observation to a certain extent. Bioreactor 1B produced an effluent ammonia concentration of 6 mg/L at one $(F/M)_{NH3\text{-}N}$ = 0.0009 mg of NH_3-N/mg of MLVSS per day. Likewise, when bioreactor 2B was operated at a 2-day HRT, effluent was 6 mg/L at an $(F/M)_{NH3\text{-}N}$ = 0.014 mg of NH_3-N/mg of MLVSS per day. However, when bioreactor 2B was operated at a 1-day HRT, effluent ammonia was 29 mg/L at an $(F/M)_{NH3\text{-}N}$ = 0.08 mg of NH_3-N/mg of MLVSS per day. Although the data are limited, there is indication that second-stage nitrification of dephenolated SRC-I water will produce low effluent ammonia at loadings less than approximately 0.02 day^{-1} (PAC-corrected MLSS basis) or approximately 0.015 day^{-1} (PAC-corrected MLVSS basis). If nitrification is a treat-

ment goal, consistent performance requires that influent to the bioreactors be steady. As discussed previously, PAC addition is one technique which may be invoked to help manage the problem of fluctuating feed characteristics adversely impacting nitrification performance.

TERTIARY TREATMENT

Tertiary treatment consisted of four unit processes: (1) coagulation and clarification, including post-biooxidation tar acid removal; (2) dual media filtration; (3) activated carbon adsorption; and (4) ozonation. Post-biooxidation tar acid removal was evaluated briefly to see if the need existed. The tertiary treatment experiment focused mainly on dephenolated wastewaters, because the tertiary treatment for nondephenolated wastewaters had been studied previously (ICRC, 1983a; Watt et al., 1984). Wherever appropriate, results from other studies for the nondephenolated wastewater are referenced and compared with the results of this study.

Tar Acid Removal

Jar tests were performed on the effluent from Unit 1B (DP/NPAC system) to determine if tar acid removal by acidification with sulfuric acid was applicable for the dephenolated systems. The following results were obtained:

pH	TSS (mg/L)	Supernatant TOC (mg/L)
7.9 (as is)	250	53
5.8	260	55
4.5	249	46
3.8	241	52
3.1	251	53
2.5	248	47

The data show that suspended solids, which are the indicator of tar acid precipitates, did not increase significantly, nor did TOC reduction.

The effluents from bioreactors 2B and 3 were also checked by filtering them to remove visible suspended solids, and then lowering the pH to 2.5; no visible precipitate formed. Thus, tar acid precipitation was eliminated as a unit process.

The fact that dephenolization of the feed to the bioreactors eliminated the need for post-biooxidation tar acid precipitation is significant. Without dephenolization, tar acid removal would be required both before and after biooxidation. The data for the non-dephenolated wastewater obtained from the other study (Watt et al., 1984) are referenced here for comparison:

pH	TSS (mg/L)	VSS (mg/L)	TOC (mg/L)
7.3	300	-	220
6.1	396	234	222
5.5	410	242	218
4.0	416	258	-
3.3	508	292	-
2.9	500	326	-
2.4	550	374	122
2.1	556	380	-

Clearly, acidification not only precipitated more "tar acids," but it also removed about half of the TOC in the bioreactor effluent.

Coagulation

Jar tests were also performed to measure coagulation. Chemicals were selected based on test work that had been performed on nondephenolated bioreactor effluent (ICRC, 1983a). Ferric chloride, ferric sulfate, alum, and lime were evaluated. "Abbreviated" silt density index (SDI) tests were performed to evaluate the supernatant clarity and the suitability for feeding to reverse osmosis when the plant effluent is to be recycled. These "mini" tests consisted of passing 25 mL of supernatant through a 0.45-mm filter under 28 in. of vacuum, and timing the rate at which the water passed through. Faster rates indicated that fewer colloidal materials were present. Of various polymers that were

evaluated, only Magnifloc 835-A significantly improved the floc size and settleability rate. This polymer was used for the SDI test at a rate of 0.5 mg/L in all cases.

Results of the coagulation tests for the nondephenolated bioreactor effluent are as follows:

Chemicals	Dosage (mg/L)	Filtration time (sec)
$FeCl_3 \cdot 6H_2O$	200	35
	400	20
	600	8
	800	6
$FeSO_4 \cdot 7H_2O$	200	33
	400	18
	600	8
	800	7
$Al_2(SO_4)_3 \cdot 18H_2O$ (alum)	400	60
	600	60
	800	60
	1,000	60

Both dephenolated effluents were also tested; no significant differences in coagulation were observed. Based on the testing, ferric chloride ($FeCl_3 \cdot 6H_2O$) at a dosage of 800 mg per L of effluent was found to be effective for both dephenolated and nondephenolated wastewaters (Watt et al., 1984). Ferric chloride was selected rather than ferric sulfate because large quantities of sulfate were already present in the wastewater, which could interact with calcium, which was also abundant, to form scale.

All the large batches of dephenolated water for the toxicology tests were treated with 800 mg of a 10% $FeCl_3 \cdot 6H_2O$ solution per liter of wastewater and then neutralized with 10% $Ca(OH)_2$ solutions. Also added was 0.5 mg of Magnifloc 835-A per liter. The solids formed were allowed to settle under quiescent conditions, and the supernatant was decanted.

The following bioreactor effluent batches were coagulated to generate the toxicology samples:

System no. & description	Bioreactor	Volume treated (L)
1: DP/NPAC	1B	83.5
2: DP/NPAC	2B	134
2: DP/NPAC	2B	7.6
3: DP/PAC	3	65
3: DP/PAC	3	103

An 83.5-L batch of bioreactor 1B effluent (DP/NPAC) was processed for the toxicology study; 670 mL of 10% $FeCl_3 \cdot 6H_2O$ was added. Addition of ferric chloride lowered the pH from 6.9 to 3.3. The pH was then raised to 7.2 with 210 mL of 10% $Ca(OH)_2$; 42 mL of a 0.1% solution of Magnifloc 835-A was also added. The sludge was allowed to settle, and the supernatant was pumped off. A 5-gal sample of the supernatant was sent to the subcontractor for mutagenicity tests, and a 1-gal sample was submitted for analyses (see summary in Table 24). The remaining supernatant was held for futher processing.

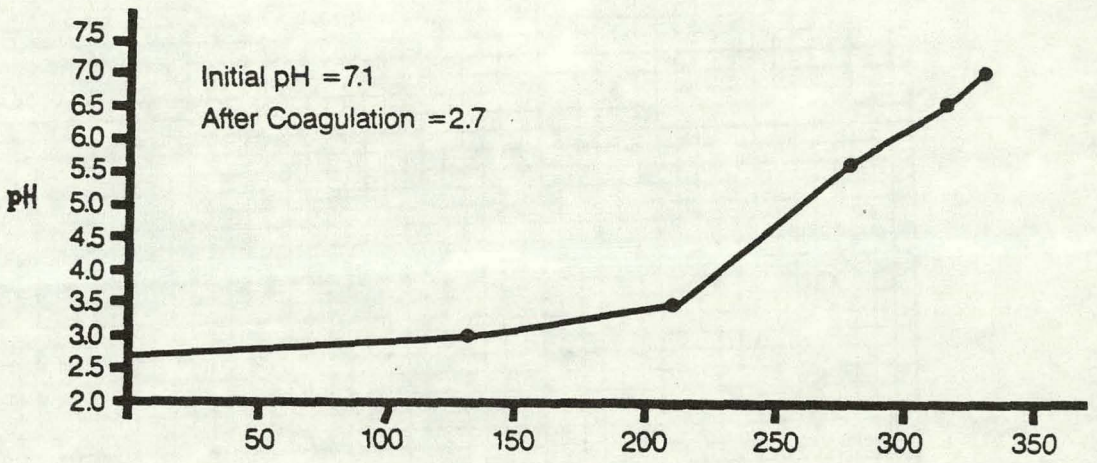
A second large batch (134 L) of bioreactor effluent was processed from Unit 2B (DP/NPAC). A 1,075-mL dose of 10% $FeCl_3 \cdot 6H_2O$ was added to the batch, which lowered the pH from 7.1 to 3.0. The pH was then raised to 6.9 with 400 mL of 10% $Ca(OH)_2$. Magnifloc 835-A was added at 0.5 mg/L to aid flocculation. The sludge was allowed to settle, and resulted in a sludge volume of 5 l containing 12,800 mg/L TSS and 5,310 mg/L VSS. The TOC was reduced from 52 to 35 mg/L during the coagulation step. No other samples were taken and the remainder of the supernatant was held for further processing.

A small, 7.6-L batch from Unit 2B was also coagulated. The initial pH was 7.1. After 60.6 mL of 10% $FeCl_3 \cdot 6H_2O$ was added, the pH dropped to 2.7. The pH was then raised to 7.1 with 10% $Ca(OH)_2$. Figure 29 graphs the amount of added lime required in the coagulation step. A 1-L settling test was conducted on this batch coagulation; settling was very rapid and the supernatant suspended solids analysis was only 4 mg/L. Figure 30 illustrates the settling curve for this batch.

Two large batches of System 3 (DP/PAC) bioreactor effluent were coagulated. The first was a 65-L batch, to which 520 mL of 10% $FeCl_3 \cdot 6H_2O$ was added, lowering the pH from 7.2 to 3.7. Then 150 mL of

Figure 29

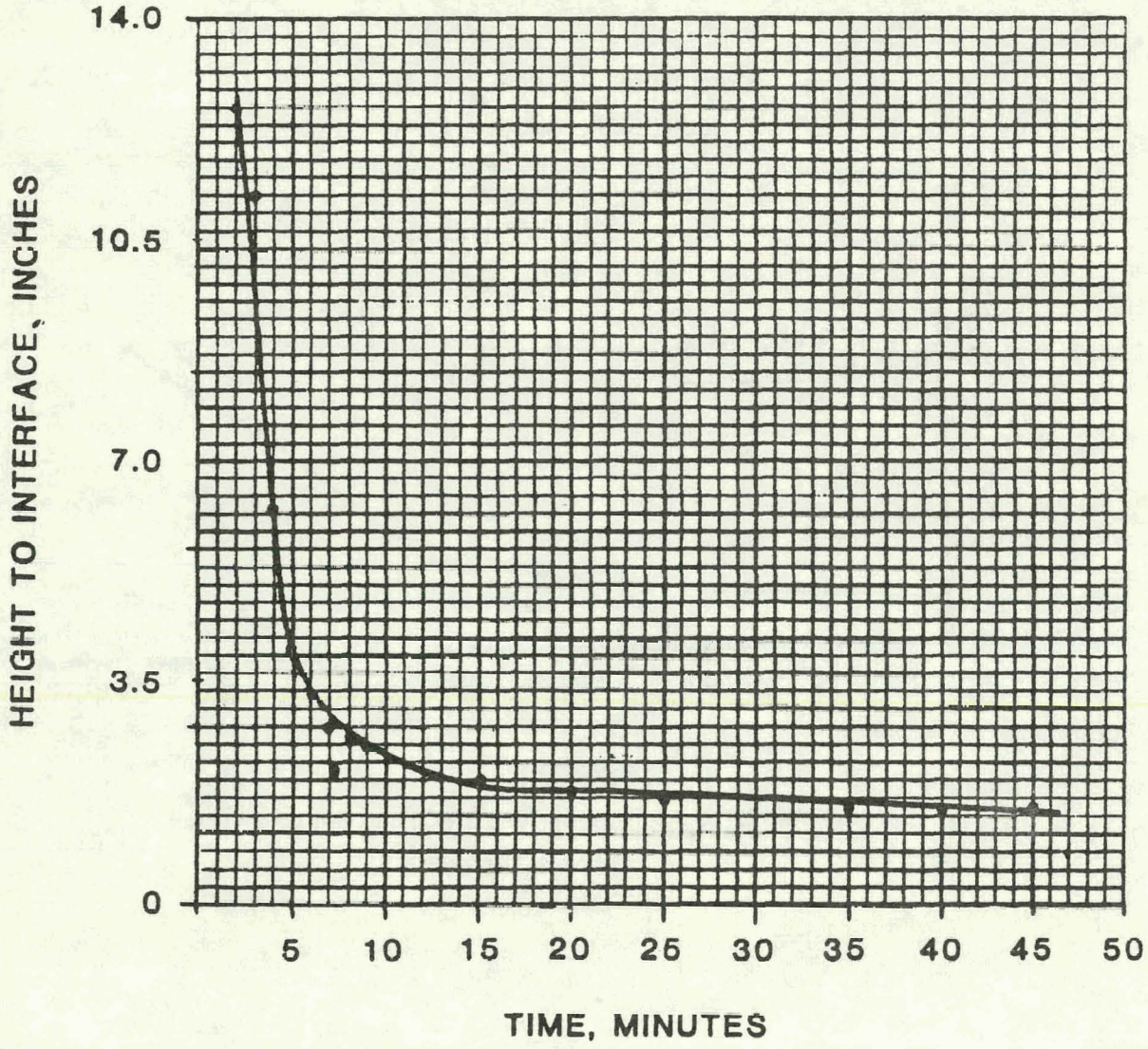
Lime Required for Coagulation
(Unit 2B, Small Batch)



Cumulative Lime Addition (ml 10% $Ca(OH)_2$/ liter wastewater)
DP/NPAC Effluent

Figure 30

Settling Curve for Unit 2B Coagulation

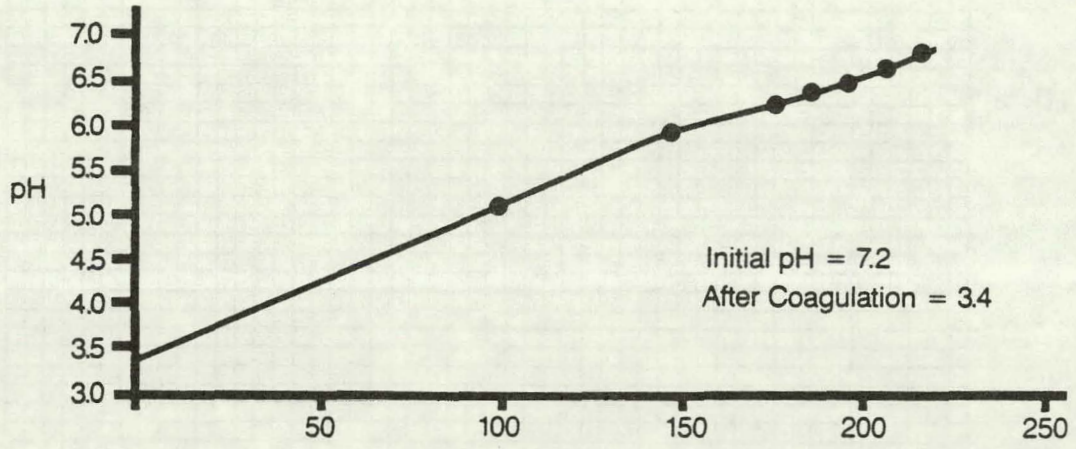


Initial Solids Conc.:276 mg/1

Supernatant Solids: 4 mg/1

Figure 31

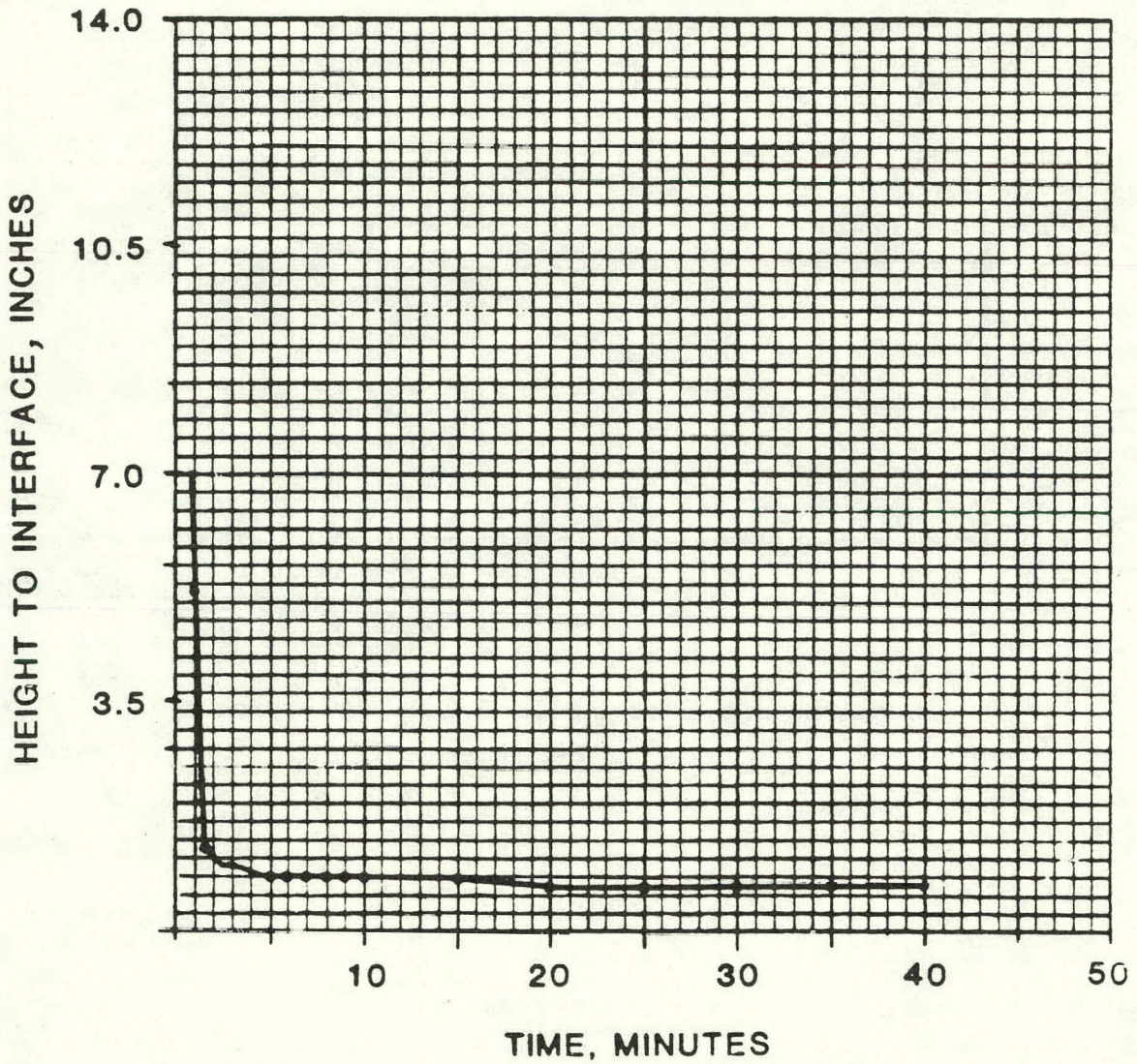
Lime Required for Coagulation
(System 3 Bioeffluent)



Cumulative Lime Addition (ml 10% $Ca(OH)_2$ / liter wastewater)
DP/PAC Effluent

Figure 32

Settling Curve for System 3 Coagulation



10% $Ca(OH)_2$ was added, raising the pH to 6.5. The same polymer, Magnifloc 835-A, was added to the wastewater at 0.5 mg/L. The suspended solids were allowed to flocculate and settle. The resulting sludge volume was 2.2 L containing 14,220 mg/L TSS and 5,430 VSS. The TOC was reduced from 61 mg/L in the biological effluent to 26 mg/L in the coagulation supernatant.

The second batch (103 L) was treated with 825 mL of 10% $FeCl_3 \cdot 6H_2O$, which lowered the pH from 7.2 to 3.4. Then, 222 mL of 10% $Ca(OH)_2$ and 0.5 mg/L of 835-A polymer were added. The curve shown in Figure 31 indicates the amount of lime required in the coagulation step. A 1-L settling test on this batch coagulation revealed that the settling rate was very rapid and the supernatant suspended solids analysis was only 5 mg/L (see Figure 32). No samples were taken at this point and both batches were held for further processing.

Coagulation is known to remove organic compounds. Samples taken for toxicology were analyzed for chemical constituents. The following table shows representative removals of key parameters by coagulation:

	NDP/PAC		DP/NPAC	
	Bioeff	After coag.	Bioeff	After coag.
COD (mg/L)	810	385	398	145
TOC (mg/L)	210	34	80	10
BOD (mg/L)	24	2	17	4
TSS (mg/L)	300	10	18	4
Turbidity (NTU)	120	8.8	100	2.9
Phenolic (mg/L)	0.026	0.013	0.025	0.004
Color (APHA)	3,000	750	1,000	400

Ammonia Removal for Toxicology Samples

Because biological ammonia removal and nitrification were not consistent, and the expected ammonia concentrations in the demonstration plant effluent will be much lower, steam-stripping should be effective for ammonia control. To remove artifacts, the residual ammonia in the bioreactor effluents was treated with clinoptolite.

Filtration

All three coagulated wastewaters were then passed through a 4-in.-diameter sand filter at a surface loading rate of 2 gpm/ft^2. During processing of the wastewaters, no pressure drop was observed through the filter because of the low suspended solids level after coagulation. Six gallons of wastewater were sampled from bioreactor 1B: 5 gallons were used for mutagenicity tests and 1 gallon was submitted for analyses. No other samples were collected at this point from either System 2B or 3.

Granular Activated Carbon Adsorption

Carbon isotherms, based on removal of TOC and color, were generated for the effluents of five biological systems. The carbon isotherms for the two nondephenolated systems were actually generated from another study (Watt et al., 1984), which evaluated pretreatment of the feed to a reverse osmosis unit. The results from that study are also reported here to facilitate comparison between dephenolated and nondephenolated wastewaters. The results are listed in Table 22.

Carbon Adsorption Models. Two models were used to evaluate the data (Metcalf & Eddy, Inc., 1979):

$$\text{Langmuir:} \quad X/M = abC/[1 + bC]$$

$$\text{Freundlich:} \quad X/M = kC^{1/n}$$

where X/M = units of contaminant adsorbed/weight of carbon at equilibrium

C = concentration of the contaminant in equilibrium with carbon

a, b, k, and n - experimentally determined constants

With the Langmuir model, C/(X/M) is plotted vs. C; with the Freundlich, X/M is plotted vs. C. Freundlich isotherms are more generally used than Langmuir, especially for wastewater treatment. The Langmuir method, which is older, is more appropriate for pure substrates

Table 22

Carbon Isotherm Data for TOC and Color

System no.	1		2		3		4		5	
	DP/NPAC		DP/NPAC		DP/PAC		NDP/NPAC[a]		NDP/PAC[a]	
Carbon dose (mg/L)	TOC (mg/L)	Color (units)	TOC (mg/L)	Color (units)	TOC (mg/L)	Color (units)	TOC (mg/L)	Color (units)	TOC (mg/L)	Color (units)
Blank	25	300	28	250	19	225	52	750	38	500
50	21	200	21	200	17	100	-	-	-	-
100	16	120	17	150	12	75	42	750	32	400
150	15	120	13	100	12	50	-	-	-	-
200	9	60	11	75	9	50	26	330	23	250
250	3	5	8	50	10	38	-	-	-	-
300	2	5	3	5	3	5	-	-	-	-
500	2	5	2	5	2	5	13	150	9	100
750	-	-	-	-	-	-	13	65	6	50
1,000	-	-	-	-	-	-	4	10	4	20
1,500	-	-	-	-	-	-	ND	5	ND	ND
2,000	-	-	-	-	-	-	ND	ND	ND	ND

[a]After Watt et al., 1984.

and very low contaminant concentrations. Linear regression analysis was performed on all isotherms.

The regression coefficients for the Langmuir model are almost all higher than those for the Freundlich. The reason for this is uncertain. The relatively low contaminant levels in the effluents may have resulted in monolayer adsorption, which is a key assumption of the Langmuir model. Also note that the regression coefficients are based on a linear interpretation of the data, which is not necessarily the curve of best fit. Langmuir isotherms are included (see Figures 33-37).

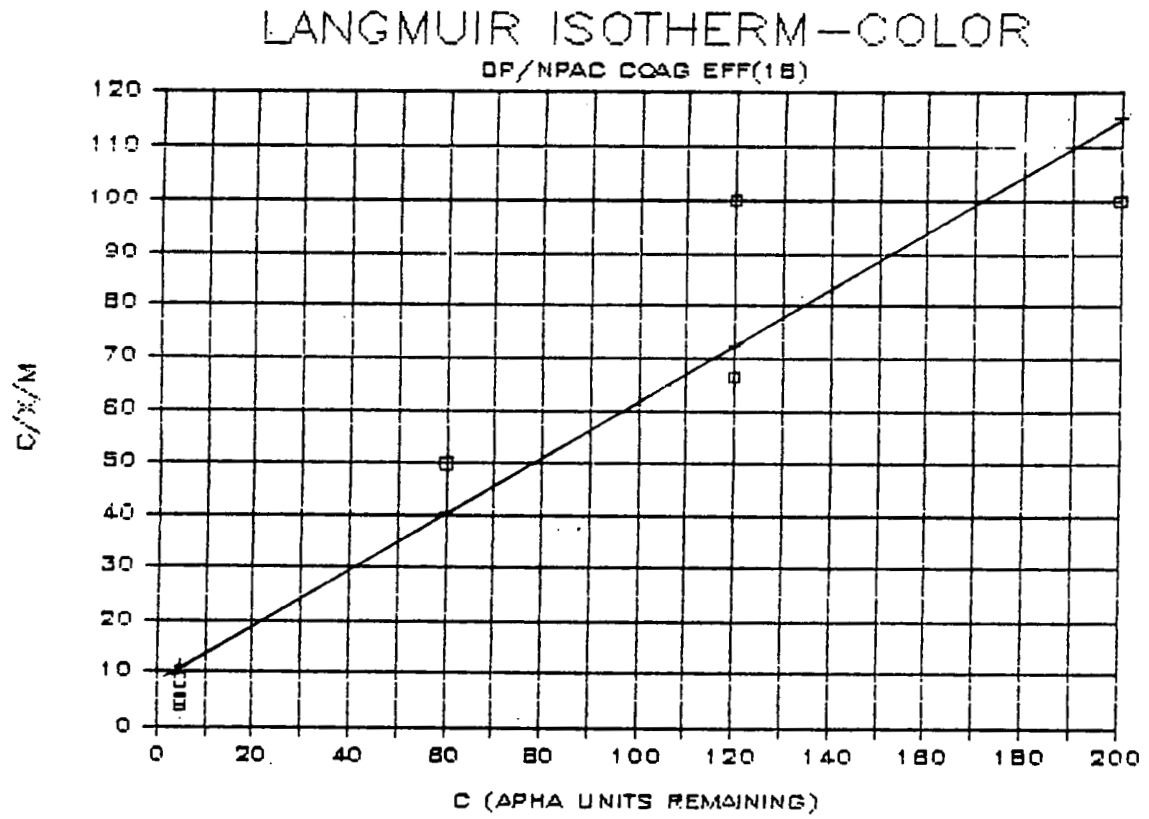
Isotherms are primarily used to compare different carbons (which was not part of this study), to determine the lowest achievable contaminant levels, and to measure the maximum theoretical carbon loading. As shown on the isotherms, and also in Table 22, very low levels were achieved for both TOC and color for all five systems. The nondephenolated effluents had higher contaminant levels to begin with, and, at equivalent carbon dosages, maintained these higher concentrations in comparison to the dephenolated systems.

The maximum theoretical TOC adsorption capacities, based on both Freundlich and Langmuir isotherms, are as follows:

		X/M at influent level (mg of TOC adsorbed/g of carbon)	
Wastewater	Influent TOC (mg/L)	Freundlich	Langmuir
DP/NPAC	25	82	79
DP/NPAC	28	131	126
DP/PAC	19	49	45
NDP/NPAC	52	122	111
NDP/PAC	38	76	66

Figure 33

Langmuir Isotherms--Color and TOC
(DP/NPAC Coagulation Effluent, Unit 1B)



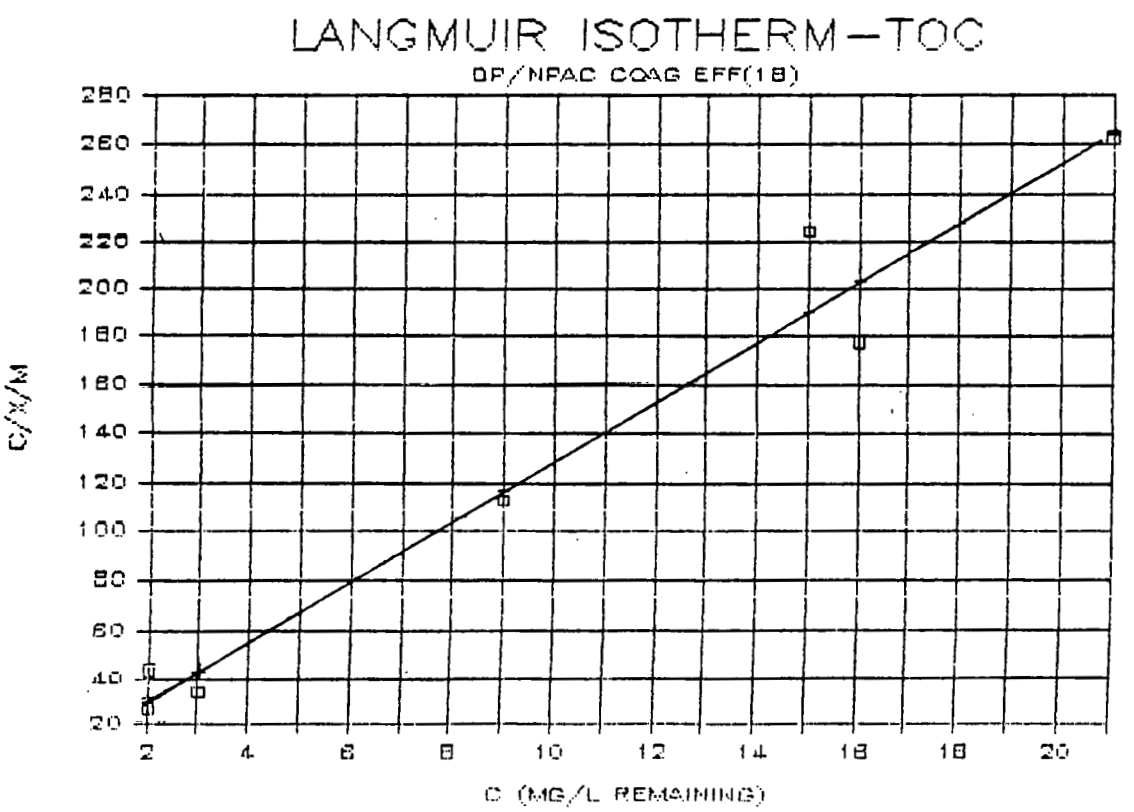
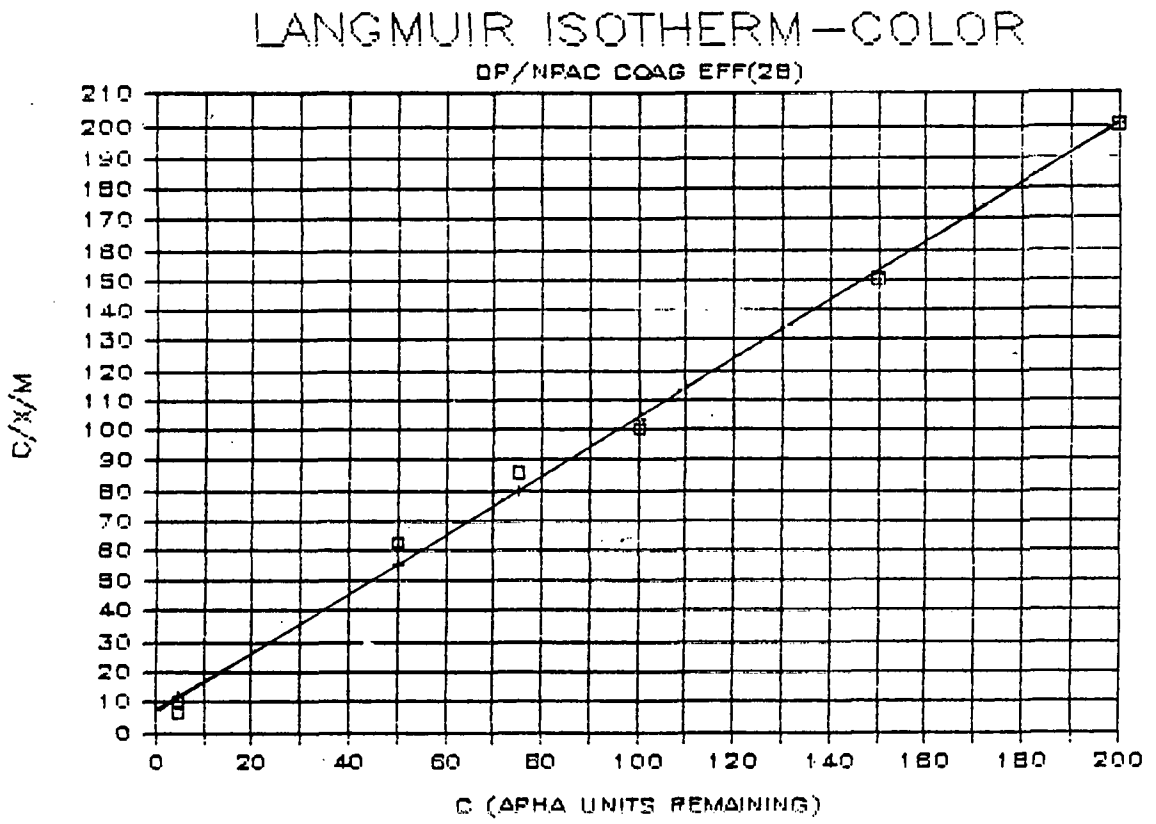


Figure 34

Langmuir Isotherms--Color and TOC
(DP/NPAC Coagulation Effluent, Unit 2B)



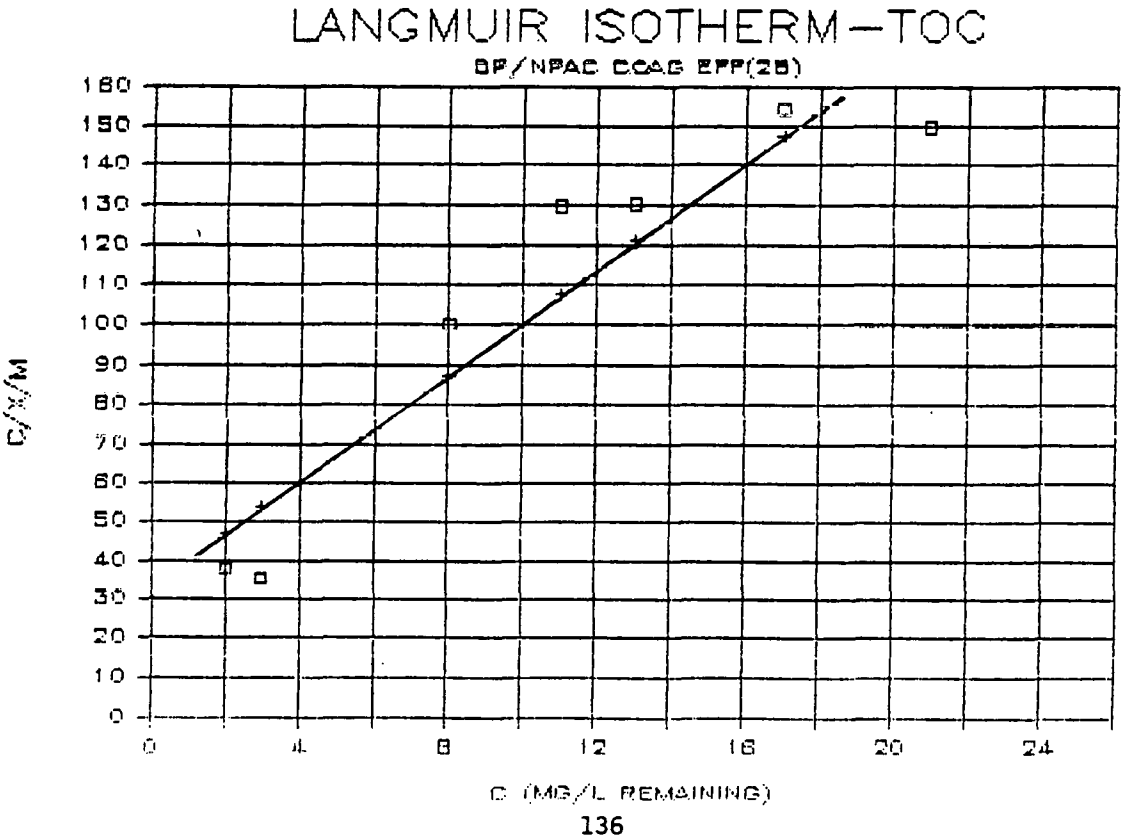
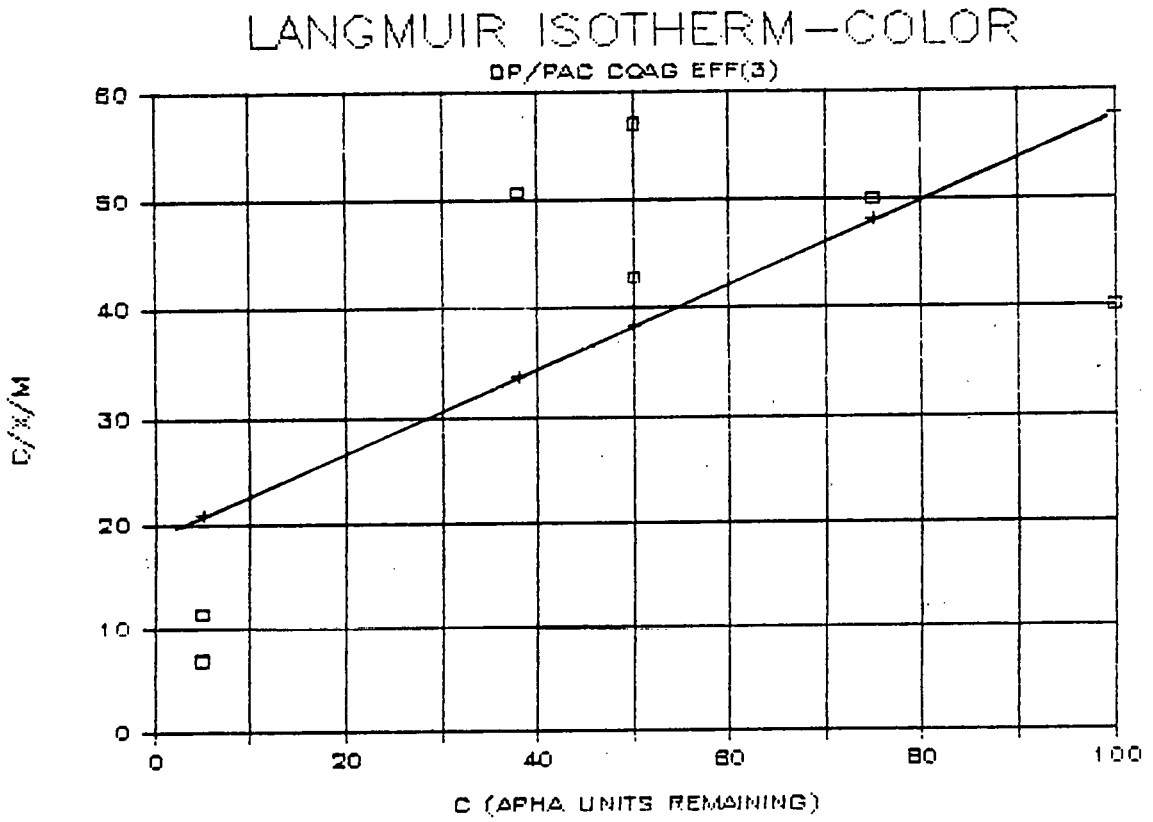


Figure 35

Langmuir Isotherms--Color and TOC
(DP/PAC Coagulation Effluent, Unit 3)



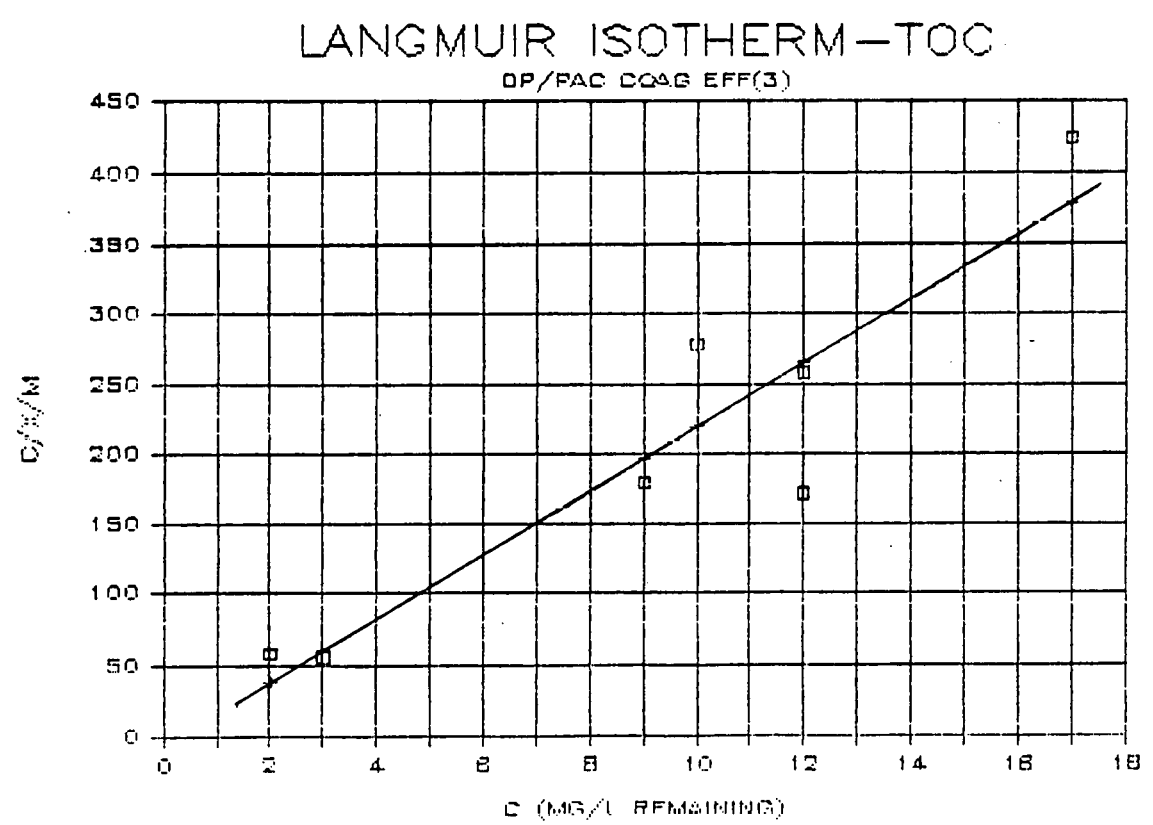
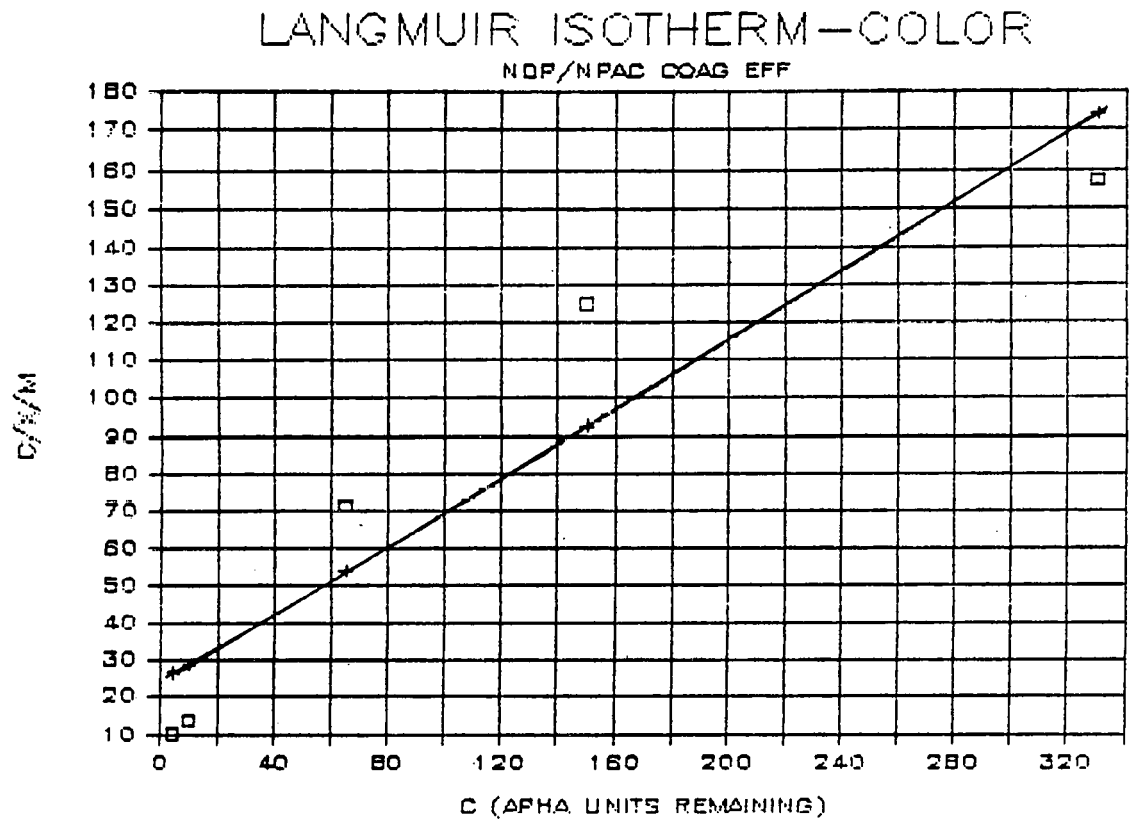


Figure 36

Langmuir Isotherms--Color and TOC
(NDP/NPAC Coagulation Effluent)



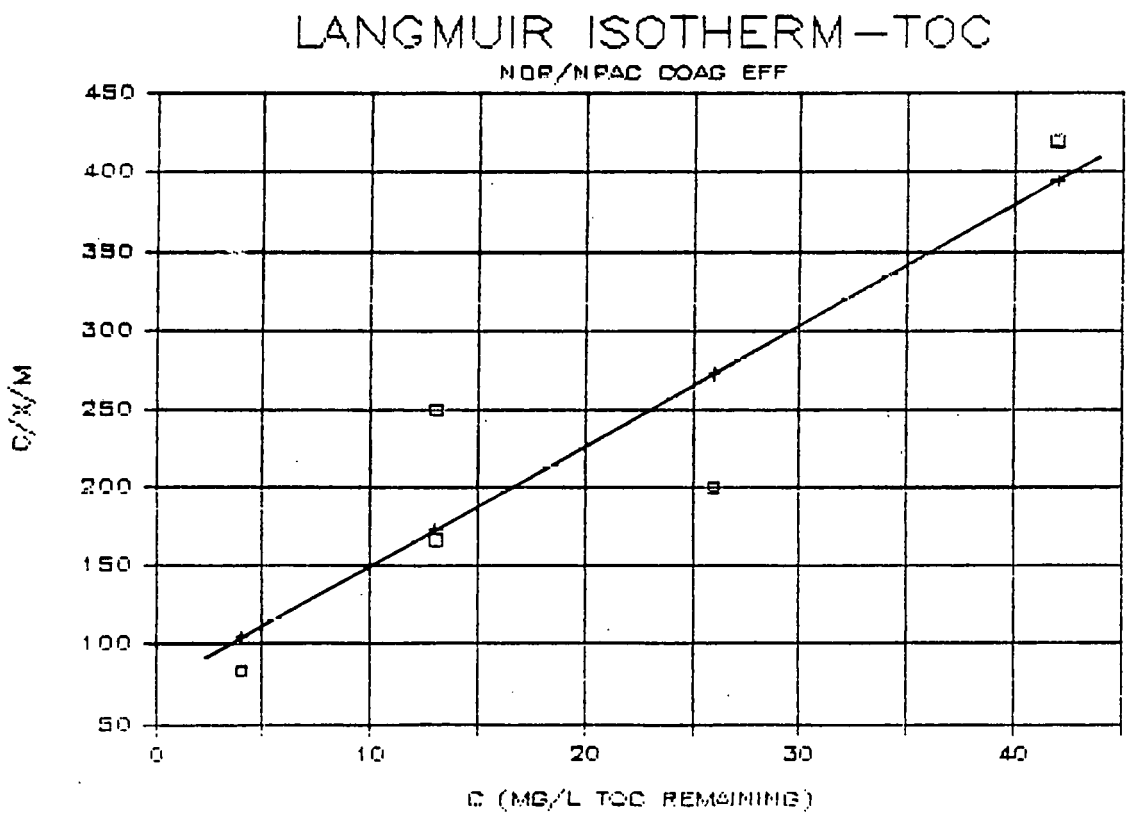
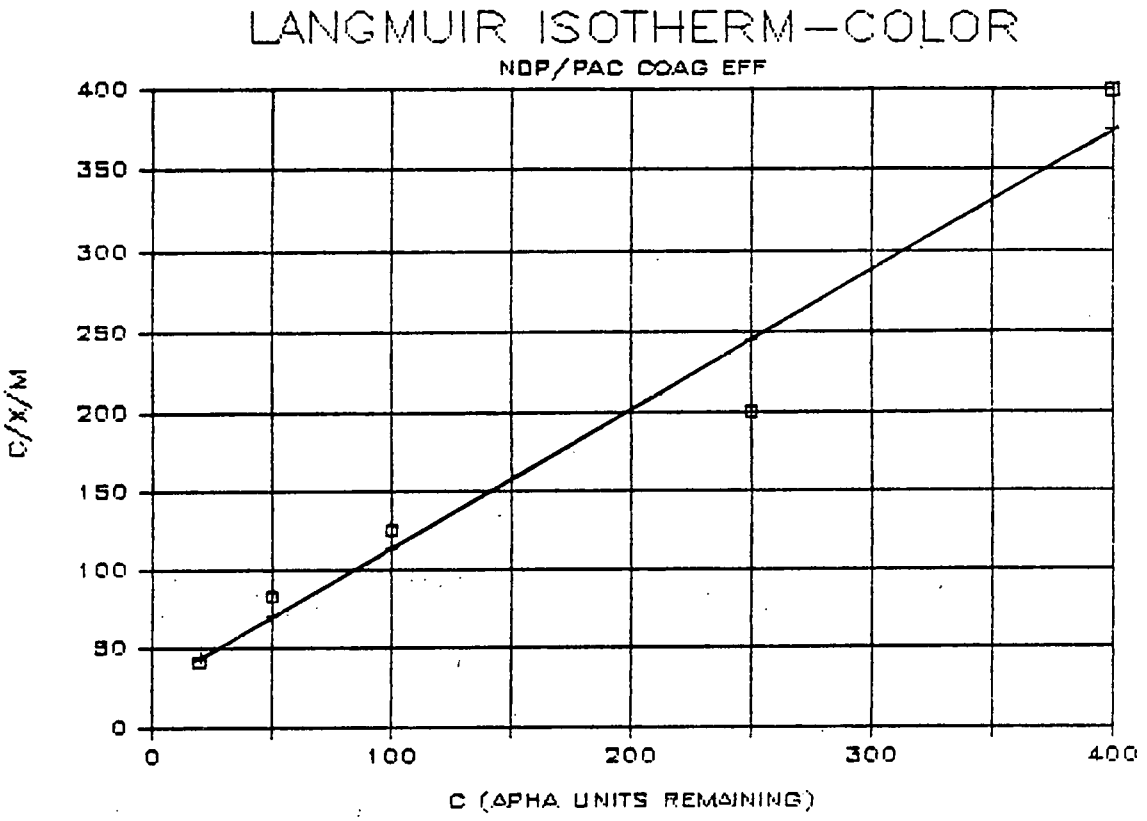
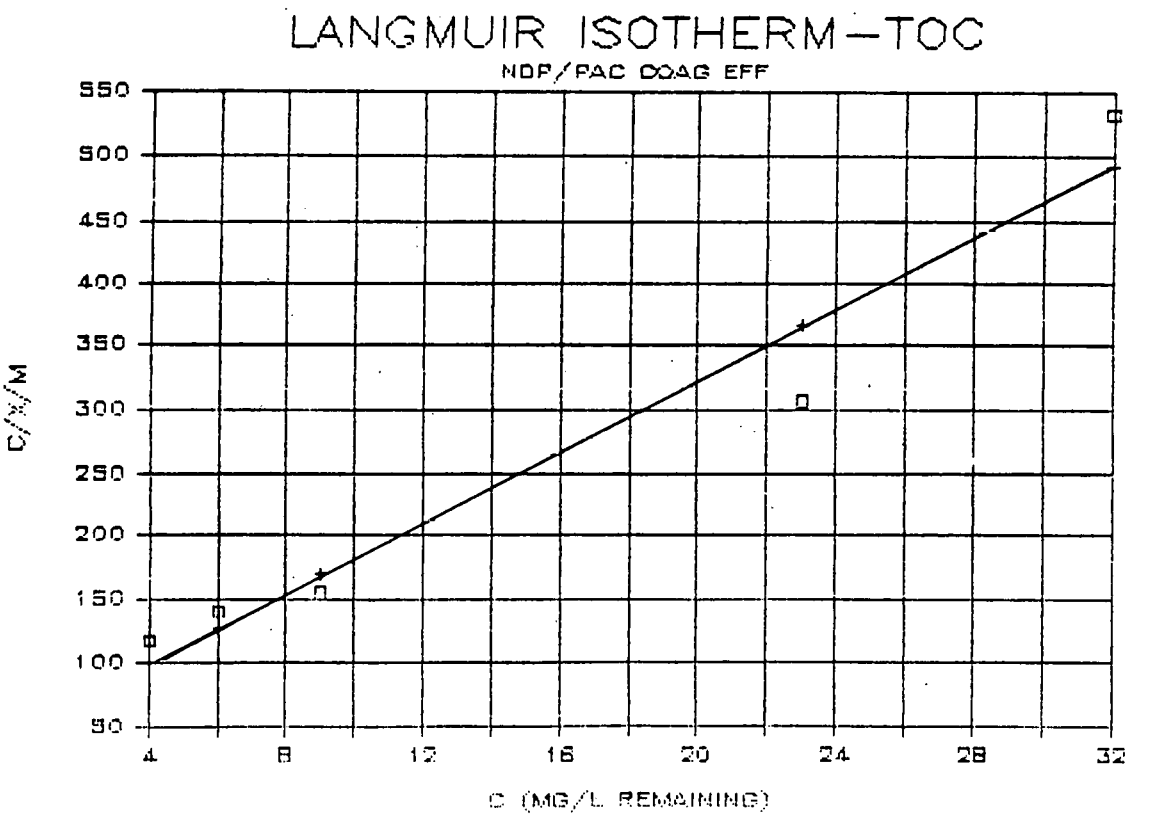


Figure 37

Langmuir Isotherms--Color and TOC
(NDP/PAC Coagulation Effluent)





Corresponding maximum color adsorption capacities are:

Wastewater	Influent color (APHA units)	X/M at influent level (APHA units adsorbed/g of carbon) Freundlich	Langmuir
DP/NPAC	300	1,803	1,775
DP/NPAC	250	1,051	1,002
DP/PAC	225	2,091	2,113
NDP/NPAC	750	2,202	2,067
NDP/PAC	500	1,257	1,084

As the data show, the maximum adsorption capacities are very similar for both models. Because the regression coefficients for the Langmuir model were somewhat higher, the Langmuir capacities are referenced in the following discussion. Note, however, that the discussion is valid for either set of isotherms.

The maximum TOC capacities, as shown by the Langmuir isotherms, are higher for the non-PAC systems than those for the PAC. This is true for both the dephenolated and nondephenolated feeds.

This suggests that the residual TOC in the effluent from the PAC bioreactors comprised less adsorbable organic species than that from the non-PAC reactors. One explanation for this is that the readily adsorbable organics had been preferentially adsorbed by the PAC. Generally, the higher molecular weight compounds are more easily adsorbed by carbon, but are more difficult to remove by biological oxidation. It is hypothesized that System 1, with a 2-day detention time per reactor (double that of System 2), was able to provide partial oxidation of the higher weight compounds. This might have produced an effluent less amenable to carbon treatment, resulting in the lower adsorption capacity.

The data for the color isotherms are somewhat ambiguous. They follow a pattern similar to the TOC isotherms for the nondephenolated feeds (2,067 vs. 1,084 APHA units/g of carbon for non-PAC vs. PAC). However, the capacity for System 1 was higher, not lower, than that for

System 2. Also, for the dephenolated feeds, the capacity of the PAC effluent was higher than that for both non-PAC effluents. The reason for these relationships is not known. However, as Table 21 shows, low levels of TOC and color coincide. This suggests that TOC be used as the basis of design, and color removal will also be achieved.

Comparisons of X/M values for the dephenolated and nondephenolated wastewaters did not reveal any pattern suggesting that the two types of wastewater are different. The effect of dephenolization on granular activated carbon adsorption appears to be greater for residual TOC in the influent, or loading to the carbon columns, rather than the adsorption capacity itself.

As discussed in Watt et al. (1984), carbon breakthrough tests were conducted on a nondephenolated PAC effluent. (The quantity of dephenolated effluent was insufficient to achieve breakthrough.) The isotherms indicate that the carbon loading for the design (DP/NPAC) system can be approximated from the breakthrough run. During that test, the influent TOC was 44 mg/L. If this same concentration is used in the isotherm equations to calculate X/M, the results are 80 and 66 mg of TOC adsorbed/g of carbon for the DP/NPAC and NDP/PAC systems, respectively. These capacities are relatively close, and show that continuous column testing can be applied to the design condition.

Ozonation

In addition to disinfection, the original goal of ozonation was to remove residual contaminants such as COD, TOC, phenolics, color, and cyanides. Because biooxidation, coagulation, and activated carbon adsorption were very effective in removing most of the contaminants, the feed to ozonation (i.e., the carbon adsorption effluent) contained nondetectable amounts of most of the contaminants. The only contaminant appreciably affected by ozonation was COD.

Screening tests to determine ozone dosage and contact times were first performed on NDP/PAC samples that had undergone tertiary treatment through carbon adsorption. As mentioned above, pollutant concentrations at this point were very low, often nondetectable. Therefore, effluent from coagulation, which had not yet been carbon-treated, was principally used in screening work. The characteristics of this sample, in terms of

the pollutants of interest in ozonation, were: 38 mg/L TOC, 245 mg/L COD, and 700 APHA color units.

The first series of screening runs on effluent from coagulation was made at a constant ozone concentration in the feed gas (2.01-2.47% O_3 in O_2), with three different gas-flow rates--0.5, 0.79, and 1.07 L/min, per liter of ozonation reactor. The reaction was monitored for about 40 min.

Color removal was complete under all conditions, but shorter contact times were required at higher gas flows. COD also was removed at faster rates with higher gas flows, but leveled off at about 40% removal. The relationship of flow rate to TOC removal was not as conclusive. TOC was reduced by about 60%.

A second series of tests was conducted with different ozone concentrations (1.64 and 4.19% O_3) at a constant flow rate of about 0.8 L/min-L. This rate had demonstrated good removal efficiency in the first set of runs. Color was completely removed in all runs in less than 10 min, and COD was reduced by about 40% at all concentrations. However, TOC removal was not as consistent as in the first set of runs; removal was poor at the low ozone concentrations.

A detailed description of the screening runs, ozone mass balances, and utilization is found in the report on the Reverse Osmosis Feed Pretreatment and Flat Cell Test (Watt et al., 1984).

Based on the screening and development work, an ozone dosage of about 280 mg/min was applied to effluents for toxicology samples. These samples were ozonated in situ (in 55-gal drums) for 4 hr. Pollutant concentrations in the influent to ozonation (effluent from activated carbon adsorption) were generally below detectable limits. COD influent was at higher concentrations, and ozonation did produce a measurable reduction. Table 23 shows the results of ozonation.

Ozonation was effective for COD reduction and the reduction was more significant for nondephenolated wastewater than dephenolated wastewater, which had a low COD concentration to begin with before ozonation. The degree of significance depends on the effluent limits for COD. The anticipated average COD effluent limit for SRC-I waste-

Table 23

Results of Ozonation
(mg/L Unless Stated Otherwise)

	DP/NPAC		DP/PAC		NDP/NPAC[a]		NDP/PAC[a]	
Treatment[d]	B	A	B	A	B	A	B	A
Sample no.[c]	(7500)	(7501)	(7503)	(7504)	(7494)	(9319)	(7490)	(7491)
COD	74	46	115	47	424	114	274	143
TOC	ND[b]	ND	ND	ND	ND	12	ND	ND
Color (APHA units)	ND	10	ND	ND	ND	ND	25	ND
Cyanide	ND	ND	ND	ND	ND	ND	ND	ND
Thiocyanate	ND	ND	ND	ND	ND	-	0.3	ND
Nitrite	14	ND	82	ND	0.59	-	0.43	0.33
Nitrate	121	72	28	81	101	123	67	54
Phenolics (µg/L)	7	5	10	13	ND	ND	4	-
Sulfide (µg/L)	10	4	6	ND	ND	-	6	4

[a]From Watt et al. (1984).
[b]ND = nondetectable.
[c]See Figures 7A and 7B for the sampling points:
[d]B, before ozonation; A, after ozonation.

water based on the Development Document (EPA, 1979) for Petroleum Refining Point Source Category Effluent Limitations (FR. 47(201), October 18, 1982) is 180 mg/L. If the same limit were to apply to the SRC-I Demonstration Plant, ozonation would be required for nondephenolated wastewater.

COMPREHENSIVE EFFLUENT QUALITY ANALYSES

Comprehensive chemical analyses were conducted on the final effluent (i.e., ozonated effluent) and on effluents taken from intermediate treatment steps from each of the five treatment systems. Figures 7A and 7B identify all these sampling points. The analyses included not only global parameters, such as COD and TOC, but also trace inorganic and organic species, including EPA priority pollutants. Tables 24 and 25 present the results for dephenolated and nondephenolated systems, respectively.

In addition, the results of gas chromatographic/mass spectroscopic analysis for organic priority pollutants are presented separately in Appendix 5.

The fully treated effluents (including tertiary treatment) produced from the five treatment systems were compared with the estimated contaminant concentrations published in the FEIS (DOE, 1981) and the anticipated effluent limits based on proposed or final EPA regulations for other industries producing wastewaters similar to SRC-I. The results are listed in Table 26.

Table 26 shows that all five fully treated effluents can meet the anticipated effluent limits, except for ammonia and arsenic. However, with steam-stripping as designed, the ammonia concentration should be reduced to 50 mg/L, which meets the ammonia limit. The arsenic limit was met except for one sample (No. 7504) from the DP/PAC system. This might have been a contaminated sample because samples upstream in the same system had concentrations below the limit.

In addition to the above exceptions, there are several borderline cases, all involving nondephenolated (NDP) systems. The FEIS value for barium is 1 mg/L. The observed concentrations in the final effluent of the NDP/NPAC and NDP/PAC systems were 0.8 and 0.7 mg/L, respectively.

Table 24

Analytical Results for Dephenolated (DP) Wastewaters

	7495 ASWS EFF	7496 NPAC 1B BIO EFF	7497 NPAC 1B COAG EFF	7498 NPAC 1B OZONE	7499 NPAC 2B BIO EFF	7500 NPAC 2B CARBON	7501 NPAC 2B OZONE	9320 NPAC 2B OZONE	7502 DP/PAC BIO EFF	7503 DP/PAC CARBON	7504 DP/PAC OZONE	9321 DP/PAC OZONE
Alk-pH4.3@CaCO3	3760	67	48	125	87	131	143		304	186	173	
BOD5 mg/l	1520	17	4	ND(1)	46	ND(1)	ND(2)		35	1	ND(2)	
COD mg/l	2880	398	145	61	233	74	46	22	282	115	47	25
TOC mg/l	690	80	10	ND(1)	52	ND(1)	ND(1)	ND(1)	61	ND(1)	ND(1)	ND(1)
TIC mg/l	170	62	15	13	90	13	12		93	27	22	
TDS mg/l	6900	4330	5460	5260	4740	4970	4970	2700	4730	4650	4720	2450
TSS mg/l	14	18	4	12	145	10	2	20	220	8	2	14
pH	12.3	6.9	7.2	8.3	7.1	8.2	7.6		7.7	8.2	7.6	
Conductivity umhos	14700	5560	7430	7170	6340	7330	7290		6220	6717	6750	
Color Pt-Co units	4000	1000	400	10	1500	ND(5)	10	ND(5)	1000	ND(5)	ND(5)	ND(5)
Turbidity-NTU	23	100	2.9	.85	45	.25	1.7		85	.25	.75	
Chloride mg/l	500	290	690	660	360	650	580	318	380	615	650	320
Cyanide mg/l	.041	.149	.194	ND(.004)	.688	ND(.005)	ND(.004)	ND(.004)	.957	ND(.004)	ND(.004)	ND(.004)
Thiocyanate mg/l	31.8	1.8	.6	ND(.2)	2.8	ND(.2)	ND(.2)	ND(.2)	2	ND(.2)	ND(.2)	ND(.2)
Flouride mg/l	1.22	.56	.81	.33	.41	.41	.37		.37	.43	.35	
Ammonia-N mg/l	95	21	2	1	25	ND(.3)	ND(.3)	ND(1)	52	ND(.3)	ND(.3)	ND(1)
Organic-N mg/l	64	10	1	2	9	3	2	ND(1)	21	ND(.3)	ND(.3)	ND(1)
Nitrite-N mg/l	.6	4.25	58.5	19.8	15	14	ND(.25)		103	81.7	ND(.25)	
Nitrate-N mg/l	3.3	86.9	64.5	118	135	121	71.9	62.6	36	28.3	80.5	40.3
Phenolics mg/l	57	.025	.004	.007	.035	.007	.005	ND(.025)	.032	.01	.013	ND(.025)
Sulfide mg/l	.22	ND(.001)	.008	.005	ND(.001)	.01	.004		.25	.006	ND(.001)	
T-Phosphate@P mg/l	.63	8.7	.04	.1	4.3	.08	.095		10.6	.09	.09	
Silica mg/l	179	8.5	5.3	6.6	20.3	6.6	7.5	3.4	21.4	9.2	8.5	3.8
Sulfate mg/l		1600	2100	2100	1900	1800	2000	1100	2000	1800	1800	1000
Aluminum mg/l	3.31	1.6	.15	.28	1.22	.17	.17	ND(.4)	2.01	.1	ND(.09)	ND(.4)
Calcium mg/l	15.2	362	375	395	375	170	170	55	562	280	273	144
Iron mg/l	1.64	1.74	.1	ND(.04)	.94	ND(.04)	ND(.04)	ND(.05)	1.36	ND(.04)	ND(.04)	.08
Magnesium mg/l	15.4	12.8	15	16.9	14.1	18.6	19.8	3	14.2	17.6	18.6	8
Manganese mg/l	.074	.014	.245	.189	.008	.202	.19	.13	.02	.139	.114	.1
Antimony mg/l	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)		ND(.2)	ND(.2)	ND(.2)	
Arsenic mg/l	1.4	ND(.015)	ND(.015)	ND(.015)	ND(.015)	ND(.015)	ND(.015)		.06	.09	.35	
Barium mg/l	ND(.5)	ND(.5)	ND(.5)	ND(.5)	ND(.5)	ND(.5)	ND(.5)		ND(.5)	ND(.5)	ND(.5)	
Beryllium mg/l	ND(.003)	ND(.003)	ND(.003)	ND(.003)	ND(.003)	ND(.003)	ND(.003)		ND(.003)	ND(.003)	ND(.003)	
Boron mg/l	97	53	56	46	56	44	59	54	70	52	45	60
Cadmium mg/l	ND(.01)	ND(.01)	ND(.01)	ND(.01)	ND(.01)	ND(.01)	ND(.01)		ND(.01)	ND(.01)	ND(.01)	
Chromium mg/l	.078	ND(.03)	ND(.03)	ND(.03)	ND(.03)	ND(.03)	ND(.03)		ND(.03)	ND(.03)	ND(.03)	
Copper mg/l	.06	.08	.03	.03	.07	ND(.02)	.02		.07	ND(.02)	ND(.02)	
Lead mg/l	ND(.11)	ND(.11)	ND(.11)	ND(.11)	ND(.11)	ND(.11)	ND(.11)		ND(.11)	ND(.11)	ND(.11)	
Mercury mg/l	.0436	.0006	.001	.0006	ND(.0004)	ND(.0002)	ND(.0002)		ND(.0004)	ND(.0002)	ND(.0002)	
Nickel mg/l	ND(.06)	ND(.06)	ND(.06)	ND(.06)	ND(.06)	ND(.06)	ND(.06)		ND(.06)	ND(.06)	ND(.06)	
Thallium mg/l	ND(.08)	ND(.08)	ND(.08)	ND(.08)	ND(.08)	ND(.08)	ND(.08)		ND(.08)	ND(.08)	ND(.08)	
Selenium mg/l	.8	.12	ND(.015)	ND(.02)	.085	ND(.015)	ND(.025)		ND(.04)	ND(.026)	ND(.026)	
Silver mg/l	ND(.006)	ND(.006)	ND(.006)	ND(.006)	ND(.006)	ND(.006)	ND(.006)		.022	.014	.014	
Sodium mg/l	1800	720	960	900	810	920	960		790	770	790	
Titanium mg/l	ND(.3)	ND(.3)	ND(.3)	ND(.3)	ND(.3)	ND(.3)	ND(.3)		ND(.3)	ND(.3)	ND(.3)	
Vanadium mg/l	ND(.15)	ND(.15)	ND(.15)	ND(.15)	ND(.15)	ND(.15)	ND(.15)		ND(.15)	ND(.15)	ND(.15)	
Zinc mg/l	.538	.101	.012	.01	.066	.01	.01		.07	.01	.01	

Table 25

Aralytical Results for Nondephenolated (NDP) Wastewaters

	7487 ASWS EFF	7488 NDP/PAC BIO EFF	7489 NDP/PAC COAG EFF	7490 NDP/PAC CARBON	7491 NDP/PAC OZONE	7492 NDP/PAC OZONE	9318 NDP/PAC OZONE	7493 NDP/NPAC BIO EFF	7494 NDP/NPAC CARBON	9319 NDP/NPAC OZONE
Alk-pH4.3@CaCO3	6840	538	247	285	268	173		103	122	
BOD5 mg/l	9600	24	2	ND(1)	ND(1)	11		5	4	
COD mg/l	16675	810	385	274	143	314	86	1603	424	114
TOC mg/l	3300	210	34	ND(1)	ND(1)	10	9	400	ND(1)	12
TIC mg/l	900	140	58	53	46	37		20	9	
TDS mg/l	14530	11090	11030	10480	10510	10330	10290	10860	10150	9410
TSS mg/l	12	300	10	6	8	16	28	420	16	18
pH	12.3	7.3	7.0	7.7	7.8	6.7		6.5	8.0	
Conductivity umhos	15700	14400	14700	14400	14400	14700		14600	13900	
Color Pt-Co units	20000	3000	750	25	ND(5)	ND(5)	ND(5)	7000	ND(5)	ND(5)
Turbidity-NTU	4.2	120	8.8	3.6	.45	.62		130	1.8	
Chloride mg/l	544	2300	2410	2500	2470	2525	2580	2240	2400	2580
Cyanide mg/l	ND(.0042)	ND(.004)	ND(.004)	ND(.0069)	ND(.0072)	ND(.004)	ND(.004)	.243	ND(.004)	ND(.004)
Thiocyanate mg/l	97	2.3	1.5	.3	ND(.2)	ND(.2)		12.5	ND(.2)	
Flouride mg/l	.96	1.1	.86	.81	.81	.91	.595	.92	.74	.713
Ammonia-N mg/l	172	4	4	4	2	ND(.3)	ND(1)	30	27	25
Organic-N mg/l	96	36	15	9	10	3		49	9	
Nitrite-N mg/l	ND(.25)	1.1	.43	.43	.33	ND(.25)		ND(.25)	.59	
Nitrate-N mg/l	3.91	67.3	77.6	67	54.4	45.1	74.3	131	101	123
Phenolics mg/l	3165	.026	.013	.004	.063	ND(.001)	.031	.093	.001	ND(.025)
Sulfide mg/l (Total	ND(.001)	ND(.001)	ND(.001)	.006	.004	ND(.001)		ND(.001)	ND(.001)	
T-Phosphate P mg/l	1.3	15.8	.19	.21	.16	.12	.08	13.1	.04	.03
Silica mg/l	205	403	12	18.3	8.7	17	23.1	34	17	22.5
Sulfate mg/l	86	3500	3500	3400	3400	3300	3600	3500	3500	3000
Aluminum mg/l	3.18	2.26	.3	.16	.24	ND(.09)	ND(.4)	1.41	.13	ND(.4)
Calcium mg/l	53.2	839	604	656	627	593	549	754	558	544
Iron mg/l	2.66	1.22	.94	.72	.18	.35	ND(.05)	.39	.05	ND(.05)
Magnesium mg/l	1.74	12.6	13.3	14	14.4	14.4	14	12.1	14.8	13
Manganese mg/l	ND(.006)	.057	.066	.239	.101	.108	ND(.02)	.012	.224	.05
Antimony mg/l	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)		ND(.2)	ND(.2)	
Arsenic mg/l	.03	.1	.32	.04	.07	ND(.015)		ND(.015)	ND(.015)	
Barium mg/l	ND(.5)	1.5	ND(.5)	ND(.5)	.7	.6		.6	.8	
Beryllium mg/l	.005	ND(.003)	ND(.003)	ND(.003)	ND(.003)	ND(.003)		ND(.003)	ND(.003)	
Boron mg/l	187	76	69	67	65	91	108	84	62	130
Cadmium mg/l	ND(.01)	ND(.01)	.102	.094	.09	.116		ND(.01)	.01	
Chromium mg/l	.06	.03	ND(.03)	ND(.03)	ND(.03)	ND(.03)		ND(.03)	ND(.03)	
Copper mg/l	.06	.06	.06	.04	.04	.06		.05	.04	
Lead mg/l	ND(.11)	ND(.11)	ND(.11)	ND(.11)	ND(.11)	ND(.11)		ND(.11)	ND(.11)	
Mercury mg/l	ND(.0002)	.0004	ND(.0002)	.0018	ND(.0002)	.0004		.0008	.0005	
Nickel mg/l	ND(.06)	ND(.06)	ND(.06)	ND(.06)	ND(.06)	ND(.06)		ND(.06)	ND(.06)	
Thallium mg/l	ND(.08)	ND(.08)	ND(.08)	ND(.08)	ND(.08)	ND(.08)		ND(.08)	ND(.08)	
Selenium mg/l	.8	ND(.015)	ND .015)	ND(.015)	ND(.03)	ND(.015)		.3	ND(.015)	
Silver mg/l	.018	.073	.044	.055	.044	.039		.058	.033	
Sodium mg/l	2740	2240	2000	2000	1900	1900		1900	1700	
Titanium mg/l	ND(.3)	ND(.3)	ND(.3)	ND(.3)	ND(.3)	ND(.3)		ND(.3)	ND(.3)	
Vanadium mg/l	ND(.15)	ND(.15)	ND(.15)	ND(.15)	ND(.15)	ND(.15)		ND(.15)	ND(.15)	
Zinc mg/l	.406	.394	.349	.083	.059	.365		1.569	ND(.01)	

Table 26

Comparison of Fully Treated Wastewaters with Effluent Limitations

	MEASURED CONCENTRATION					EFFLUENT LIMITATIONS		
PARAMETER	DP/NPAC 7498	DP/NPAC 7501	DP/PAC 7504	NDP/NPAC 7491	NDP/PAC 9319	FEIS	Petroleum Refining	Iron and Steel
Alk-pH4.3@CaCO3	125	143	173	268	122			
BOD5 mg/l	ND(1)	ND(2)	ND(2)	ND(1)	4	20	26	
COD mg/l	61	46	47	143	114	150	180	
TOC mg/l	ND(1)	ND(1)	ND(1)	ND(1)	12	150	46	
TIC mg/l	13	12	22	46	9			
TDS mg/l	5260	4970	4720	10510	9410			
TSS mg/l	12	2	2	8	18	20	21	14
pH	8.3	7.6	7.6	7.8	8	6-9	6-9	6-9
Conductivity umhos	7170	7290	6750	14400	13900			
Color Pt-Co units	10	10	ND(5)	ND(5)	ND(5)			
Turbidity-NTU	.85	1.7	.75	.45	1.8			
Chloride mg/l	660	580	650	2470	2580			
Cyanide mg/l	ND(.004)	ND(.004)	ND(.004)	ND(.0072)	ND(.004)	.45		.1
Thiocyanate mg/l	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)			
Flouride mg/l	.33	.37	.35	.81	.713			
Ammonia-N mg/l	1	ND(.3)	ND(.3)	2	25	5	17	6
Organic-N mg/l	2	2	ND(.3)	10	9			
Nitrite-N mg/l	19.8	ND(.25)	ND(.25)	.33	.59			
Nitrate-N mg/l	118	71.9	80.5	54.4	123			
Phenolics mg/l	.007	.005	.013	.063	.001	.1	.17	.3
Sulfide mg/l(Total	.005	.004	ND(.001)	.004	ND(.001)	.04	.13	.1
T-Phosphate@P mg/l	.1	.035	.09	.16	.03	5		
Silica mg/l	6.6	7.5	8.5	8.7	22.5			
Sulfate mg/l	2100	2000	1800	3400	3500			
Aluminum mg/l	.28	.17	ND(.09)	.24	.13			
Calcium mg/l	395	170	273	627	558			
Iron mg/l	ND(.04)	ND(.04)	ND(.04)	.18	.05	2		
Magnesium mg/l	16.9	19.8	18.6	14.4	14.8			
Manganese mg/l	.189	.19	.114	.101	.224	2		
Antimony mg/l	ND(.2)	ND(.2)	ND(.2)	ND(.2)	ND(.2)			
Arsenic mg/l	ND(.015)	ND(.015)	.35	.07	ND(.015)	.1		
Barium mg/l	ND(.5)	ND(.5)	ND(.5)	.7	.8	1		
Beryllium mg/l	ND(.003)	ND(.003)	ND(.003)	ND(.003)	ND(.003)	.005		
Boron mg/l	46	39	45	65	120			
Cadmium mg/l	ND(.01)	ND(.01)	ND(.01)	.09	.01	.15		
Chromium mg/l	ND(.03)	ND(.03)	ND(.03)	ND(.03)	ND(.03)	1	.425	
Copper mg/l	.03	.02	ND(.02)	.04	.04	1		
Lead mg/l	ND(.11)	ND(.11)	ND(.11)	ND(.11)	ND(.11)	.25		
Mercury mg/l	.0006	ND(.0002)	ND(.0002)	ND(.0002)	.0005	.001		
Nickel mg/l	ND(.06)	ND(.06)	ND(.06)	ND(.06)	ND(.06)	.5		
Thallium mg/l	ND(.08)	ND(.08)	ND(.08)	ND(.08)	ND(.08)			
Selenium mg/l	ND(.02)	ND(.025)	ND(.026)	ND(.03)	ND(.015)	.35		
Silver mg/l	ND(.006)	ND(.006)	.014	.044	.033	.1		
Sodium mg/l	900	960	790	1900	1700			
Titanium mg/l	ND(.3)	ND(.3)	ND(.3)	ND(.3)	ND(.3)			
Vanadium mg/l	ND(.15)	ND(.15)	ND(.15)	ND(.15)	ND(.15)	1		
Zinc mg/l	.01	.01	.01	.059	ND(.01)	1		

Another case pertains to COD in the NDP/PAC effluent. The observed COD was 143 mg/L, which is close to the FEIS value of 150 mg/L. However, another sample (no. 98318) showed COD of only 86 mg/L. The difference may be due to different degrees of ozonation. This discrepancy shows the importance of ozonation when the wastewater is not treated with phenol recovery.

For organic priority pollutants, there are no effluent limits. However, this is not significant for the treated SRC-I wastewater. All of the priority organic contaminants in the treated wastewaters (after biological oxidation) were below the detection limits except for methylene chlorides, chloroform, di-n-butyl phthalate, bis(2-ethylhexyl) phthalate, and toluene. The highest methylene chloride measured was about 16 µg/L. The source of the methylene chloride is likely the tap water used to dilute the feeds for the bioreactors. The methylene chloride measured in the tap water was 13 µg/L. Likewise, the source of the chloroform was probably the tap water, which had a concentration of 61 µg/L. The highest concentration of chloroform measured in the treated wastewater was 11 µg/L. Phthalates are plasticizers which are ubiquitous in the laboratory environment (EPA, 1982). Trace amounts of the phthalates could leach out from plastic containers, tubing, valves, and the like, contaminating the samples. Toluene was detected in only one sample. Sample 7503 (dephenolated wastewaters after granular activated carbon adsorption) had a concentration of 0.12 µg/L. However, neither the sample upstream (No. 7502) nor the sample downstream (No. 7504) showed any toluene. Also, no other samples in other treatment trains contained measurable toluene. Therefore, the toluene was probably due to contamination of the sample or an artifact.

VI. CONCLUSIONS

The results of this biooxidation study lead to the following conclusions:

1. Dephenolization resulted in a bioreactor effluent with much lower organics concentrations. Typical COD concentrations in the bioreactor effluents of the DP systems were 150 to 250 mg/L. For the NDP systems, the concentration was above 550 mg/L without PAC. For an NDP system to produce an effluent comparable to the DP systems, a longer HRT and PAC addition were required. With PAC, a COD of 260 mg/L was attainable. Effluent TOC and BOD_5 patterns were similar to those of COD.
2. With dephenolization, continuous, high-dose PAC addition to a single-stage system with an HRT of 2 days did not provide better COD removal than a non-PAC, two-stage system with an equal combined HRT. Mean steady-state effluent concentrations for non-PAC (NPAC) and PAC systems were 170-221 and 204 mg/L, respectively.
3. The two-stage bioreactors in series demonstrated advantages over a single-stage bioreactor. The second stage removed additional contaminants and provided operational stability. The second-stage bioreactors in the dephenolated, NPAC systems removed an additional 75-100 mg/L of COD, or about 30% of the COD in the effluents of the first-stage bioreactors.
4. Stable nitrification for the DP systems required a long acclimation period. Changes in the feed characteristics, i.e., COD and sodium contents, affected ammonia removal performance more than any other parameter. The best performance during steady state was achieved by the two-stage system (HRT = 1 day per stage, SRT = 30 days), when effluent ammonia averaged 5.5 mg/L. The single-stage DP/PAC system did not obtain better nitrification even with a longer SRT (40 days) and HRT (3.5 days). The best it could attain was about 50 mg/L.

5. The NDP/PAC system was most stable with regard to nitrification. It reached steady state rapidly, and the typical effluent concentration was 6.5 mg/L.
6. The high sensitivity of nitrification to feed conditions indicates that biological treatment is not the most reliable method for removing ammonia. Steam-stripping is a more positive and sure way of controlling ammonia.
7. In terms of color removal, the DP systems are better than NDP systems. The DP/NPAC systems reduced color to a range of 900-1,000 APHA units. Adding PAC to the DP system reduced color even more, to about 400 units. In contrast, the NDP systems reduced the color to only 2,000 to 3,000 units, even with PAC.
8. Residual phenolic concentrations in all but the NDP/NPAC system were generally below 100 µg/L. During steady state, effluent concentrations of less than 25 µg/L were achieved. The NDP/PAC system approached the performance of dephenolated systems, despite the fact that phenolic feed concentrations were over 1,000 mg/L, compared to dephenolated feed concentrations of about 10 mg/L.
9. The results of CN removal are not conclusive, primarily because of analytical problems. The recovery of CN was poor. Spiking the bioreactor feeds for the dephenolated systems with NaCN failed to increase the cyanide (as measured) to the desired concentration of 10 mg/L. The average measured concentrations were typically less than 3 mg/L. The exact cause of this disparity is unknown.
10. Thiocyanates were effectively removed biologically by all systems, although DP systems performed slightly better than NDP systems. PAC did not affect SCN removal significantly. The average feed SCN concentration for the DP systems was 195 mg/L, and the residual concentrations in the effluents were consistently below 5 mg/L. The feed concentration to the NDP systems was the same (193 mg/L), but the effluent concentrations normally ranged between 5 and 10 mg/L.

11. Phenol extraction of the feed to the bioreactor seemed to have eliminated the need to remove "tar acids," which would have required a large quantity of sulfuric acid and lime (or caustic), and would have added a significant amount of dissolved solids to the wastewater. There were no significant differences in organic removal, nitrification, color removal, or SCN oxidation between the time periods when tar acid was and was not removed.
12. Phenol extraction improved operational stability of the bioreactors. The DP systems were less sensitive to organic shock loadings, and recovered more rapidly from shock loads than the NDP systems.
13. There was little significant difference in effluent quality between the two-stage dephenolated systems operated at 1- and 2-day HRTs (each stage). The system with 1-day HRTs performed slightly better than the system with 2-day HRTs in terms of COD and color removal.
14. With PAC, the DP system (with an HRT of 2 days) produced an effluent similar to the NPAC/DP systems. Color was better, but ammonia removal was not as good. Other parameters were equivalent. The basis for selection of either system will be mainly economic.
15. Solid residence time (SRT) and food-to-microorganism (F/M) ratios employed for this study were predetermined based on published values. No systematic study was intended. The values selected from the literature were adequate. With dephenolization, both two-stage NPAC systems had 30 days in each stage. Steady-state F/Ms (COD) were 0.25 and 0.28 day^{-1} in the first stage and 0.09 in the second stage of each system. The single-stage PAC system was operated at 40-days SRT and the F/M was between 0.14 and 0.27 day^{-1}. Without dephenolization, the single-stage PAC system ran successfully at an SRT of 40-45 days, and an F/M of 0.16 to 0.28 day^{-1}.
16. The PAC dose and inventory in the single-stage dephenolated system were adequate to produce an effluent comparable to the

two-stage systems. The dose was 500 mg/L of feed, and resulted in a basin inventory ranging between 6,500 and 8,000 mg/L. The PAC reduction study showed that one-half this dose, or about 250 mg/L of feed, might be adequate, but a long-term run was not made at a fixed reduced value. The NDP/PAC system performed well (although it could not match the DP systems) at a dose of 1,200 mg/L of feed and inventory in the bioreactor ranging from 8,000 to 11,000 mg/L, compared to the two-stage NPAC (NDP) system. However, it did not approach the performance of the DP system. The effectiveness of adding a small PAC dose to the second-stage bioreactors as a settling aid is inconclusive.

17. Apparent yield coefficients, ratios of biomass wastage to COD removed, were calculated for all systems. The values of apparent yield coefficients fell between 0.103 and 0.186, which are comparable to the yield coefficients reported for coal-coking wastes (0.13) and nondephenolated gasification wastes (0.1 to 0.29).

18. Ammonia removal can be expressed as a first-order reaction: $C/C_o = e^{-k_N X \Theta}$. The k_N's for this study, using steady-state data, ranged from 5.3×10^{-4} to 8.7×10^{-4} L/mg-day, which are comparable to the literature values. The H-coal and coal liquefaction process studies reported 3×10^{-4} L/mg-day. Luthy and Jones (1980) observed 1×10^{-4} L/mg-day for coal-coking wastes. For other wastes, including pulp and paper and petroleum refining wastes, Adams and Eckenfelder (1977) indicated the range was between 3.9×10^{-4} and 5.0×10^{-4} L/mg-day.

19. Basin foaming was not significant in DP systems, but caused severe operational and performance (effluent solids) problems in NDP systems. Use of antifoam in conjunction with minimization of aeration provided limited control.

20. The mixed liquor from System 3 (DP/PAC) exhibited the most rapid settling characteristics, from the standpoint of both solids loading and surface overflow rate (SOR). A 3% sludge could be produced at a flux rate of 211 lb/ft^2-day. Settling

was hindered in System 5, which had a mixed-liquor concentration exceeding 17,000 mg/L, resulting in a flux of 134 lb/ft^2-day and an SOR of 901 gpd/ft^2. System 1A had a lower flux 25 vs. 49) but a higher SOR (948 vs. 609) than System 2A. Reactors 4A and 4B, which had mixed liquors about 50% higher than 1A and 1B, showed higher flux and overflow rates than System 1.

21. This study has also demonstrated that phenol recovery eliminates the need for post-biooxidation tar acid removal.
22. Coagulation with $FeCl_3 \cdot 6H_2O$ at a dosage of 800 mg/L was effective in removing colloidal materials and suspended solids from both the dephenolated and nondephenolated bioreactor effluents and reduced TOC and COD significantly. Magnifloc 835-A (an anionic polymer) at a dosage of 0.5 mg/L aided in coagulation.
23. Granular activated carbon following coagulation can remove TOC down to detection limits for both DP and NDP wastewaters. However, the isotherm data cannot determine if dephenolization will affect the adsorption capacity of the carbon. The effect of dephenolization appears to be a reduction in the organic (TOC) loading to the carbon column rather than a change in adsorption capacity.
24. Aside from disinfection, the significance of ozonation is COD reduction for the nondephenolated wastewater. Without ozonation, the residual COD concentrations in the carbon column effluents, derived from the nondephenolated systems (PAC or NPAC), were higher than or close to the anticipated effluent limit of 180 mg/L.
25. Comprehensive analyses showed that the fully treated effluents, both dephenolated and nondephenolated, can meet the effluent limits stated in the FEIS and those estimated from EPA effluent guidelines and standards for industries producing wastewaters similar to that of SRC-I, provided that ammonia stripping and ozonation are as effective as designed. However, dephenolization does provide a wider safety margin.
26. All organic priority pollutants originally present in the raw SRC-I wastewater were removed below detection limits.

VII. RECOMMENDATIONS

Based on the data generated from this study, as well as previously (ICRC, 1983a), the following recommendations are in order:

1. Phenol recovery before biooxidation significantly reduces residual organics and color in the bioreactor effluent. Based on this particular technical advantage, phenol recovery is recommended.
2. The results of this laboratory-scale study indicate that phenol recovery might eliminate the need for tar acid removal before biooxidation. However, there are still many unanswered questions. Therefore, elimination of the tar acid removal step is recommended, but this should be considered preliminary, pending further research.
3. For a given hydraulic residence time (HRT), a two-stage configuration is better than a single stage for COD removal. This study shows that two bioreactors in series, with 1-day HRT each, performed better than a single bioreactor with a 2-day HRT. The second bioreactor is effective both as a polishing unit and in dampening upsets in the first stage. Therefore, the two-stage configuration is recommended.
4. With dephenolization, a single-stage PAC system could remove as many organics as a two-stage NPAC system. The final selection should take into account economic tradeoffs and the results of other studies, such as tertiary treatment (included in this report) and toxicology tests.
5. With dephenolization, the minimum HRT for the two-stage NPAC system tested was 1 day in each stage and it provided satisfactory performance. This is based on the result of the laboratory-scale, steady-state study. To extrapolate the steady-state results from the laboratory to a full-scale system in the field, safety margins should be provided.

6. Without dephenolization, the two-stage NPAC system with a combined HRT of 6 days could not provide a comparable effluent to any systems treating dephenolized wastewater. Therefore, it is not recommended.
7. In contrast, with PAC, the single-stage bioreactor system treating nondephenolated wastewater produced bioreactor effluent quality close (although inferior) to that of the dephenolated systems. Because tertiary treatment can polish the bioreactor effluent, the nondephenolated NPAC system cannot be entirely rejected based only on the results of the biooxidation studies. Economic tradeoffs and results of additional studies, including tertiary treatment and aquatic ecotoxicity assays, should also be considered. See the Integration Report (Yen, 1984) for more details.
8. Biological ammonia removal/nitrification was possible, but it was very sensitive to changes in feed characteristics. It is not recommended as a backup for steam-stripping. Steam stripping should be the primary method for ammonia removal.
9. If phenol recovery is employed, post-biooxidation tar acid removal can be eliminated.
10. Provisions should be made to coagulate the bioreactor effluents with ferric salts. Coagulation is recommended for both treatment schemes, with or without phenol recovery.
11. Granular activated carbon adsorption can remove TOC down to detection limits; therefore, it should be considered as a polishing process.
12. In order to meet effluent COD limits, which are anticipated to be very low, ozonation following carbon adsorption would be required in a system treating nondephenolated wastewater.

VIII. ACKNOWLEDGMENT

The authors wish to express their appreciation to Dr. Richard Luthy, who wrote "Comparison with Other Studies" included in Section V. He also provided valuable suggestions and advice throughout the study. The authors also thank Mr. Thomas C. Hess for performing statistical evaluations of the bioreactor data.

Special thanks are extended to Mr. William L. K. Schwoyer, who was the program manager for ICRC. Finally, we thank the dedicated team in Marcus Hook that kept systems in operation around the clock for over nine months.

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Appendix 1

Analytical Methods

QUALITY CONTROL PROCEDURES

The routine quality control procedures described in Quality Assurance Program for Environmental Systems Division Laboratory Facility, Catalytic, Inc., were strictly followed. To control "accuracy" of analyses, that program requires spike recovery determination on distilled water and samples. For distilled water spiking, the following equation is used to calculate the recovery:

$$P = 100(C/T) \quad (1)$$

where P is percent recovery of a standard, C is the measured concentration, and T is the true concentration. For each analysis, P must fall within the prescribed range for that analysis.

For sample spiking, the percent recovery P is:

$$P = 100(dC/\text{spike added}) \quad (2)$$

where dC is the difference between the concentrations measured for the spiked and unspiked samples. Spike added is the concentration increase of the analyte if the recovery were 100%. Again, P must fall within the acceptable range for a given analyte.

The quality assurance program also controlled "precision" of the analyses. Precision was controlled by analysis of replicate pairs; the difference between the two analyses was compared to a prescribed standard. This is expressed mathematically as:

$$R = |A - B| \quad (3)$$

where A and B are observed concentrations of the replicate analyses, and R is the absolute value of the difference. R must fall within the

acceptable range for each analytical procedure and is concentration dependent.

A frequency of 10% of sample load was used for analyzing sample spikes or water spikes. Also, 10% of the sample load was used for replicate sample analysis. Where replicates were run, the average value was reported.

Figure A-1 shows the reporting form for quality control data collected under this program. In addition to spiked-sample, distilled-water spike, and replicate sample data, the analyst was required to report the standard curve. In this way, the analyst could tell if the standard curve had changed. By comparing spike and replication data to tables of initial QC data prepared for the method, the analyst could detect out-of-control situations.

Gas chromatography/mass spectrometry (GC/MS) analyses of SRC wastewaters were performed by Mead CompuChem, Research Triangle Park, North Carolina, or Radiation Management Corporation, Phoenixville, Pennsylvania. These laboratories used the following methods to analyze the wastewaters: Purgeable Halocarbons, Method 624 (EPA, 1982), and Base/Neutral and Acid Compounds, Method 625 (EPA, 1982).

These analyses are designed to detect, identify, and quantitate EPA organic priority pollutants. Other compounds present in the wastewater are not reported by these methods.

Quality control measures included with these GC/MS methods included daily calibration of the GC/MS with decafluorotriphenylphosphine (DFTPP) or parafluorobromobenzene (PFBB), depending upon whether base/neutrals/acids or volatiles are being run, respectively. In addition, method water blanks were run to ensure that the system was interference-free. Where possible, internal standards were used to calibrate the method. Otherwise, calibration curves were prepared using the external standard method.

Those quality control procedures that are specific to the analytical method are presented with the following method descriptions.

Figure A-1

Laboratory Analysis Quality Control Data

Test for: _____ Method: _____ Date Completed: _____

Laboratory Nos. Analyzed: _____ Total No. of Samples: _____

Type Container: _____ Preservative: _____

Standard Curve: _____

STANDARD CURVE:

SECTION 1

Standard Concentration ( )	Response ( )	Standard Concentration ( )	Response ( )

Lab. Notebook No. _____

Stock Solution Ref. No. _____

Analyst _____

Reviewer _____

ACCURACY CHECK (Standards):

SECTION 2

Standard Concentration ( )	Response ( )	Calculated Concentration ( )	% Recovery

PRECISION CHECK (Duplicate Samples):

SECTION 3

Sample Number	Duplicate Number	Responses ( )		Concentrations ( )		Range ( )
		Sample	Dupl.	Sample	Dupl.	

ACCURACY CHECK (Spiked Samples):

SECTION 4

Sample Numbers		Responses ( )		Concentrations ( )		Conc. Diff.	Spike Conc. Added ( )	% Recovery
Unspiked	Spiked	Unspiked	Spiked	Unspiked	Spiked			

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BORON

Boron was measured in unfiltered samples by Method 404A (Curcumin Method) of Standard Methods (1981). The sample was acidified and evaporated in the presence of curcumin. After dissolution of the colored residue in 95% ethanol and dilution to 25 mL, boron was measured using a spectrophotometer. A cell length of 1 cm on the Bausch and Lomb Spectronic 710 provided a limit of detection of 0.02 mg/L for boron. Quality control procedures consisted of measuring spiked samples and replicate samples.

TOTAL CYANIDE/CYANIDES AMENABLE TO CHLORINATION

Total cyanide was stripped from the samples by distillation and digestion according to EPA Method 335.2 (1979b). The distillates were treated with approximately 0.2 g of cadmium carbonate to precipitate sulfide, according to the procedure proposed by Barton et al. (1978), to remove interferences from thiocyanate breakdown during distillation.

The cyanide trapped in the distillates was measured by the pyridine/barbituric acid method (EPA Method 335.2), with either a 1- or 5-cm cell on a Spectronic 710 spectrophotometer. For a 500-mL sample distilled for total cyanide, limits of detection of 0.02 and 0.004 mg/L were estimated for the 1- and 5-cm cells, respectively.

Cyanide present in either an uncomplexed or readily dissociated, complexed form was determined by Method 412F of Standard Methods (1981), "Cyanides Amenable to Chlorination after Distillation." Following chlorination to decompose those cyanides amenable to chlorination, the remaining cyanide was distilled for analysis by the same method described for total cyanide.

Quality control procedures included analyzing spiked distilled water solutions to check recovery of cyanide in the distillation/digestion step, analyzing spiked samples, and analyzing in replicate. Several of the sample types showed low recoveries of sodium cyanide spikes, due to reactions of the cyanide with sample components. The nature of these reactions was not investigated. Both distilled water

and sample spikes were tabulated to indicate the method's performance. Replicate analyses were recorded on precision control tables.

CHLORIDE

After preliminary digestion of unfiltered samples, chloride was determined by the method of Luthy (1978), using Method 408C (potentiometric method) of Standard Methods (1981). Titration with silver nitrate was performed using an Orion Model 94-16 silver ion/sulfide ion activity electrode and Orion Model 90-02-00 reference electrode to indicate the end point. By using a potentiometric end-point detection system, sample color did not interfere with the titrations. Interferences from organic compounds, cyanide, sulfide, sulfite, and ferric iron were removed in the digestion pretreatment. The estimated limit of detection of this method was 0.25 mg/L for 100 mL of digested sample.

Quality control measures included sample spiking prior to digestion and replicate sample analyses. The silver nitrate titrant was restandardized as needed with standard sodium chloride solution.

THIOCYANATE

Thiocyanate (SCN^-) was determined with a color blank/standard additions procedure to correct for sample color and response variations due to sample type. The samples were diluted into four 50-mL volumetric flasks (minimum dilution 40/50 mL), and then acidified to pH 5-7 with 1 + 1 HNO_3. To one of the four volumetric flasks in each set was added 5 mL of 2.5% (v/v) nitric acid only, to act as a color blank, while the other flasks were treated with 5 mL of color reagent containing iron and nitric acid, as specified in Standard Methods (1981), Method 412-K. One of the flasks in each set was spiked with 2 mg/L and another with 4 mg/L of thiocyanate from a 100-mg/L standard solution. The concentration of thiocyanate in the unspiked sample was found by the method of standard additions, using readings made on a Spectronic 710 spectrophotometer (1-cm cell), after subtracting the color blank absorbance reading from that of each of the other sample dilutions in each set.

With a sample dilution of 40/50 mL and a 1-cm spectrophotometer cell, the detection limit of the method was estimated to be 0.25 mg/L.

Quality control steps included titration of the standard stock thiocyanate solution by the Volhard methods, using a silver/sulfide (Orion Model 94-16) electrode to indicate the end point, as described by Burroughs and Attia (1968). To 75 mL of water was added 10 mL of 0.0142 N $AgNO_3$, followed by 10 mL of 20% (w/v) $Fe(NO_3)_3 \cdot 9H_2O$ solution and 5 mL of 1 + 1 HNO_3 (boiled to remove NO_2). The solution was then titrated with the thiocyanate solution to the electrode inflection end point. The stock thiocyanate solution used to make standard addition spikes was checked daily by developing a standard curve in distilled water with the referenced method (Standard Methods, 1981), and by checking the response of the spectrophotometer (absorbance/concentration ratio). Replicate analyses carried through the entire standard addition method were performed and recorded on precision control tables.

AMMONIA

Ammonia-N analyses were performed on unfiltered samples using EPA Method 350.2 (1979). This method employed distillation and titrimetric analysis of the ammonia trapped in boric acid, using 0.02 N sulfuric acid. With a 400-mL sample taken for distillation, the estimated limit of detection was 1 mg/L.

Any volatile amines present interfered with the method, by titrating as ammonia in the boric acid collection medium. Such interferences could not be eliminated.

Quality control measures included analyzing distilled water and sample spikes and an accuracy check standard. Replicate analyses were also run to check the method's precision. The sulfuric acid used for titration was standardized, via standard NaOH solution, with a potassium acid phthalate acidimetric standard.

TOTAL KJELDAHL NITROGEN (TKN)

TKN was analyzed on unfiltered samples using EPA Method 351.3 (1979). As in the ammonia analysis, the boric acid solutions of dis-

tilled ammonia were titrated with 0.02 N sulfuric acid. The estimated limit of detection for this method with a 500-mL sample was 1 mg/L.

Quality control measures included analysis of an ammonium chloride accuracy check standard and replicate sample analyses. The same standardized sulfuric acid (via potassium acid phthalate) was used for both TKN and ammonia-N analyses.

CHEMICAL OXYGEN DEMAND (COD)

COD was determined on unfiltered samples by EPA Method 410.4 (1979), using sealed-ampule digestion in an oven with subsequent colorimetric analysis on a Spectronic 710 spectrophotometer. One-half of all the volumes in EPA Method 410.4 were used with this ampule method.

Interferences in this procedure, due mainly to chlorides, were overcome by sample dilution and by the complexation of chloride by mercury ion present in the catalyst solution.

The lower limit of detection for this method was approximately 9 mg/L.

Quality control measurements were made on accuracy check standards and sample spikes, as well as on replicate samples. Standards were prepared with potassium acid phthalate.

NITRATE-NITROGEN

Nitrate-N was determined on filtered samples, using the cadmium reduction method, EPA Method 353.3 (1979), to determine (nitrate + nitrite)-N. Nitrate-N was then calculated by subtracting the nitrite-N concentration.

Because of low recovery in the cadmium reduction step, a minimum dilution of 2 mL/100 mL of water followed by 10 mL/25 mL of water and then dilution of this 25 mL of solution to 100 mL with ammonium chloride buffer was required. The nitrate plus nitrite color following cadmium reduction was read on a Spectronic 710 spectrophotometer with a 1-cm cell.

With a sample dilution of 2 mL/100 mL and then 10 mL/25 mL, the lower limit of detection for the method was 1.25 mg/L.

Quality control analysis included determination of the cadmium column efficiency before each use, and analysis of accuracy check standards or spiked samples, as well as replicate analyses.

NITRITE-NITROGEN

Nitrite-N was determined on filtered samples, also with EPA Method 353.3 (1979). Poor recoveries were found unless the samples were diluted prior to analysis. The samples were first diluted 1 mL/25 mL with water, and then diluted again by 25/100 with ammonium chloride buffer before colorimetric analysis on a Spectronic 710 spectrophotometer with a 1-cm cell. Interferences due to colored organic matter were avoided or reduced by dilution or by running color blanks made up with color reagent that did not contain N-1-(1-naphthyl)ethylenediamine reagent.

With a 1/25 dilution and the method as practiced, a lower limit of detection of 0.25 mg/L was estimated.

Quality control for this method consisted of frequent standardization of the stock nitrite solution with standardized (vs. primary standard grade sodium oxalate) potassium permanganate. Sample spikes and sample replicates were also run.

FLUORIDE

Fluoride was determined in unfiltered samples after Bellock distillation, using an Orion Model 94-09 fluoride electrode and an Orion Model 90-02-00 double junction reference electrode. The digestion procedure is described in EPA Method 340.2. In addition, the SPADNS colorimetric procedure, EPA Method 340.1, was used with some of the samples. The distillation was expected to remove interferences from the analysis for fluoride, particularly interference due to possible fluoroborate (BF_4) ion in the samples. Recovery from a dephenolated feed sample was found to be 100%, even though the boron in such samples was known to be approximately 100 mg/L.

The approximate lower limit of detection for the electrode measurement after distillation of a 300-mL sample, with a final volume of 300 mL, was 0.1 mg/L. For the SPADNS method, the lower limit of detection was also 0.1 mg/L.

Quality control checks included analyses of accuracy check standards, spiked samples, replicate samples, and distilled fluoride standards made up in distilled water. Distilled blanks were also run with each set of samples.

ALKALINITY (TOTAL)

Alkalinity was determined by titration to pH 4.5 with a pH meter and electrode, as described in EPA Method 310.1. If necessary, a curve was plotted from intermediate points between the initial pH and pH 4.5.

Quality control measures for this parameter included frequent standardization of the electrode. The standard sulfuric acid titrant sodium hydroxide (standardized vs. potassium acid phthalate solution) was used to titrate the sulfuric acid titrant to pH 7.0. The limit of detection for this titration was about 10 mg/L as $CaCO_3$.

TOTAL ORGANIC CARBON (TOC)

TOC was determined on unfiltered samples after treatment with concentrated hydrochloric acid, to remove inorganic carbon during analysis on a Dohrman DC-50 TOC Analyzer. Interferences were due to sulfate, which gradually lowered the conversion efficiency of the rhodium catalyst in the reduction zone of the furnace tube, where carbon dioxide was reduced to methane for detection. This interference was accounted for by frequently recalibrating the instrument with potassium acid phthalate standards. Also, samples were diluted whenever possible to reduce the sulfate burden on the instrument. The rhodium catalyst was periodically regenerated by heat treatment or by stripping with strong hydrochloric acid.

A lower limit of detection for the 30-mL sample injection used was estimated at 4 mg/L.

Quality control measurements included reinjection of potassium acid phthalate standards to validate or recalibrate the instrument response, and analysis of an independently prepared accuracy check standard (made with potassium acid phthalate). Replicate injections were also made to check method precision.

TOTAL INORGANIC CARBON/BICARBONATE ALKALINITY

Total inorganic carbon (TIC) was found by first determining TOC on an unacidified sample, and then determining total carbon (TC) on the same sample. The difference, TC - TOC = TIC, was then calculated. Both analyses were run with a 30-mL sample on the Dohrman DC-50 instrument.

The TIC value (mg of C/L) was then used with the sample pH to calculate the bicarbonate alkalinity (mg/L as $CaCO_3$), as follows. First:

$$\text{determine pH} = -\log (H^+) \text{ so } (H^+) = 10^{-pH} \qquad (4)$$

Second, to find the ratio of moles of HCO_3 to H_2CO_3 or to CO_3^{2-}, use either:

$$(HCO_3^-)/(H_2CO_3) = K_1/(H^+) \qquad (5)$$

where $K_1 = 10^{-6.36}$, or:

$$(HCO_3^-)/(CO_3^{2-}) = (H^+)/K_2 \qquad (6)$$

where $K_2 = 10^{-10.33}$. Third, to calculate the HCO_3^- concentration as mg/L as $CaCO_3$, use the ratio found in either equation 5 or 6 and the following equation:

$$\text{TIC (mg of C/L)} \times \frac{100}{12} = (HCO_3^- + H_2CO_3 \text{ or } CO_3^{2-}) \qquad (7)$$

The limit of detection for this method was the same (10 mg/L) as that given for TOC. Similar interferences were expected for TOC and TIC.

Bicarbonate and carbonate were also determined by calculation from pH, phenolphthalein alkalinity, and total alkalinity measurements, as described in Standard Methods, Method 403. This procedure was used for lime-softened samples, where most of the alkalinity was expected to be due to carbonate or hydroxide, rather than salts of silica, phosphoric, or boric acids. The limit of detection for the alkalinity titration was about 10 mg/L as $CaCO_3$.

BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD was determined on unfiltered, unpreserved samples, using Method 507 in Standard Methods. Nitrification was inhibited by adding 2-chloro-6-trichloromethylpyridine for all determinations. Seed was derived from bench-scale biological reactor mixed liquor, composited from reactors 1A and 1B and 4A and 4B. A lower limit of detection of 2 mg/L was expected for a 300-mL sample volume, assuming a depletion of 2 mg/L dissolved oxygen and a zero blank value.

Quality control procedures for BOD included replicate sample analyses, seed curves for each sample set, dilution water checks, and a glucose/glutamic acid standard with an expected value of 200 ± 37 mg/L.

PHENOLICS (COLORIMETRIC)

Phenolics were determined on unfiltered samples. The samples were distilled and analyzed with or without solvent extraction, using the 4-aminoantipyrene colorimetric procedure of EPA Method 420.1 (EPA, 1979b). A 1-cm cell was used with the Spectronic 760 spectrophotometer.

No interferences were found with this procedure, although the feed samples required extra dilution (usually 2 mL/100 mL) in order to obtain a sample response within the calibrated scale of phenol concentrations in the colorimetric step of the procedure.

Using the extraction procedure, the detection limit with a 100-mL effluent sample was 25 µg/L. For a 10-mL sample (used for analysis of feed samples) analyzed without extraction, a detection limit of 2.5 mg/L was estimated.

Quality control analysis included sample replicates and analyses of standard carried through the distillation procedure. In addition, sample spikes were processed.

TOTAL DISSOLVED SOLIDS (TDS)

TDS was measured by filtering unpreserved samples and evaporating the filtrates in an oven set at 180°C, according to EPA Method 160.1. The practical range of the determination is 10 to 20,000 mg/L; the method's lower detection limit practiced with a sample volume of 50 mL was estimated to be 20 mg/L.

Quality control measures involved prewashing the glass fiber filters used to separate solids from the samples, as well as analyzing in replicate.

TOTAL SUSPENDED SOLIDS (TSS) AND VOLATILE SUSPENDED SOLIDS (VSS)

TSS and VSS in unpreserved samples were measured according to Methods 209.D and 209.E in Standard Methods (1981). In these procedures, the residue on the filter from the TDS determination is dried first at 103-105°C and then at 550°C to find the TSS and VSS components of the wastewater.

The detection limit for a 50-mL sample volume was estimated to be 20 mg/L, for either TSS or VSS.

Quality control measures involved prewashing the glass fiber filters and passing distilled water rather than sample through the filters as a check. The weight change was recorded on quality control sheets. Sample replicate data were also recorded for TSS. The results of the TSS showed a high variability (low precision) for samples with very high suspended solids levels, due to the difficulty of sampling these suspensions.

pH

pH was measured with a combination glass electrode standardized against commercially available buffer solutions, as referenced in EPA Method 150.1. Temperature compensation, if required, was provided by manually adjusting the meter control, after measuring the sample temperature.

SULFATE

Sulfate was determined by EPA Method 375.5, the turbidimetric procedure, using a Monitek nephelometer. The procedures's lower detection limit is approximately 1 mg/L sulfate.

Interferences from sample turbidity and color were accounted for by running color/turbidity blanks (conditioning reagent only was added to the sample, and barium chloride was omitted). In some cases, sample dilution was also useful in reducing interferences.

Quality control measures included sample spikes and replicate analyses. The standard sulfate stock solution was prepared from anhydrous sodium sulfate.

PHOSPHATE (TOTAL)

Total phosphate was determined by EPA Method 365.2, using persulfate digestion to convert organic phosphates or condensed phosphates to ortho-phosphate for colorimetric analysis on a Spectronic 710 spectrophotometer with a 1-cm cell.

The lower detection limit of this method was approximately 0.01 mg/L. Generally, sample dilutions were required to remain within the range of 0-0.5 mg/L for the colorimetric step.

Quality control procedures included spiked samples and replicate sample analyses and analyses of an accuracy check standard.

SILICA (DISSOLVED)

Dissolved reactive silica was determined with EPA Method 370.1, the colorimetric method. Samples were filtered (0.45 mm) before analysis, and the color resulting from reaction with molybdate was measured at 410 μm on a Spectronic 20 spectrophotometer with a ½-in. cell.

The lower detection limit for this method was approximately 0.1 mg/L. Interferences found from the sample color were compensated for by running color blanks.

Quality control was performed with sample replicates and sample spikes. In some samples, the sample had to be diluted before spike recovery was considered adequate.

TURBIDITY

Turbidity was measured on a Monitek nephelometer. The nephelometer was adjusted to read nephelometric turbidity units (NTU) by using freshly prepared standards according to EPA Method 180.1.

The detection limit was about 0.02 NTU.

Quality control included calibrating all instrument ranges used, with 20- or 40-NTU standard solutions.

SULFIDE

Sulfur in the form of sulfide ion was measured in samples that were treated with three drops of 2 N zinc acetate and two drops of 6 N NaOH per 100 mL, to precipitate the sulfide as zinc sulfide. Following overnight settling, the supernatant was discarded and the residual suspension was mixed and analyzed by the colorimetric methylene blue procedure of EPA Method 376.2. The resulting blue color was read on a Spectronic 710 spectrophotometer. The spectrophotometer response was calibrated by analyzing sodium sulfide standards, which were freshly prepared and titrated against standard thiosulfate using EPA Method 376.1 (the iodine titrimetric procedure).

The major interferences were from color and turbidity. Diluting the zinc hydroxide suspension at the time of color analysis reduced the interferences, and color blanks were run without aminosulfuric acid reagent to compensate for the remaining turbidity and color. Where these interferences could not be removed, the sample was titrated with standard silver nitrate using an Orion Model 94-16 silver/sulfide specific electrode.

The lower detection limit for the methylene blue method was 0.004 mg/L when a 200-mL sample was concentrated by five times as a result of the zinc precipitation procedure. The detection limit for the silver electrode titration was 0.2 mg/L for a 100-mL sample volume.

Quality control measures included sample replicates and restandardization of the sodium thiosulfate or silver nitrate titrants with potassium biiodate and sodium chloride, respectively.

COLOR

Color was measured in 50-mL Nessler tubes by visual comparison against a standard made up with potassium chloroplatinate, as described in Standard Methods, Method 204A. The samples were diluted if necessary to bring the color into the range of 0-70 color units.

The practical detection limit is 5 color units.

METALS

All metals analyses were performed on unfiltered samples that were preserved with nitric acid to a pH of 2 or less. The samples were digested with the following procedures, to obtain an estimate of the "total" metal in the samples.

a. For antimony: Digested according to the EPA Manual's nitric acid digestion procedure in the metals section of the manual, paragraph 4.1.3. The digested samples were diluted to volume with 5 mL of 1:1 HCl/water and 0.5 mL of HNO_3 per 100 mL final volume for analysis.

b. For mercury: Digested according to EPA Method 245.1 (manual cold vapor technique).

c. For arsenic and selenium: Digested according to EPA Method 206.2. The digested samples were treated with nickel nitrate to give a final concentration of 0.1% nickel nitrate in the solutions taken for analysis.

d. For titanium: Digested according to EPA Method 283.1, with 2 mL of concentrated sulfuric acid added in addition to the nitric acid (0.5 mL) per 100 mL of final dilution.

e. For all other metals: Digested according to the EPA Manual's nitric acid digestion procedure in the metals section, paragraph 4.1.3. Early in the program, calcium and magnesium samples were digested by dry ashing at 550°C in vycor dishes; later, samples were digested with the nitric acid procedure.

The digested solutions were analyzed by one of three atomic absorption techniques:

a. For mercury: Analyzed by the manual cold vapor technique, EPA Method 245.1, with an Instrumentation Laboratories Model 457 atomic absorption (AA) spectrophotometer.

b. For arsenic and selenium: Analyzed by aspiration of the sample via an Instrumentation Laboratories Model 254 FASTAC autosampler into a graphite tube of an IL Model 655 furnace mounted in the IL Model 457 AA spectrophotometer.

c. For all other metals: Analyzed by aspiration of sample into either an air/acetylene or nitrous oxide/acetylene flame on an IL 457 AA spectrophotometer.

In graphite furnace analyses, interferences in the wastewaters were corrected for by using the method of standard additions. Background correction with a deuterium lamp was used on those flame and furnace analyses conducted at wavelengths below 300 nm.

Quality control steps included measuring at least four standards and a blank with each analysis, plus a digestion blank containing those

reagents used for the digestion. Spikes were added to samples before and after digestion, and replicate samples were processed through the digestion and analysis steps.

OIL AND GREASE

Freon-extractable compounds in the wastewaters were determined by Method 413.1 of Standard Methods (1981). This procedure uses separatory funnel extraction of an acidified sample to partition the compounds into the Freon. Evaporation of the Freon in a tared flask then yields the weight of material extracted. The detection limit of this method was about 0.5 mg/L for extraction of a 1-L volume of sample, although the useful range is usually from 5 to 1,000 mg/L. Freon solvent blanks were run to ensure contaminant-free solvent.

Appendix 2

Summary of Dephenolated Feed Aralysis

BATCH NO.	1	2	3	4	5	6	8
VOL, liters	108	144	144	180	190	145	172
W.W. SOURCE	Extract 1-3	Extract 4-7	Extract 8-11	Extract 12-16	Extract 17-21	Extract 22-26	Extract 32-36
SYSTEM USE	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
START	11/18/82	11/25/82	12/02/82	12/08/82	12/18/82	12/26/82	01/12/83
			PARAMETERS Mg/l				
COD	1810	2060	2500	2220	2460	2210	2170
TOC	620	620	788	626	730	410	558
Ammonia -N	184	167	193	195	192	177	186
Nitrate -N	0.7	ND	1.85	ND	ND	4.5	1.5
Nitrite -N	ND (0.25)	ND (0.25)	ND (0.01)	ND (0.25)	ND (0.25)	0.25	0.37
Cyanide	0.166	0.27	10	21.7	9.7	1.92	3.96
Thiocyanate	142	88	215	248	241	187	220
Phenolics	32	25.9	20	17.2	22	22.6	19
Calcium	1640	1620	950	1030	774	715	258
Iron	0.44	ND(.04)	0.5	5.3	4.9	4.8	1.2
Magnesium	16.3	4	4	16	14	11	15.1
Phosphorus, Total	42.2	2.4	82.6	178	125	64	16.5
TDS	6204	6606	5100	4320	5610	3846	4528
pH	7.8	7.7	7.6	7.5	7.8	8.1	7.8

ND = NOT DETECTED(VALUE REPORTED IS LIMIT OF DETECTION)

Appendix 2 (Continued)

BATCH NO.	9	10	11	12	13	14	15	16
VOL, liters	184	176	127	127	151	111	81	134
W.W. SOURCE	Extract 37-41	Extract 42-46	Extract 47-51	Extract 47-51	75% STOCK 25% CHEMPRO	50% STOCK 50% CHEMPRO	25% STOCK 75% CHEMPRO	CHEMPRO DRUM 1
SYSTEM USE	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
START	01/23/83	02/02/83	02/12/83	02/18/83	02/27/83	03/07/83	03/13/83	03/17/83
PARAMETERS Mg/l								
COD	1860	3230	2030	2020	1678	2081	2130	2216
TOC	400	760	440	440	500	540	580	580
Ammonia -N	185	192	165	168	123	191	186	179
Nitrate -N	ND (1.25)	2.5	3.0	2.7	4.9	4.6	3.1	ND (1.25)
Nitrite -N	ND (0.25)	ND (0.25)	ND (0.25)	.37	0.25	ND (0.25)	ND (0.25)	ND (0.25)
Cyanide	0.93	4.75	6.5	9.4	3.98	5.4	3.4	1.2
Thiocyanate	222	227	224	183	116	146	227	194
Phenolics	19.6	30.2	15	14	11	10	6	10.3
Calcium	839	832	680	680	530	520	260	760
Iron	10.9	6.5	7.1	6.3	4.4	11	9	7.9
Magnesium	14	12.7	16	15	14	21	26	25
Phosphorus, Total	136	58	61	69	43	104	81	73
Sodium	396	786	390	230	290	490	1200	1300
TDS	3832	6140	3860	3050	3170	3030	3570	6900
pH	8.0	9.4	8.0	8.1	8.0	7.9	8.1	8.3

ND = NOT DETECTED, (VALUE REPORTED IS LIMIT OF DETECTION)

Appendix 2 (Continued)

BATCH NO.	17	18	19	20	21	22	23	24
VOL, liters	170	156	180	175	190	198	190	205
W.W. SOURCE	CHEMPRO DRUM 2	CHEMPRO DRUM 2	CHEMPRO DRUM 3	CHEMPRO DRUM 3	CHEMPRO DRUM 4	CHEMPRO DRUM 4	CHEMPRO DRUM 5	CHEMPRO DRUM 5
SYSTEM USE	TAR ACID SYS 2	1,3	TAR ACID SYS 2	1,3	TAR ACID SYS 2	1,3 5/25-SYS 3	TAR ACID SYS 2	TAR ACID SYS 1,2
START	03/20/83	03/30/83	04/05/83	04/18/83	04/25/83	05/10/83	05/14/83	06/01/83
				PARAMETERS Mg/l				
COD	2165	2084	2215	1960	2210	2045	1945	2150
TOC	630	480	650	530	502	620	540	650
Ammonia -N	221	196	215	202	195	214	193	195
Nitrate -N	2.45	0.48	2.0	1.6	2.3	3.6	2.3	6.7
Nitrite -N	0.43	0.28	ND (0.25)	0.20	ND (0.25)	ND (0.25)	ND (0.25)	ND (0.25)
Cyanide	0.5	3.5	0.7	1.27	0.90	5.1	0.48	0.31
Thiocyanate	217	205	197	195	206	204	189	178
Phenolics	3.5	6.8	2.7	1.3	0.99	1.1	0.58	0.28
Calcium	600	620	620	250	460	220	520	500
Iron	7.7	20	6.4	6.2	7.6	7.8	6.5	7.0
Magnesium	21	21	17	13.3	16.6	18.0	18.1	18.3
Phosphorus, Total	68	176	57	73.2	71.6	70	64.6	59.6
Sodium	970	920	900	690	710	848	840	790
TDS	4820	4330	4370	3710	4250	3520	4400	4670
pH	9.1	8.2	9.0	8.2	9.3	8.2	9.5	9.5

ND = NOT DETECTED, (VALUE REPORTED IS LIMIT OF DETECTION)

Appendix 3

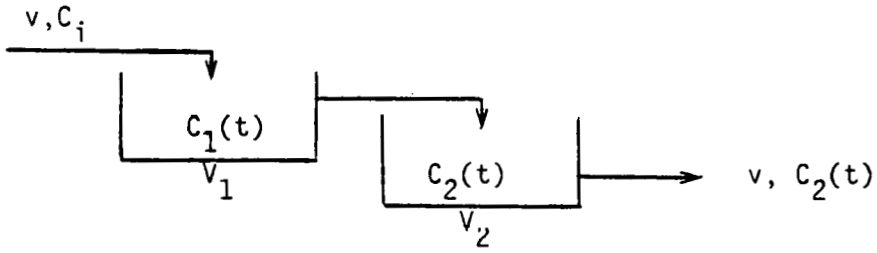
Summary of Control Systems Feed Analysis

BATCH NO.	1	2	3	4	5	6	7	8	9	10	11
VOL, liters	108	115	115	36	40	147	115	128	40	44	44
W.W. SOURCE	DRUM 24	DRUM 24	DRUM 24	DRUM 24	DRUM 24	PASSES 1-5	PASSES 6-8	PASSES 9-11	PASS 12	PASS 13	PASS 14
SYSTEM USE	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4	4	4
START	11/17/82	12/07/82	12/26/82	01/18/83	01/27/83	02/03/83	03/11/83	04/01/83	05/05/83	05/17/83	05/27/83
		PARAMETERS	Mg/l								
COD	5660		7330	8060	7570	8910	6143	5274	5920	6425	6480
TOC	2320	1903	1900	2540	1910	1630	1340	1300	1260	1340	1630
Ammonia -N	177	170	163	211	181	163	147	174	215	198	206
Nitrate -N	3.0	2.8	1.6	0.73	3.7	1.5	2.9	2.5	4.9	5.8	2.5
Nitrite -N	ND (0.25)	ND (0.25)	ND (0.25)	ND (0.25)	ND (0.25)	ND (0.25)	ND (0.25)	0.25	0.35	ND (0.25)	ND (0.25)
Cyanide	0.96	4.74	0.44	0.08	3.46	19.4	30.7	16.7	4.1	0.66	1.35
Thiocyanate	160	183	185	220	198	240	129	183	207	211	213
Phenolics	1052	1214	1230	1614	1476	1484	1083	1019	917		962
Calcium	990	1650	240	1640	789	652	730	710	990	630	980
Iron	4.24	5.2	10.8	10.1	6.5	1.5	3.4	8.2	5.5	8.3	4.5
Magnesium	13	17	15.6	17.7	12.3	15.8	19	18	15.8	17.1	16.9
Phosphorus, Total	19.3	207	187	132	109	9.7	123	162	132	182	124
Sodium	--	--	--	--	--	906	540	400	480	380	210
TDS	10450	11400	9283	13492	11764	7680	4230	3460	5720	3900	4100
pH	7.6	8.1	9.1	8.9	8.4	9.2	8.1	8.2	8.7	8.6	8.6

ND = NOT DETECTED (VALUE REPORTED IS LIMIT OF DETECTION)

Appendix 4

First-Order Kinetics in Two Serial CSTRs



At steady state with a first-order reaction in COD:

$$C_i v = C_1 v + kVC_1$$

$$C_1 v = C_2 v + kVC_2$$

$$\text{let } \tau = V/v$$

$$k = [(C_i/C_2)^{\frac{1}{2}} - 1]/\tau$$

where C = COD concentration
C_i = COD inlet
v = volumetric flow rate
$V_1 = V_2 = V$ = volume of reactor
k = reaction rate constant

For System 1, overall conversion of COD was about 90%, with each reactor nominally having τ = 2 days:

$$k = [(C_i/0.1C_i)^{\frac{1}{2}} - 1]/2 = 1.08 \text{ days}^{-1}$$

For the effluent concentration response to a stepwise change in feed concentration:

$$\text{Reactor 1:} \quad V(dC_i/dt) = C_i v - C_1(t)v - kVC_1(t)$$

Solution:

$$C_1(t) = \frac{C_i/\tau}{\alpha} - [C_i/\tau - \alpha C_1(0)] \frac{e^{-\alpha t}}{\alpha}$$

where $C_1(0)$ is COD concentration in Reactor 1 at $t = 0$ and $\alpha = 1/\tau + k$.

$$\text{Reactor 2:} \quad V[dC_2(t)/dt] = C_1(t) - C_2(t)v - kVC_2(t)$$

Solution:

$$C_2(t) = \frac{C_i}{(\alpha\tau)^2} - \frac{te^{-\alpha t}}{\alpha\tau} \frac{C_i}{\tau} - \alpha C_1(0) + e^{-\alpha t}\left(C_2(0) - \frac{C_i}{(\alpha\tau)^2}\right)$$

where $C_2(0)$ is COD concentration in Reactor 2 at $t = 0$.

Given the system at steady state with a feed COD of 2,000 mg/L, $\tau = 2$ days, and $k = 1.08$ days^{-1}:

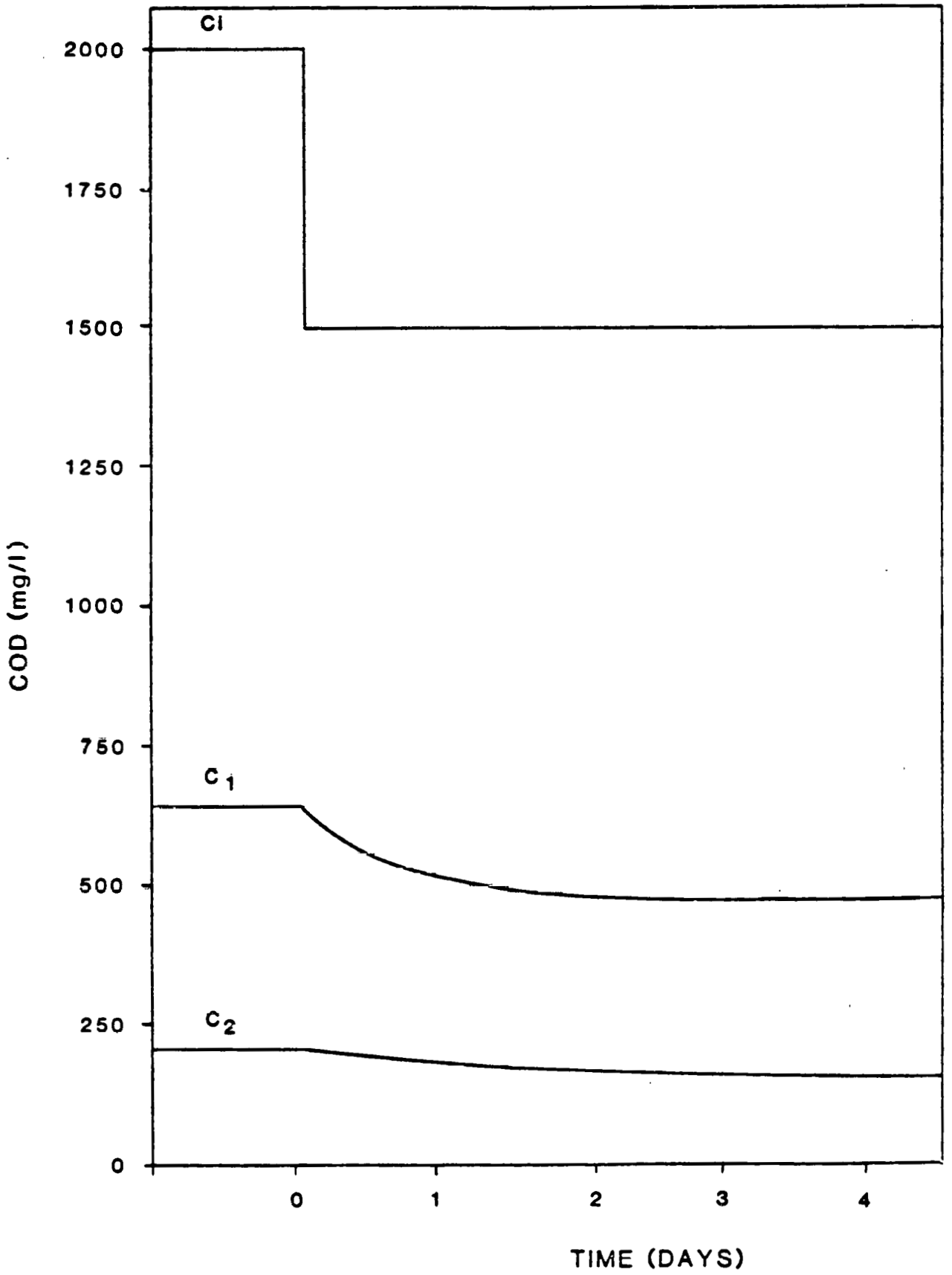
$$C_1(0) = 633 \text{ mg/L}, \quad C_2(0) = 200 \text{ mg/L}$$

With a step decrease in COD in the feed of 500 mg/L, the COD concentrations would respond as shown in Figure A-2.

Similar derivations can be made for System 2.

Figure A-2

COD Response to Stepwise Changes in Feed Concentration



Appendix 5

Gas Chromatographic/Mass Spectroscopic Analyses for Organic Priority Pollutants

8807 Cary Algonquin Road
Post Office Box 130
Cary, Illinois 60013

Telephone: 312-639-8818
800-334-8525

MeadCompuChem

May 26, 1983

Mr. W. M. Heintzelman
Catalytic Inc.
c/o ESD Lab
201 East 10th Street
Marcus Hook, PA 19061

Dear Mr. Heintzelman:

Thank you for selecting Mead CompuChem® for your recent sample analysis. We have completed the analysis that you requested and have enclosed a summary of the CompuChem data for your review. Additional data details are available for purchase if you require them.

As you know, EPA has proposed detection limits for the priority pollutants in the December 3, 1979, Federal Register, and we have reported all priority pollutant concentrations which have exceeded these limits. In addition, we have permanently stored a complete record of your data on magnetic tape. This includes chromatograms, mass spectra, calibration and quality control data for the organics. Therefore, your original data is readily available for future reference. Should you require additional information from your data base, please contact us at 1/800-334-8525.

In order to expedite data to you, we have forwarded the results to all completed analyses. If you submitted more samples than are included in the enclosed results, the data will be forthcoming upon completion of our final review.

Your confidence in our CompuChem service is appreciated. We look forward to a continuing association.

Sincerely,

Customer Service Dept.
Mead CompuChem®

Enclosure:

Report:

Sample Identifier Number:		CompuChem Number:	
	BIO UNIT 2B EFFLUENT		3547
	BIO UNIT 3 EFFLUENT		3548
	BIO UNIT 5 EFFLUENT		3549
	BIO UNIT 1B EFFLUENT		3550
	DEPHENOLATED FEED		3551

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*VIII CHAIN-OF-CUSTODY

2. ANALYTICAL METHODS, DEFINITIONS AND EXPLANATIONS

3. REPORT OF QUALITY CONTROL DATA *

A. MATRIX SPIKE ANALYSIS
B. DUPLICATE ANALYSIS
C. METHOD BLANK ANALYSIS
D. SURROGATE SPIKE RECOVERIES

EXHIBITS

I	VOA	BLANK RIC **
II	VOA	BFB TUNING
III	ACID	BLANK RIC **
IV	ACID	DFTPP TUNING
V	B/N/P	BLANK RIC **
VI	B/N/P	DFTPP TUNING
VII	PESTICIDE BLANK	(Method 608)

* if ordered

** Spectra and Spectral Match Diagrams included only if compounds in blank are above EPA specified detection limits.

MeadCompuChem

1A. REPORT OF DATA

SAMPLE IDENTIFIER NUMBER: BIO UNIT 2B EFFLUENT

COMPUCHEM SAMPLE NUMBER: 3547

SUBMITTED TO:

Mr. W. M. Heintzelman
Catalytic Inc.
c/o ESD Lab
201 East 10th Street
Marcus Hook, PA 19061

Gerald D Wright

GERALD D. WRIGHT, CPIM
MANAGER, PRODUCTION PLANNING AND CONTROL

R. L. MYERS, PH.D.
PRESIDENT

PAUL E. MILLS
DIRECTOR OF QUALITY ASSURANCE

JAMES J. ZOLDAK
DIRECTOR OF LABORATORY OPERATIONS

EXHIBIT I - LABORATORY CHRONICLE

SAMPLE IDENTIFIER: BIO UNIT 2B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3547

	Date
Received/Refrigerated	05/02/83
Organics	
Extracted	05/04/83
Analyzed	
1. Volatiles	05/13/83
2. Acids	05/11/83
3. Base/Neutrals	05/12/83
4. Pesticides/PCBS	Not Requested
Inorganics	
1. Metals	Not Requested
2. Cyanides	Not Requested
3. Phenols	Not Requested

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 2B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3547

	VOLATILE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1V.	ACROLEIN	BDL	100	
2V.	ACRYLONITRILE	BDL	100	
3V.	BENZENE	BDL	10	
4V.	BIS (CHLOROMETHYL) ETHER	BDL	10	
5V.	BROMOFORM	BDL	10	
6V.	CARBON TETRACHLORIDE	BDL	10	
7V.	CHLOROBENZENE	BDL	10	
8V.	CHLORODIBROMOMETHANE	BDL	10	
9V.	CHLOROETHANE	BDL	10	
10V.	2-CHLOROETHYLVINYL ETHER	BDL	10	
11V.	CHLOROFORM	BDL	10	
12V.	DICHLOROBROMOMETHANE	BDL	10	
13V.	DICHLORODIFLUOROMETHANE	BDL	10	
14V.	1,1-DICHLOROETHANE	BDL	10	
15V.	1,2-DICHLOROETHANE	BDL	10	
16V.	1,1-DICHLOROETHYLENE	BDL	10	
17V.	1,2-DICHLOROPROPANE	BDL	10	
18V.	1,3-DICHLOROPROPYLENE	BDL	10	
19V.	ETHYLBENZENE	BDL	10	
20V.	METHYL BROMIDE	BDL	10	
21V.	METHYL CHLORIDE	BDL	10	
22V.	METHYLENE CHLORIDE	BDL	10	
23V.	1,1,2,2-TETRACHLOROETHANE	BDL	10	
24V.	TETRACHLOROETHYLENE	BDL	10	
25V.	TOLUENE	BDL	10	
26V.	1,2-TRANS-DICHLOROETHYLENE	BDL	10	
27V.	1,1,1-TRICHLOROETHANE	BDL	10	
28V.	1,1,2-TRICHLOROETHANE	BDL	10	
29V	TRICHLOROETHYLENE	BDL	10	
30V.	TRICHLOROFLUOROMETHANE	BDL	10	
31V.	VINYL CHLORIDE	BDL	10	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 2B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3547

	ACID EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1A.	2-CHLOROPHENOL	BDL	25	
2A.	2,4-DICHLOROPHENOL	BDL	25	
3A.	2,4-DIMETHYLPHENOL	BDL	25	
4A.	4,6-DINITRO-O-CRESOL	BDL	250	
5A.	2,4-DINITROPHENOL	BDL	250	
6A.	2-NITROPHENOL	BDL	25	
7A.	4-NITROPHENOL	BDL	25	
8A.	P-CHLORO-M-CRESOL	BDL	25	
9A.	PENTACHLOROPHENOL	BDL	25	
10A.	PHENOL	BDL	25	
11A.	2,4,6-TRICHLOROPHENOL	BDL	25	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 2B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3547

	BASE-NEUTRAL EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1B.	ACENAPHTHENE	BDL	10	
2B.	ACENAPHTHYLENE	BDL	10	
3B.	ANTHRACENE	BDL	10	
4B.	BENZIDINE	BDL	10	
5B.	BENZO (A) ANTHRACENE	BDL	10	
6B.	BENZO (A) PYRENE	BDL	10	
7B.	3,4-BENZOFLUORANTHENE	BDL	10	
8B.	BENZO (GHI) PERYLENE	BDL	25	
9B.	BENZO (K) FLUORANTHENE	BDL	10	
10B.	BIS (2-CHLOROETHOXY) METHANE	BDL	10	
11B.	BIS (2-CHLOROETHYL) ETHER	BDL	10	
12B.	BIS (2-CHLOROISOPROPYL) ETHER	BDL	10	
13B.	BIS (2-ETHYLHEXYL) PHTHALATE	BDL	10	
14B.	4-BROMOPHENYL PHENYL ETHER	BDL	10	
15B.	BUTYL BENZYL PHTHALATE	BDL	10	
16B.	2-CHLORONAPHTHALENE	BDL	10	
17B.	4-CHLOROPHENYL PHENYL ETHER	BDL	10	
18B.	CHRYSENE	BDL	10	
19B.	DIBENZO (A,H) ANTHRACENE	BDL	25	
20B.	1,2-DICHLOROBENZENE	BDL	10	
21B.	1,3-DICHLOROBENZENE	BDL	10	
22B.	1,4-DICHLOROBENZENE	BDL	10	
23B.	3,3'-DICHLOROBENZIDINE	BDL	10	
24B.	DIETHYL PHTHALATE	BDL	10	
25B.	DIMETHYL PHTHALATE	BDL	10	
26B.	DI-N-BUTYL PHTHALATE	BDL	10	
27B.	2,4-DINITROTOLUENE	BDL	10	
28B.	2,6-DINITROTOLUENE	BDL	10	
29B.	DI-N-OCTYL PHTHALATE	BDL	10	
30B.	1,2-DIPHENYLHYDRAZINE	BDL	10	
31B.	FLUORANTHENE	BDL	10	
32B.	FLUORENE	BDL	10	
33B.	HEXACHLOROBENZENE	BDL	10	
34B.	HEXACHLOROBUTADIENE	BDL	10	
35B.	HEXACHLOROCYCLOPENTADIENE	BDL	10	

Continued...

BDL = BELOW DETECTION LIMIT

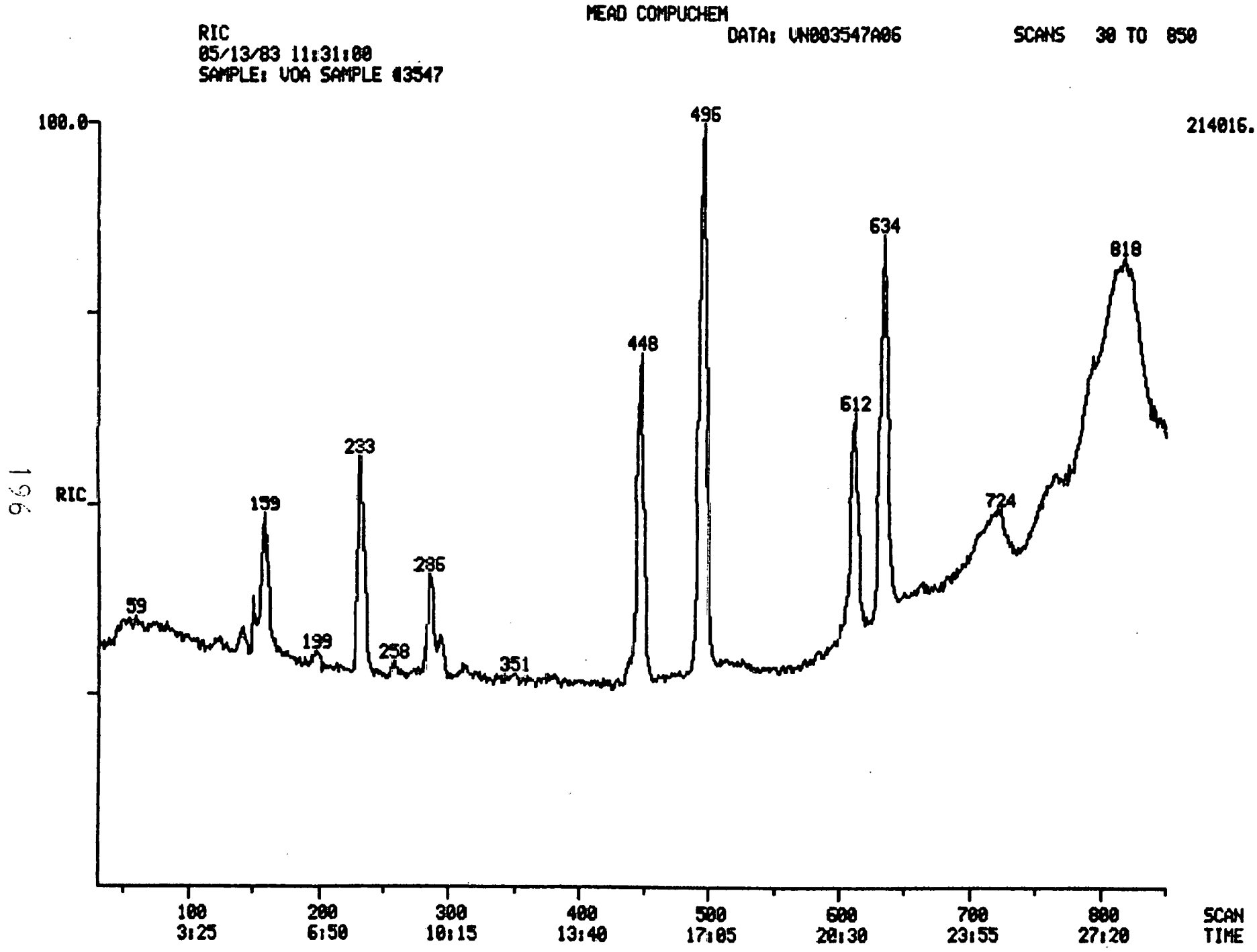
EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 2B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3547

	BASE-NEUTRAL EXTRACTABLE ORGANICS (Continued)	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
36B.	HEXACHLOROETHANE	BDL	10	
37B.	INDENO (1,2,3-CD) PYRENE	BDL	25	
38B.	ISOPHORONE	BDL	10	
39B.	NAPHTHALENE	BDL	10	
40B.	NITROBENZENE	BDL	10	
41B.	N-NITROSODIMETHYLAMINE	BDL	10	
42B.	N-NITROSODI-N-PROPYLAMINE	BDL	10	
43B.	N-NITROSODIPHENYLAMINE	BDL	10	
44B.	PHENANTHRENE	BDL	10	
45B.	PYRENE	BDL	10	
46B.	1,2,4-TRICHLOROBENZENE	BDL	10	

BDL = BELOW DETECTION LIMIT

CompuChem employs Methods 624 and 625 for priority pollutant analysis. These methods were proposed by the U.S. E.P.A. in Volume 44 of the Federal Register on December 3, 1979. As these methods are currently in a "proposed" status, all aspects of the methods may not be validated until the U.S. E.P.A. promulgates the methods in "final" form.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RIC
961
59
159
199
233
258
286
351
448
496
612
634
724
818
100
3:25
200
6:50
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600
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700
23:55
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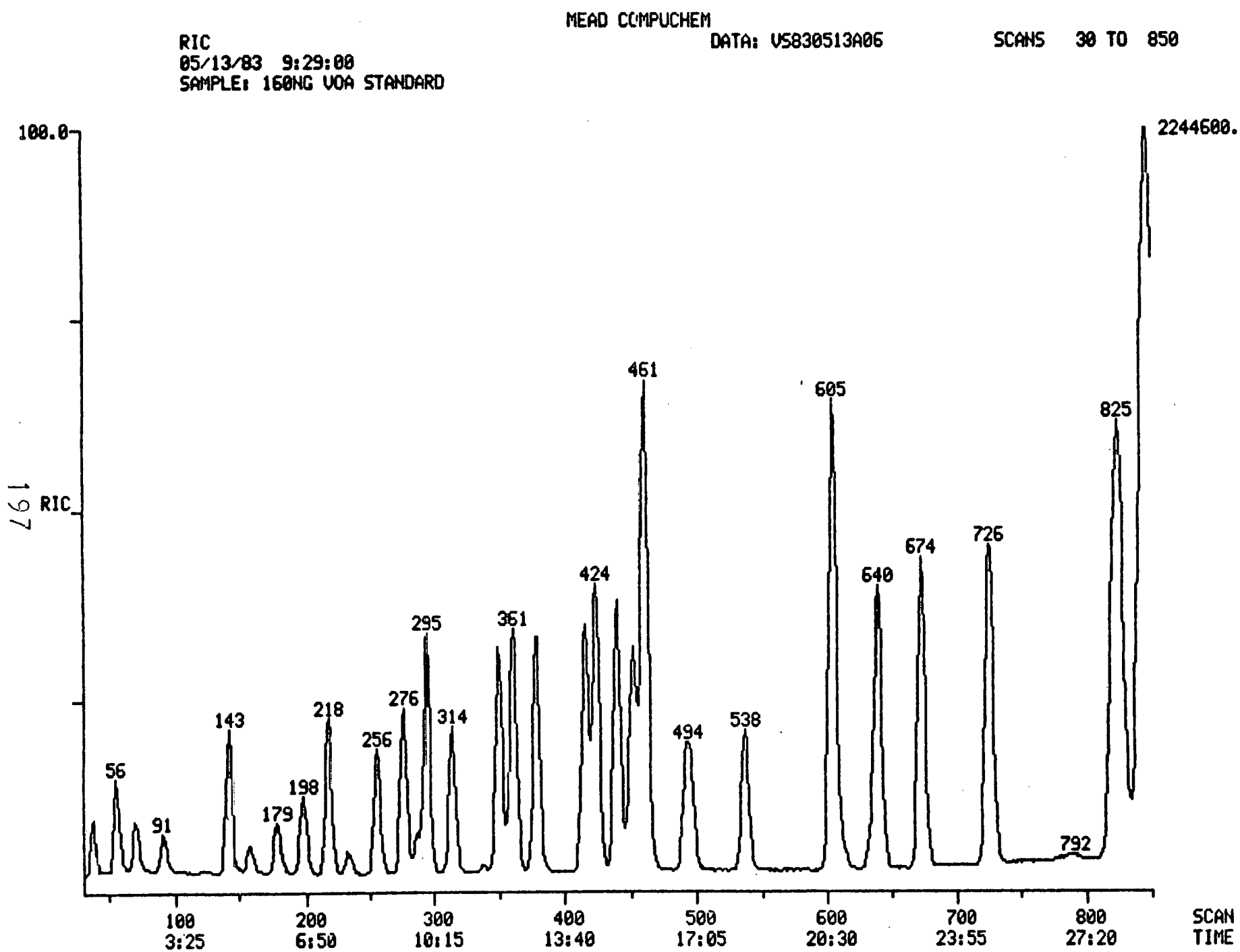
27:20
SCAN
TIME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198
218
256
276
295
314
361
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538
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674
726
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100
3:25
200
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17:05
600
20:30
700
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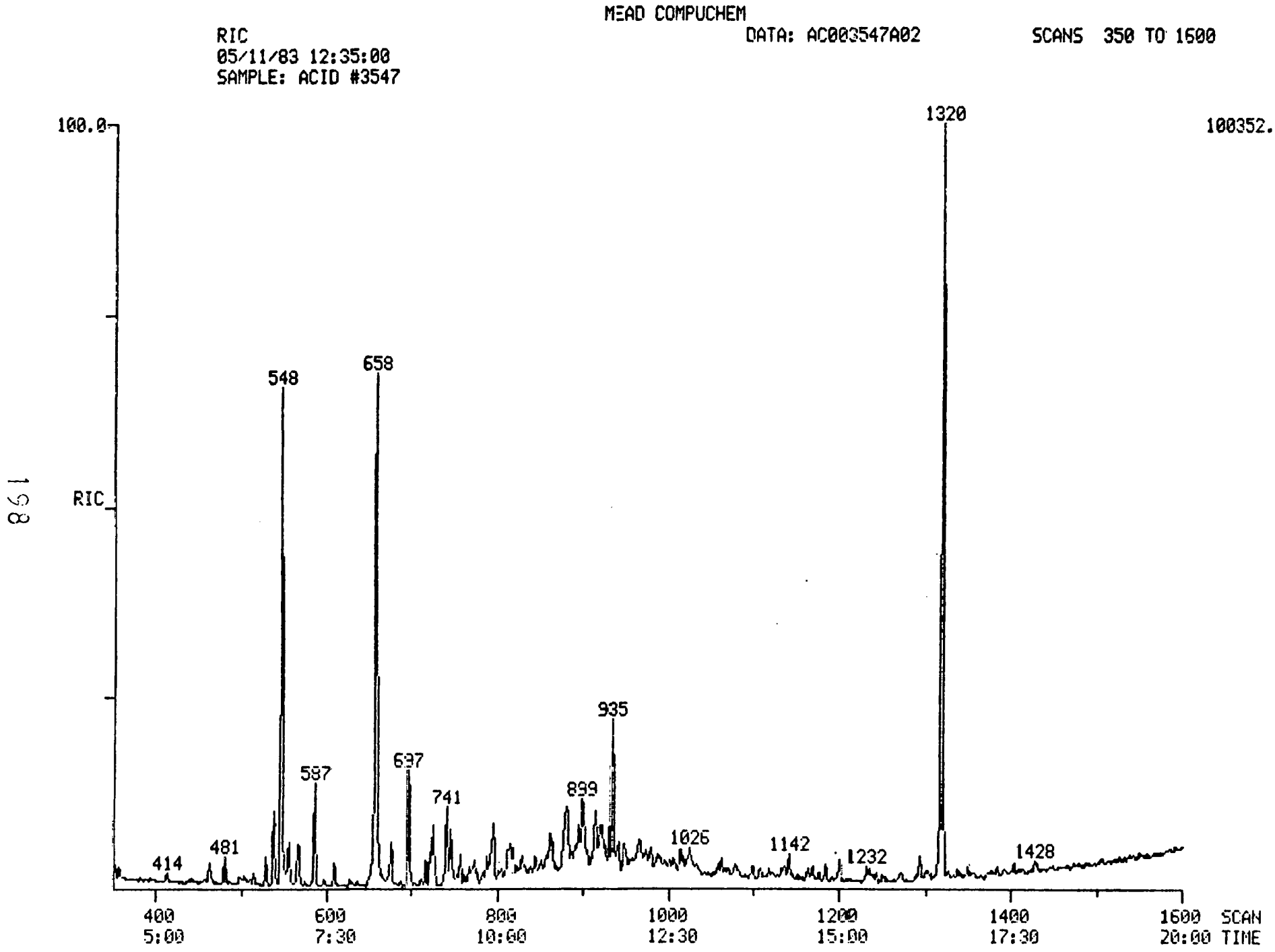
27:20
SCAN
TIME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414
481
1026
1142
1232
1428
400
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600
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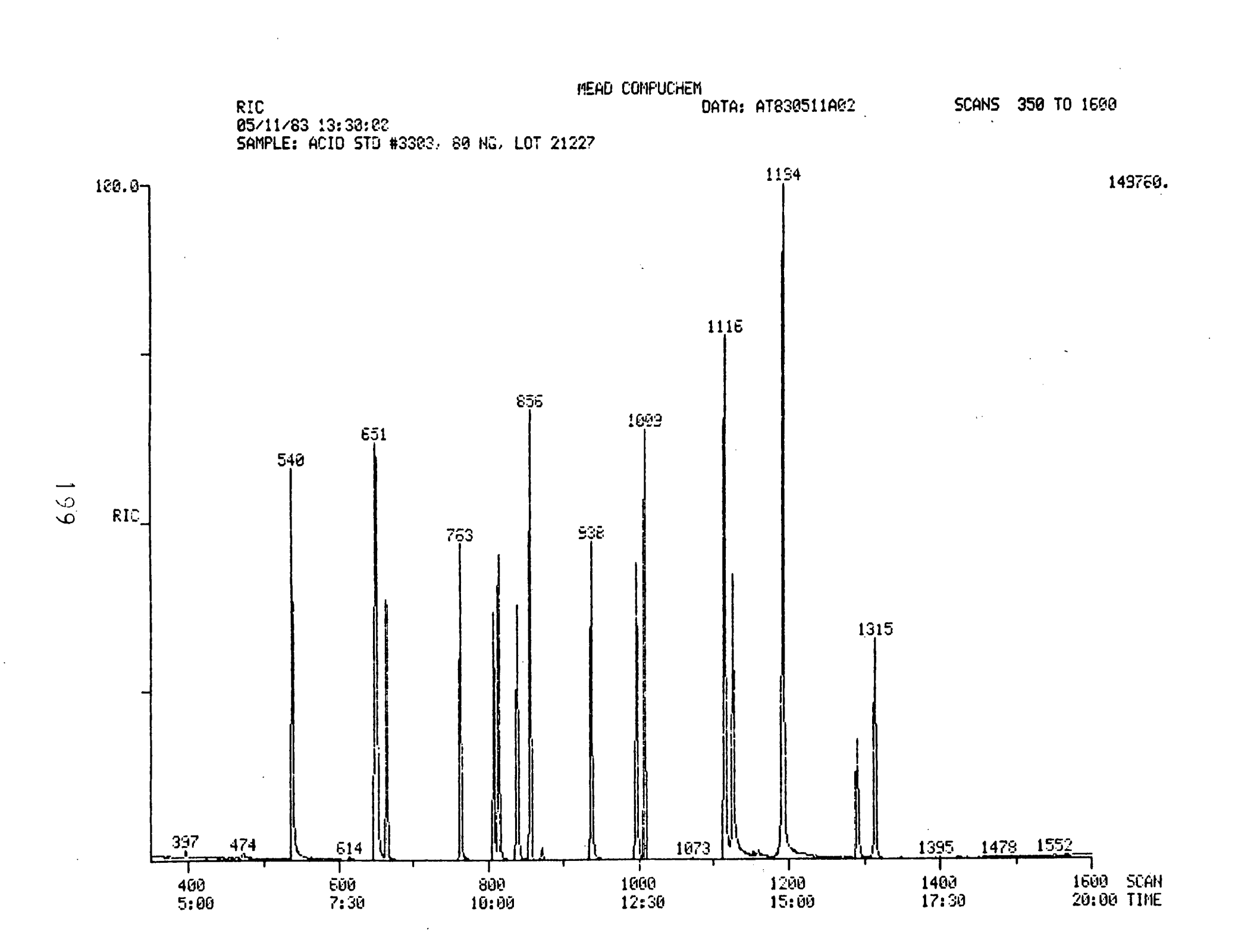
800
10:00
1000
12:30
1200
15:00
1400
17:30
1600
20:00
SCAN
TIME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400
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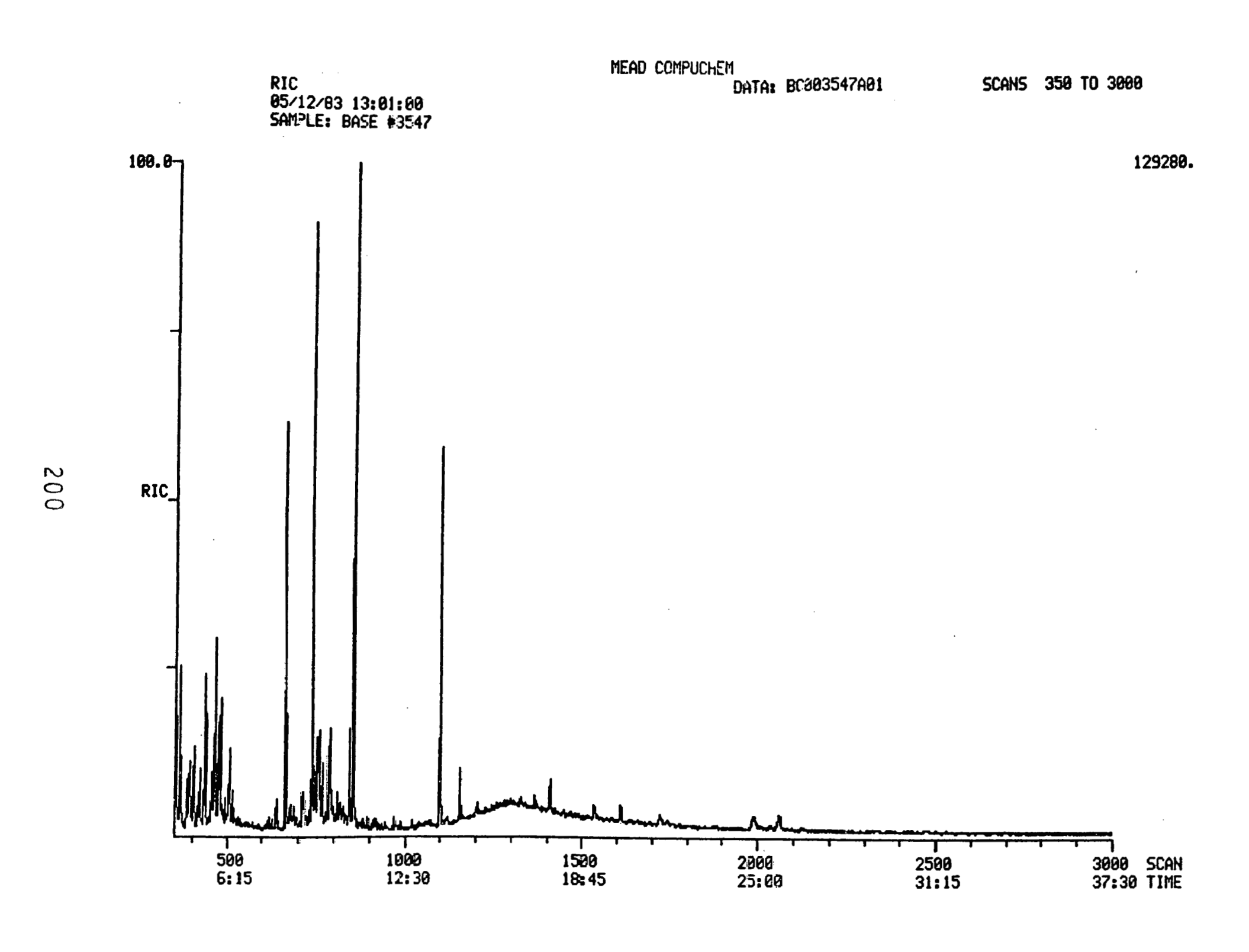
TIME
196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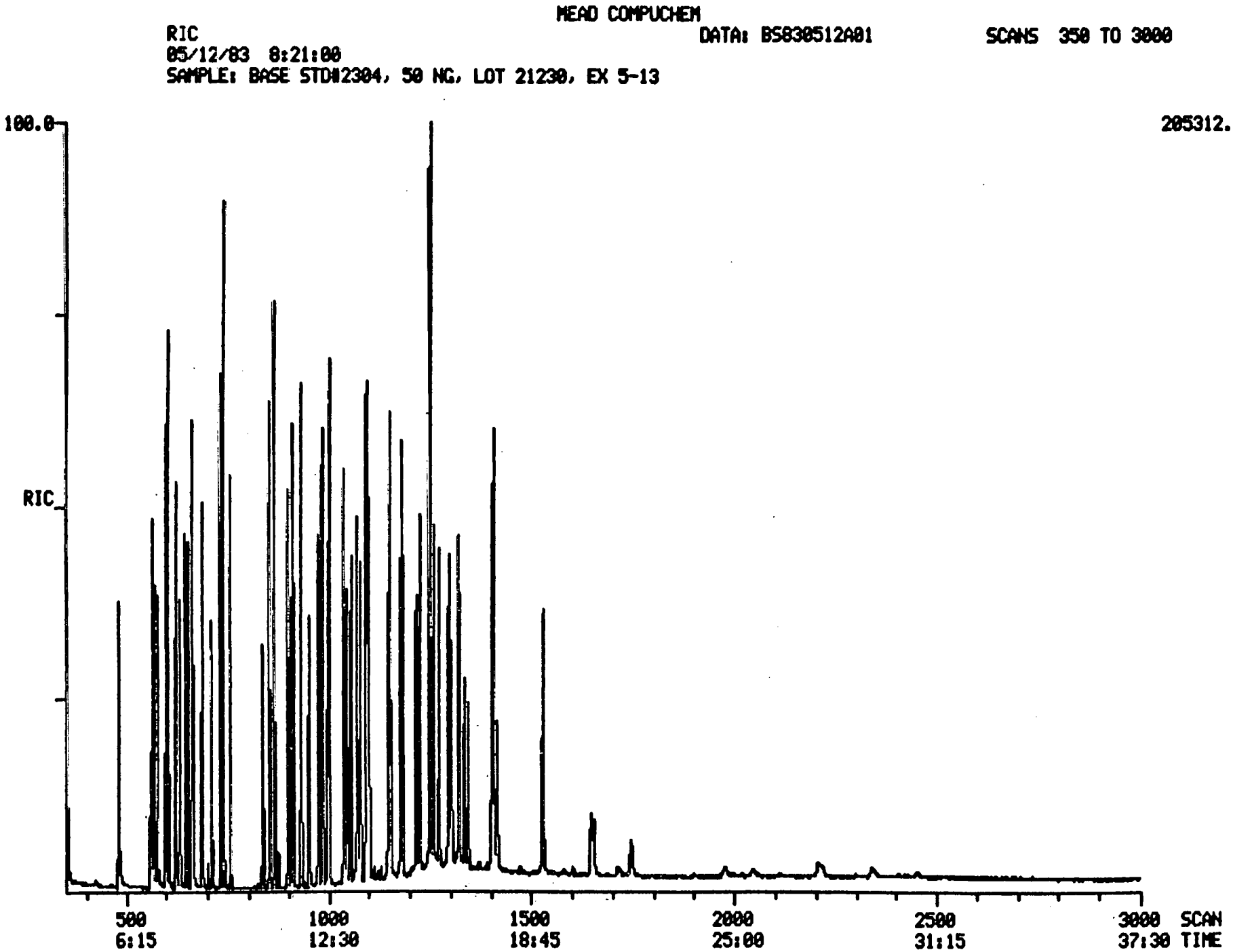
6:15
1000
12:30
1500
18:45
2000
25:00
2500
31:15
3000 SCAN
37:30 TIME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205312.
RIC
500
6:15
1000
12:30
1500
18:45
2000
25:00
2500
31:15
3000 SCAN
37:30 TIME

MeadCompuChem

1B. REPORT OF DATA

SAMPLE IDENTIFIER NUMBER: BIO UNIT 3 EFFLUENT

COMPUCHEM SAMPLE NUMBER: 3548

SUBMITTED TO:

Mr. W. M. Heintzelman
Catalytic Inc.
c/o ESD Lab
201 East 10th Street
Marcus Hook, PA 19061

Gerald D. Wright

GERALD D. WRIGHT, CPIM
MANAGER, PRODUCTION PLANNING AND CONTROL

R. L. MYERS, PH.D.
PRESIDENT

PAUL E. MILLS
DIRECTOR OF QUALITY ASSURANCE

JAMES J. ZOLDAK
DIRECTOR OF LABORATORY OPERATIONS

EXHIBIT I - LABORATORY CHRONICLE

SAMPLE IDENTIFIER: BIO UNIT 3 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3548

	Date
Received/Refrigerated	05/02/83
Organics	
Extracted	05/04/83
Analyzed	
1. Volatiles	05/13/83
2. Acids	05/11/83
3. Base/Neutrals	05/13/83
4. Pesticides/PCBS	Not Requested
Inorganics	
1. Metals	Not Requested
2. Cyanides	Not Requested
3. Phenols	Not Requested

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 3 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3548

	VOLATILE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1V.	ACROLEIN	BDL	100	
2V.	ACRYLONITRILE	BDL	100	
3V.	BENZENE	BDL	10	
4V.	BIS (CHLOROMETHYL) ETHER	BDL	10	
5V.	BROMOFORM	BDL	10	
6V.	CARBON TETRACHLORIDE	BDL	10	
7V.	CHLOROBENZENE	BDL	10	
8V.	CHLORODIBROMOMETHANE	BDL	10	
9V.	CHLOROETHANE	BDL	10	
10V.	2-CHLOROETHYLVINYL ETHER	BDL	10	
11V.	CHLOROFORM	BDL	10	
12V.	DICHLOROBROMOMETHANE	BDL	10	
13V.	DICHLORODIFLUOROMETHANE	BDL	10	
14V.	1,1-DICHLOROETHANE	BDL	10	
15V.	1,2-DICHLOROETHANE	BDL	10	
16V.	1,1-DICHLOROETHYLENE	BDL	10	
17V.	1,2-DICHLOROPROPANE	BDL	10	
18V.	1,3-DICHLOROPROPYLENE	BDL	10	
19V.	ETHYLBENZENE	BDL	10	
20V.	METHYL BROMIDE	BDL	10	
21V.	METHYL CHLORIDE	BDL	10	
22V.	METHYLENE CHLORIDE	BDL	10	
23V.	1,1,2,2-TETRACHLOROETHANE	BDL	10	
24V.	TETRACHLOROETHYLENE	BDL	10	
25V.	TOLUENE	BDL	10	
26V.	1,2-TRANS-DICHLOROETHYLENE	BDL	10	
27V.	1,1,1-TRICHLOROETHANE	BDL	10	
28V.	1,1,2-TRICHLOROETHANE	BDL	10	
29V	TRICHLOROETHYLENE	BDL	10	
30V.	TRICHLOROFLUOROMETHANE	BDL	10	
31V.	VINYL CHLORIDE	BDL	10	

BDL = BELOW DETECTION LIMIT

EXHIBIT II

QUALITY CONTROL QUALIFIER

DATE: May 25, 1983

SAMPLE IDENTIFIER: BIO UNIT 3 EFFLUENT

COMPUCHEM SAMPLE NUMBER: 3548

FRACTION: Acid

PROBLEM: Low Surrogate Recoveries

DISCUSSION:

Sample 3548 had low surrogate recoveries in the Acid fraction and does not meet CompuChem Quality Control protocols. The Base/Neutral fraction had normal surrogate recoveries and is within Quality Control protocols. There was no sample remaining for reextraction.

CONCLUSION:

The low Acid surrogate recoveries may be due to the sample matrix.

Thomas B. Clyne
Manager, Quality Assurance/Quality Control
Cary Facility

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 3 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3548

	ACID EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1A.	2-CHLOROPHENOL	BDL	25	
2A.	2,4-DICHLOROPHENOL	BDL	25	
3A.	2,4-DIMETHYLPHENOL	BDL	25	
4A.	4,6-DINITRO-O-CRESOL	BDL	250	
5A.	2,4-DINITROPHENOL	BDL	250	
6A.	2-NITROPHENOL	BDL	25	
7A.	4-NITROPHENOL	BDL	25	
8A.	P-CHLORO-M-CRESOL	BDL	25	
9A.	PENTACHLOROPHENOL	BDL	25	
10A.	PHENOL	BDL	25	
11A.	2,4,6-TRICHLOROPHENOL	BDL	25	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 3 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3548

	BASE-NEUTRAL EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1B.	ACENAPHTHENE	BDL	10	
2B.	ACENAPHTHYLENE	BDL	10	
3B.	ANTHRACENE	BDL	10	
4B.	BENZIDINE	BDL	10	
5B.	BENZO (A) ANTHRACENE	BDL	10	
6B.	BENZO (A) PYRENE	BDL	10	
7B.	3,4-BENZOFLUORANTHENE	BDL	10	
8B.	BENZO (GHI) PERYLENE	BDL	25	
9B.	BENZO (K) FLUORANTHENE	BDL	10	
10B.	BIS (2-CHLOROETHOXY) METHANE	BDL	10	
11B.	BIS (2-CHLOROETHYL) ETHER	BDL	10	
12B.	BIS (2-CHLOROISOPROPYL) ETHER	BDL	10	
13B.	BIS (2-ETHYLHEXYL) PHTHALATE	BDL	10	
14B.	4-BROMOPHENYL PHENYL ETHER	BDL	10	
15B.	BUTYL BENZYL PHTHALATE	BDL	10	
16B.	2-CHLORONAPHTHALENE	BDL	10	
17B.	4-CHLOROPHENYL PHENYL ETHER	BDL	10	
18B.	CHRYSENE	BDL	10	
19B.	DIBENZO (A,H) ANTHRACENE	BDL	25	
20B.	1,2-DICHLOROBENZENE	BDL	10	
21B.	1,3-DICHLOROBENZENE	BDL	10	
22B.	1,4-DICHLOROBENZENE	BDL	10	
23B.	3,3'-DICHLOROBENZIDINE	BDL	10	
24B.	DIETHYL PHTHALATE	BDL	10	
25B.	DIMETHYL PHTHALATE	BDL	10	
26B.	DI-N-BUTYL PHTHALATE	BDL	10	
27B.	2,4-DINITROTOLUENE	BDL	10	
28B.	2,6-DINITROTOLUENE	BDL	10	
29B.	DI-N-OCTYL PHTHALATE	BDL	10	
30B.	1,2-DIPHENYLHYDRAZINE	BDL	10	
31B.	FLUORANTHENE	BDL	10	
32B.	FLUORENE	BDL	10	
33B.	HEXACHLOROBENZENE	BDL	10	
34B.	HEXACHLOROBUTADIENE	BDL	10	
35B.	HEXACHLOROCYCLOPENTADIENE	BDL	10	

Continued...

BDL = BELOW DETECTION LIMIT

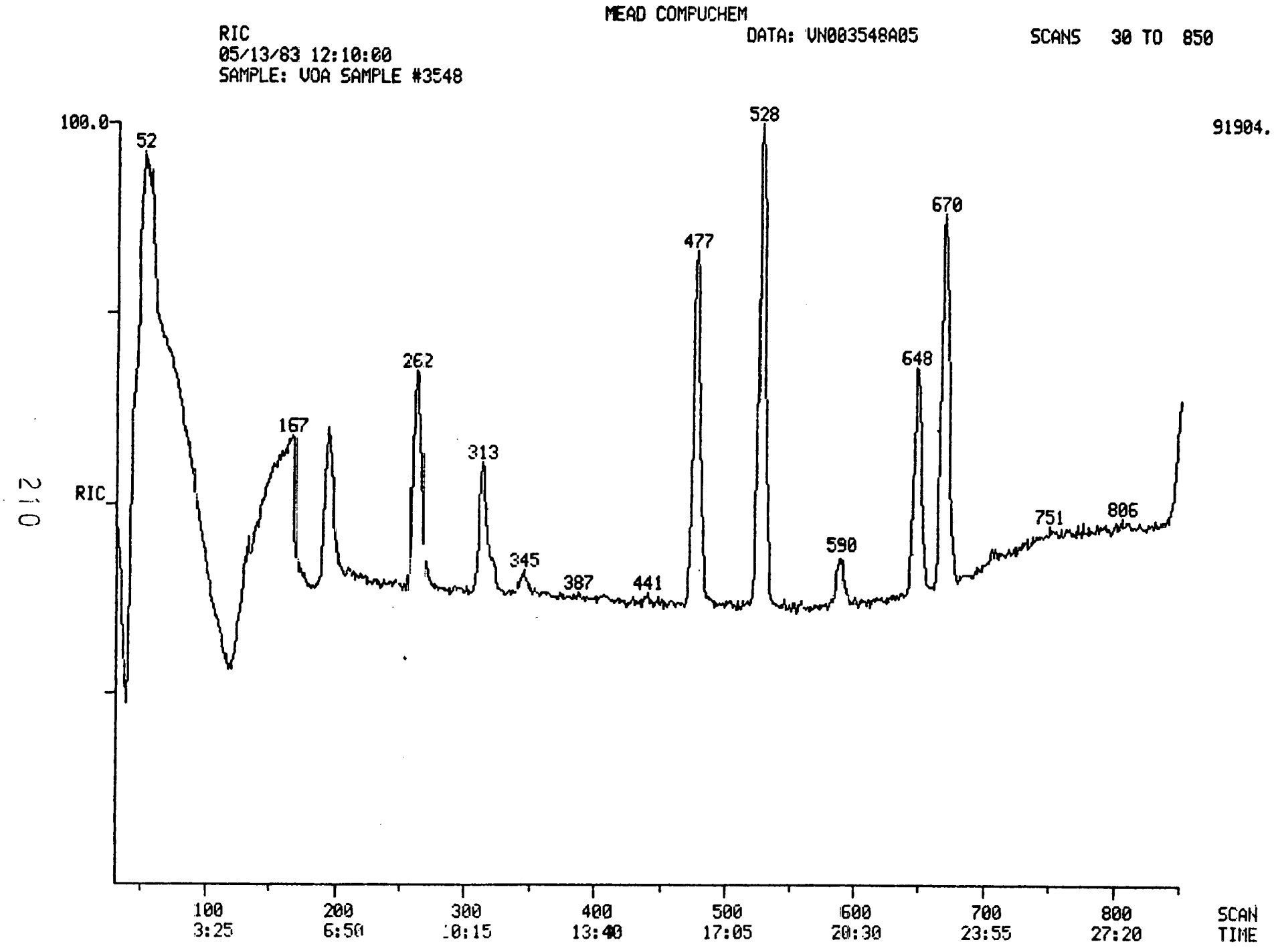
EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 3 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3548

	BASE-NEUTRAL EXTRACTABLE ORGANICS (Continued)	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
36B.	HEXACHLOROETHANE	BDL	10	
37B.	INDENO (1,2,3-CD) PYRENE	BDL	25	
38B.	ISOPHORONE	BDL	10	
39B.	NAPHTHALENE	BDL	10	
40B.	NITROBENZENE	BDL	10	
41B.	N-NITROSODIMETHYLAMINE	BDL	10	
42B.	N-NITROSODI-N-PROPYLAMINE	BDL	10	
43B.	N-NITROSODIPHENYLAMINE	BDL	10	
44B.	PHENANTHRENE	BDL	10	
45B.	PYRENE	BDL	10	
46B.	1,2,4-TRICHLOROBENZENE	BDL	10	

BDL = BELOW DETECTION LIMIT

CompuChem employs Methods 624 and 625 for priority pollutant analysis. These methods were proposed by the U.S. E.P.A. in Volume 44 of the Federal Register on December 3, 1979. As these methods are currently in a "proposed" status, all aspects of the methods may not be validated until the U.S. E.P.A. promulgates the methods in "final" form.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387
441
477
528
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648
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751
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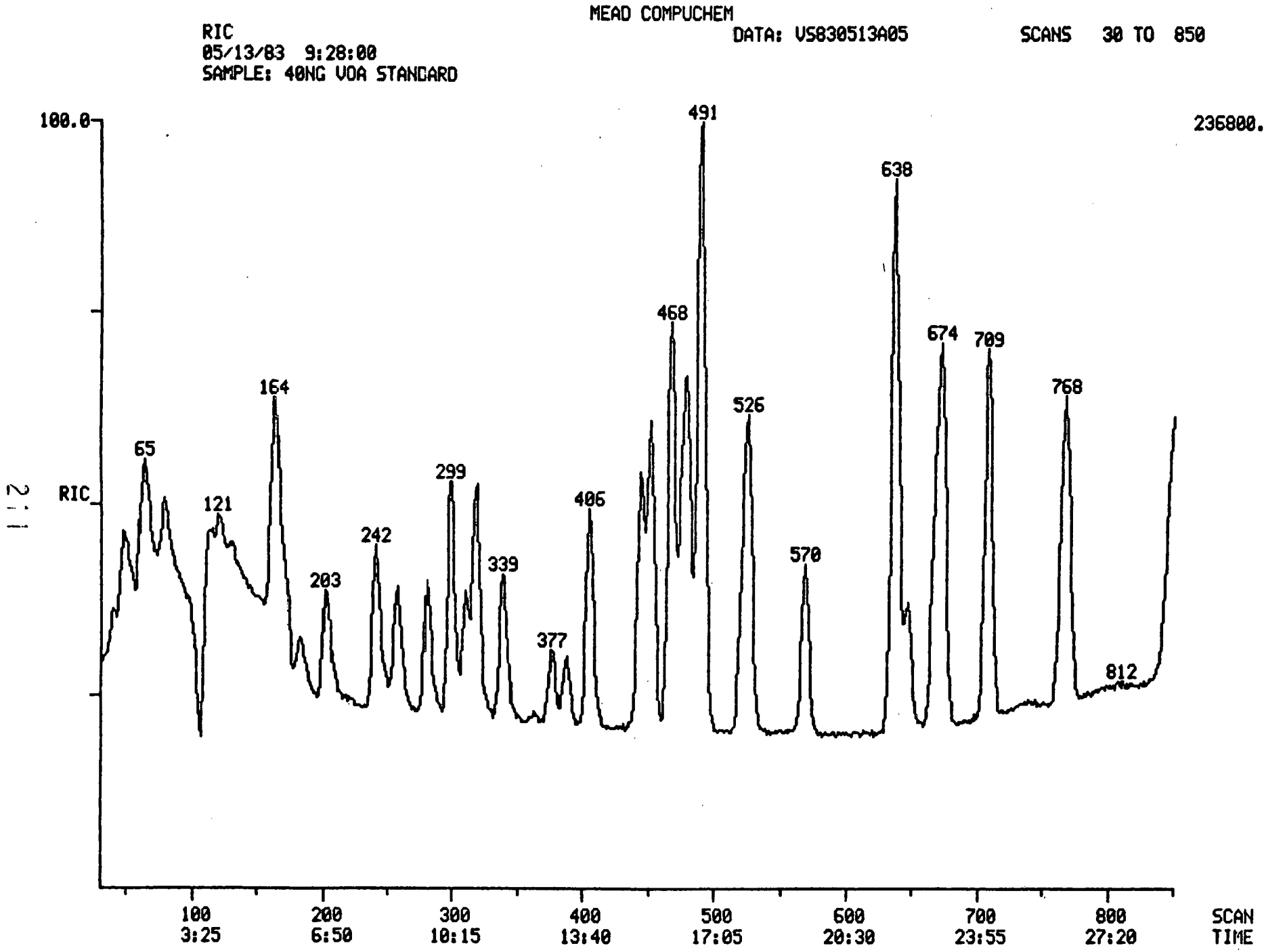
SCAN
TIME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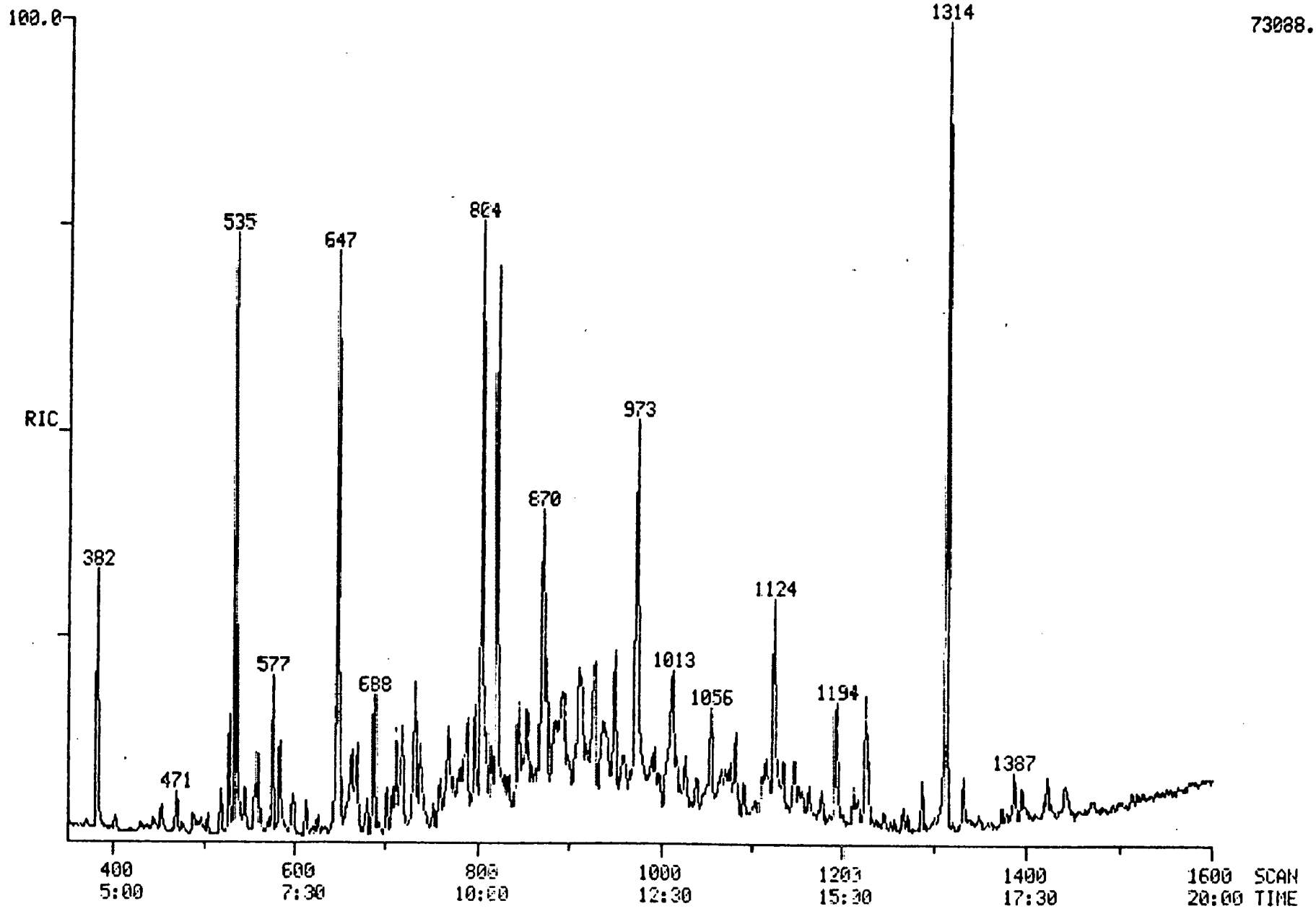
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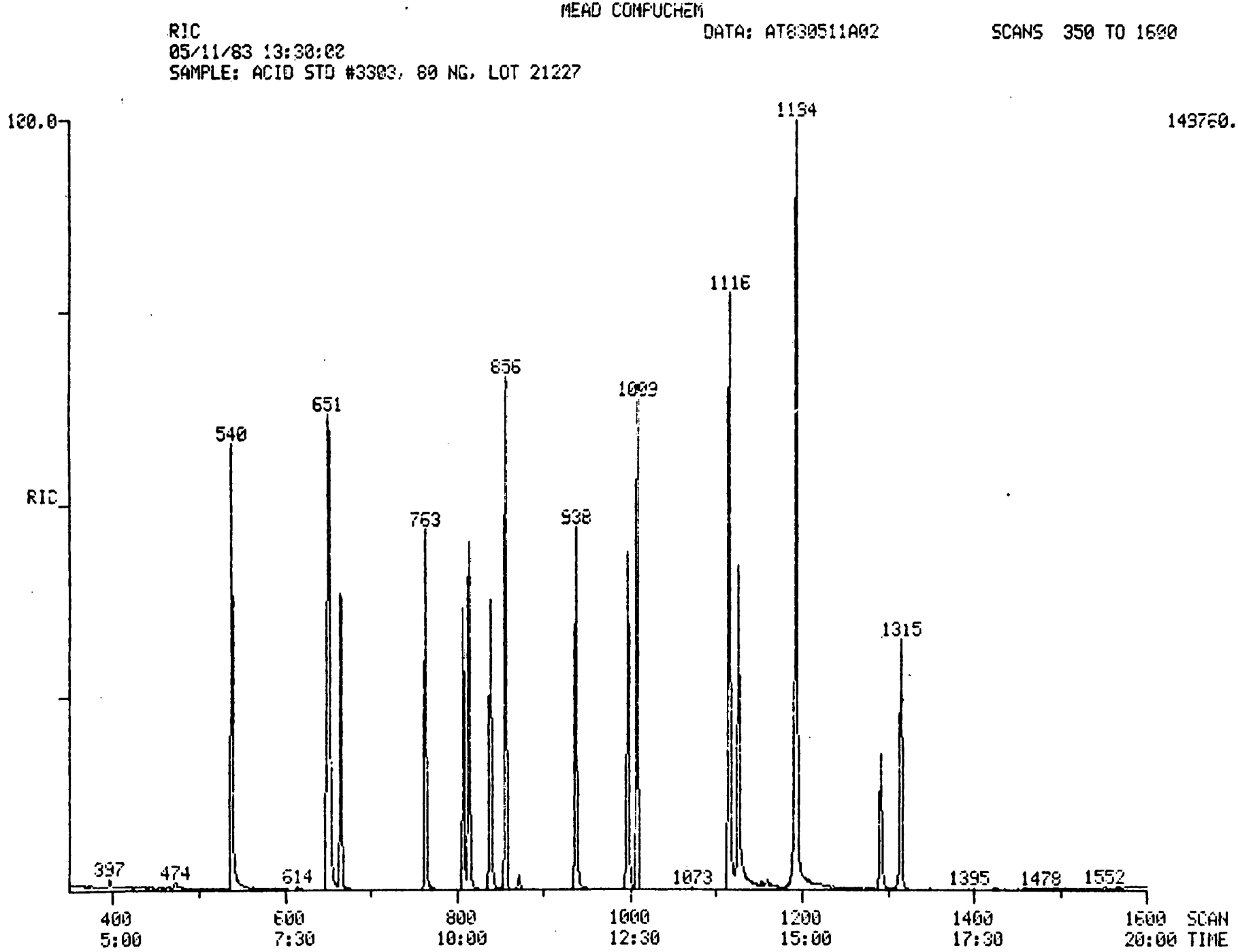
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656
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1009
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763
938
1315
397
474
614
1073
1395
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1552
400
5:00
600
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1400
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1600
20:00
SCAN
TIME

MEAD COMPUCHEM

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05/13/83 13:37:00
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DATA: BN003548A04

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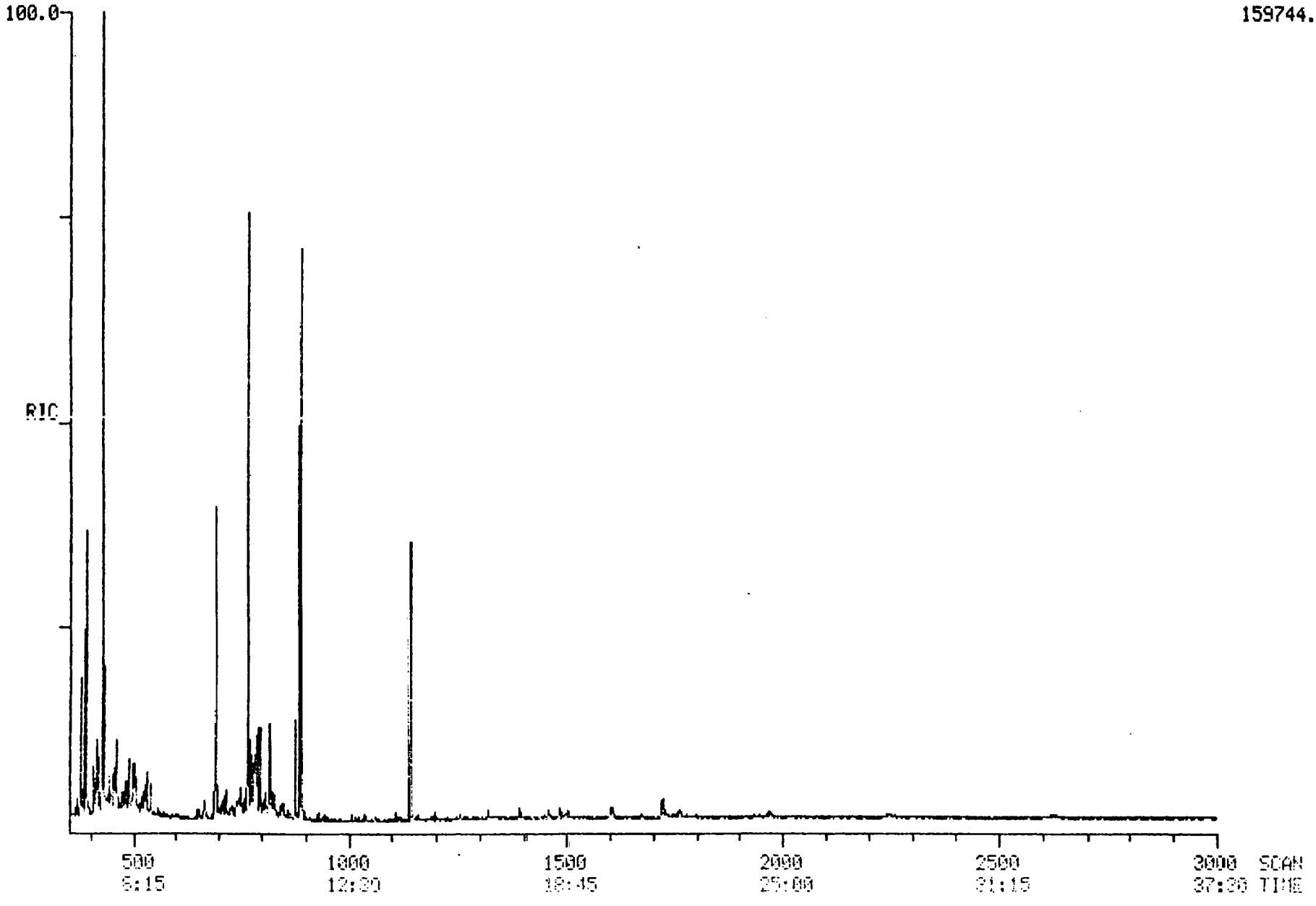

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MEAD COMPUCHEM

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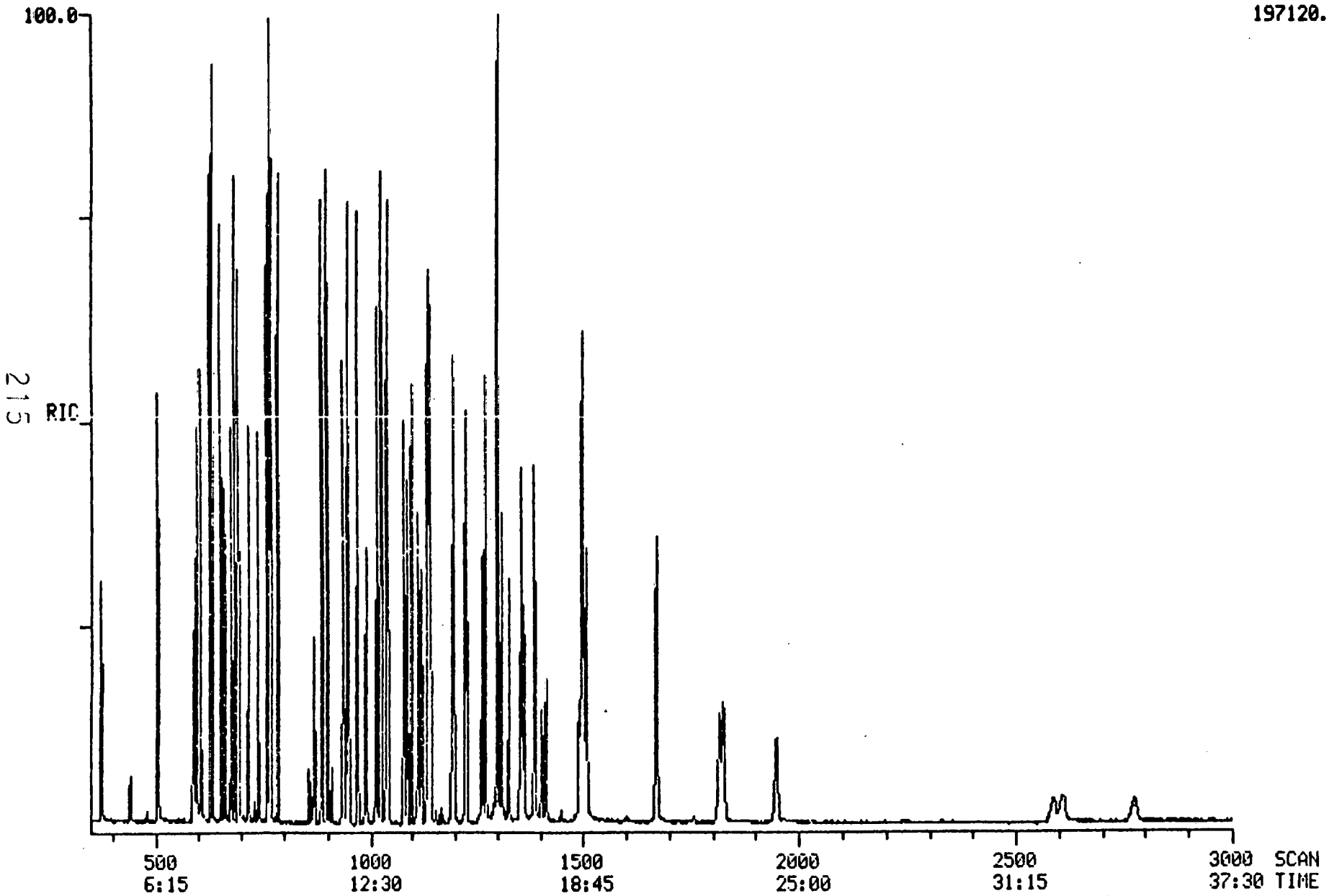


215

MeadCompuChem

1C. REPORT OF DATA

SAMPLE IDENTIFIER NUMBER: BIO UNIT 5 EFFLUENT

COMPUCHEM SAMPLE NUMBER: 3549

SUBMITTED TO:

Mr. W. M. Heintzelman
Catalytic Inc.
c/o ESD Lab
201 East 10th Street
Marcus Hook, PA 19061

Gerald D. Wright

GERALD D. WRIGHT, CPIM
MANAGER, PRODUCTION PLANNING AND CONTROL

R. L. MYERS, PH.D.
PRESIDENT

PAUL E. MILLS
DIRECTOR OF QUALITY ASSURANCE

JAMES J. ZOLDAK
DIRECTOR OF LABORATORY OPERATIONS

EXHIBIT I - LABORATORY CHRONICLE

SAMPLE IDENTIFIER: BIO UNIT 5 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3549

	Date
Received/Refrigerated	05/02/83
Organics	
Extracted	05/04/83
Analyzed	
1. Volatiles	05/13/83
2. Acids	05/12/83
3. Base/Neutrals	05/17/83
4. Pesticides/PCBS	Not Requested
Inorganics	
1. Metals	Not Requested
2. Cyanides	Not Requested
3. Phenols	Not Requested

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 5 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3549

	VOLATILE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1V.	ACROLEIN	BDL	100	
2V.	ACRYLONITRILE	BDL	100	
3V.	BENZENE	BDL	10	
4V.	BIS (CHLOROMETHYL) ETHER	BDL	10	
5V.	BROMOFORM	BDL	10	
6V.	CARBON TETRACHLORIDE	BDL	10	
7V.	CHLOROBENZENE	BDL	10	
8V.	CHLORODIBROMOMETHANE	BDL	10	
9V.	CHLOROETHANE	BDL	10	
10V.	2-CHLOROETHYLVINYL ETHER	BDL	10	
11V.	CHLOROFORM	BDL	10	
12V.	DICHLOROBROMOMETHANE	BDL	10	
13V.	DICHLORODIFLUOROMETHANE	BDL	10	
14V.	1,1-DICHLOROETHANE	BDL	10	
15V.	1,2-DICHLOROETHANE	BDL	10	
16V.	1,1-DICHLOROETHYLENE	BDL	10	
17V.	1,2-DICHLOROPROPANE	BDL	10	
18V.	1,3-DICHLOROPROPYLENE	BDL	10	
19V.	ETHYLBENZENE	BDL	10	
20V.	METHYL BROMIDE	BDL	10	
21V.	METHYL CHLORIDE	BDL	10	
22V.	METHYLENE CHLORIDE	BDL	10	
23V.	1,1,2,2-TETRACHLOROETHANE	BDL	10	
24V.	TETRACHLOROETHYLENE	BDL	10	
25V.	TOLUENE	BDL	10	
26V.	1,2-TRANS-DICHLOROETHYLENE	BDL	10	
27V.	1,1,1-TRICHLOROETHANE	BDL	10	
28V.	1,1,2-TRICHLOROETHANE	BDL	10	
29V	TRICHLOROETHYLENE	BDL	10	
30V.	TRICHLOROFLUOROMETHANE	BDL	10	
31V.	VINYL CHLORIDE	BDL	10	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 5 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3549

	ACID EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1A.	2-CHLOROPHENOL	BDL	25	
2A.	2,4-DICHLOROPHENOL	BDL	25	
3A.	2,4-DIMETHYLPHENOL	BDL	25	
4A.	4,6-DINITRO-O-CRESOL	BDL	250	
5A.	2,4-DINITROPHENOL	BDL	250	
6A.	2-NITROPHENOL	BDL	25	
7A.	4-NITROPHENOL	BDL	25	
8A.	P-CHLORO-M-CRESOL	BDL	25	
9A.	PENTACHLOROPHENOL	BDL	25	
10A.	PHENOL	BDL	25	
11A.	2,4,6-TRICHLOROPHENOL	BDL	25	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 5 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3549

	BASE-NEUTRAL EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1B.	ACENAPHTHENE	BDL	10	
2B.	ACENAPHTHYLENE	BDL	10	
3B.	ANTHRACENE	BDL	10	
4B.	BENZIDINE	BDL	10	
5B.	BENZO (A) ANTHRACENE	BDL	10	
6B.	BENZO (A) PYRENE	BDL	10	
7B.	3,4-BENZOFLUORANTHENE	BDL	10	
8B.	BENZO (GHI) PERYLENE	BDL	25	
9B.	BENZO (K) FLUORANTHENE	BDL	10	
10B.	BIS (2-CHLOROETHOXY) METHANE	BDL	10	
11B.	BIS (2-CHLOROETHYL) ETHER	BDL	10	
12B.	BIS (2-CHLOROISOPROPYL) ETHER	BDL	10	
13B.	BIS (2-ETHYLHEXYL) PHTHALATE	BDL	10	
14B.	4-BROMOPHENYL PHENYL ETHER	BDL	10	
15B.	BUTYL BENZYL PHTHALATE	BDL	10	
16B.	2-CHLORONAPHTHALENE	BDL	10	
17B.	4-CHLOROPHENYL PHENYL ETHER	BDL	10	
18B.	CHRYSENE	BDL	10	
19B.	DIBENZO (A,H) ANTHRACENE	BDL	25	
20B.	1,2-DICHLOROBENZENE	BDL	10	
21B.	1,3-DICHLOROBENZENE	BDL	10	
22B.	1,4-DICHLOROBENZENE	BDL	10	
23B.	3,3'-DICHLOROBENZIDINE	BDL	10	
24B.	DIETHYL PHTHALATE	BDL	10	
25B.	DIMETHYL PHTHALATE	BDL	10	
26B.	DI-N-BUTYL PHTHALATE	BDL	10	
27B.	2,4-DINITROTOLUENE	BDL	10	
28B.	2,6-DINITROTOLUENE	BDL	10	
29B.	DI-N-OCTYL PHTHALATE	BDL	10	
30B.	1,2-DIPHENYLHYDRAZINE	BDL	10	
31B.	FLUORANTHENE	BDL	10	
32B.	FLUORENE	BDL	10	
33B.	HEXACHLOROBENZENE	BDL	10	
34B.	HEXACHLOROBUTADIENE	BDL	10	
35B.	HEXACHLOROCYCLOPENTADIENE	BDL	10	

Continued...

BDL = BELOW DETECTION LIMIT

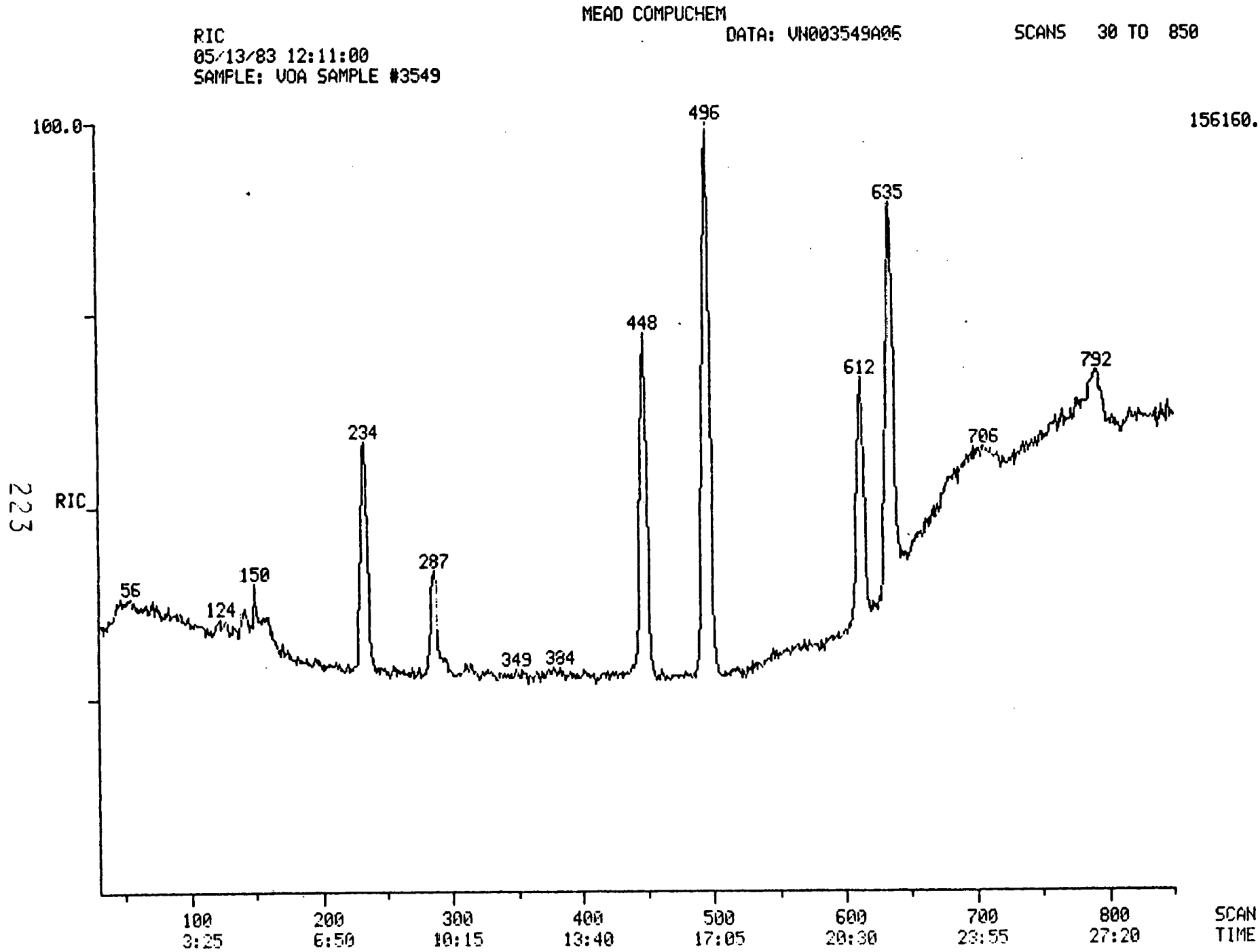
EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 5 EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3549

	BASE-NEUTRAL EXTRACTABLE ORGANICS (Continued)	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
36B.	HEXACHLOROETHANE	BDL	10	
37B.	INDENO (1,2,3-CD) PYRENE	BDL	25	
38B.	ISOPHORONE	BDL	10	
39B.	NAPHTHALENE	BDL	10	
40B.	NITROBENZENE	BDL	10	
41B.	N-NITROSODIMETHYLAMINE	BDL	10	
42B.	N-NITROSODI-N-PROPYLAMINE	BDL	10	
43B.	N-NITROSODIPHENYLAMINE	BDL	10	
44B.	PHENANTHRENE	BDL	10	
45B.	PYRENE	BDL	10	
46B.	1,2,4-TRICHLOROBENZENE	BDL	10	

BDL = BELOW DETECTION LIMIT

CompuChem employs Methods 624 and 625 for priority pollutant analysis. These methods were proposed by the U.S. E.P.A. in Volume 44 of the Federal Register on December 3, 1979. As these methods are currently in a "proposed" status, all aspects of the methods may not be validated until the U.S. E.P.A. promulgates the methods in "final" form.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700
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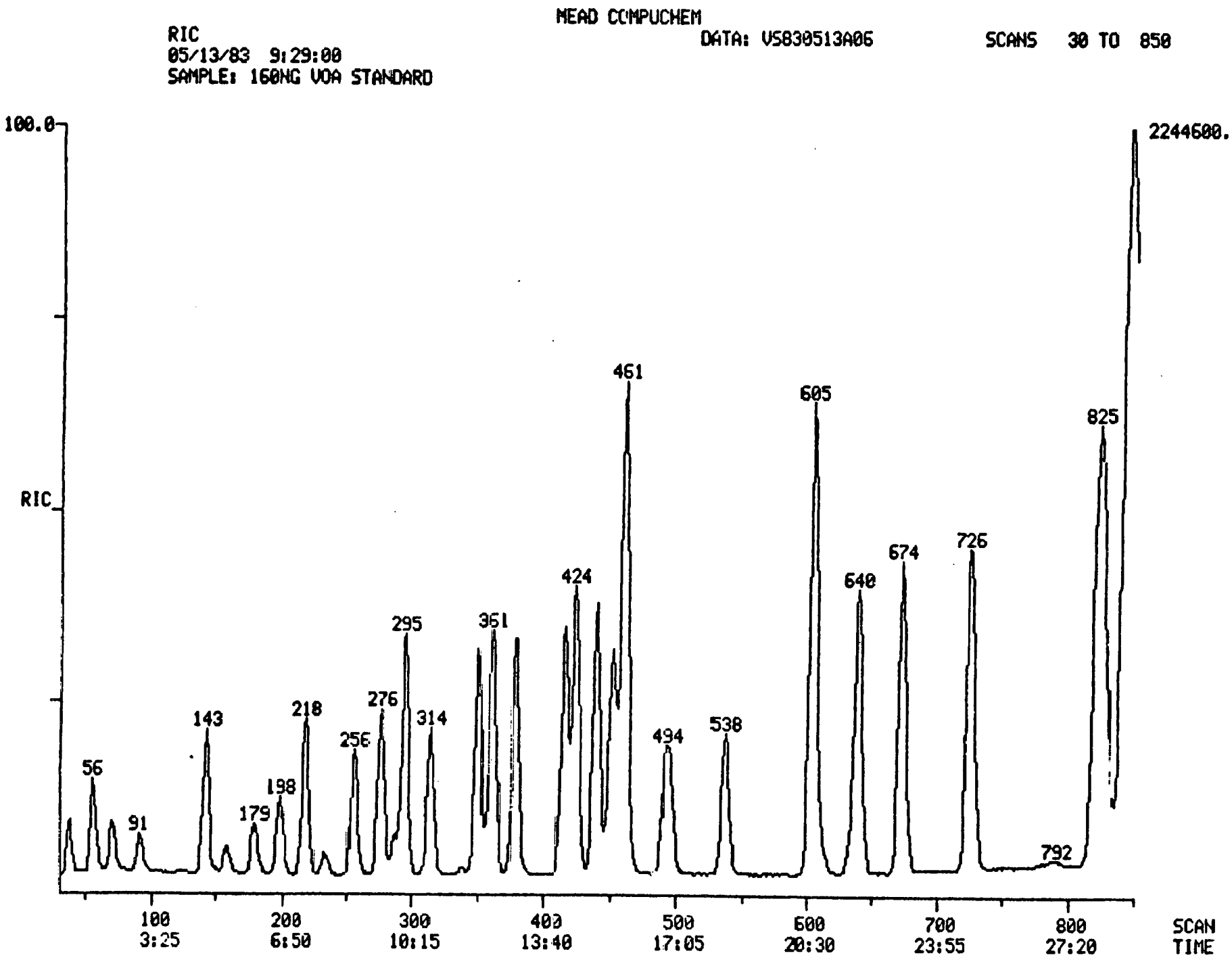
SCAN
TIME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314
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674
726
792
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100
3:25
200
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800
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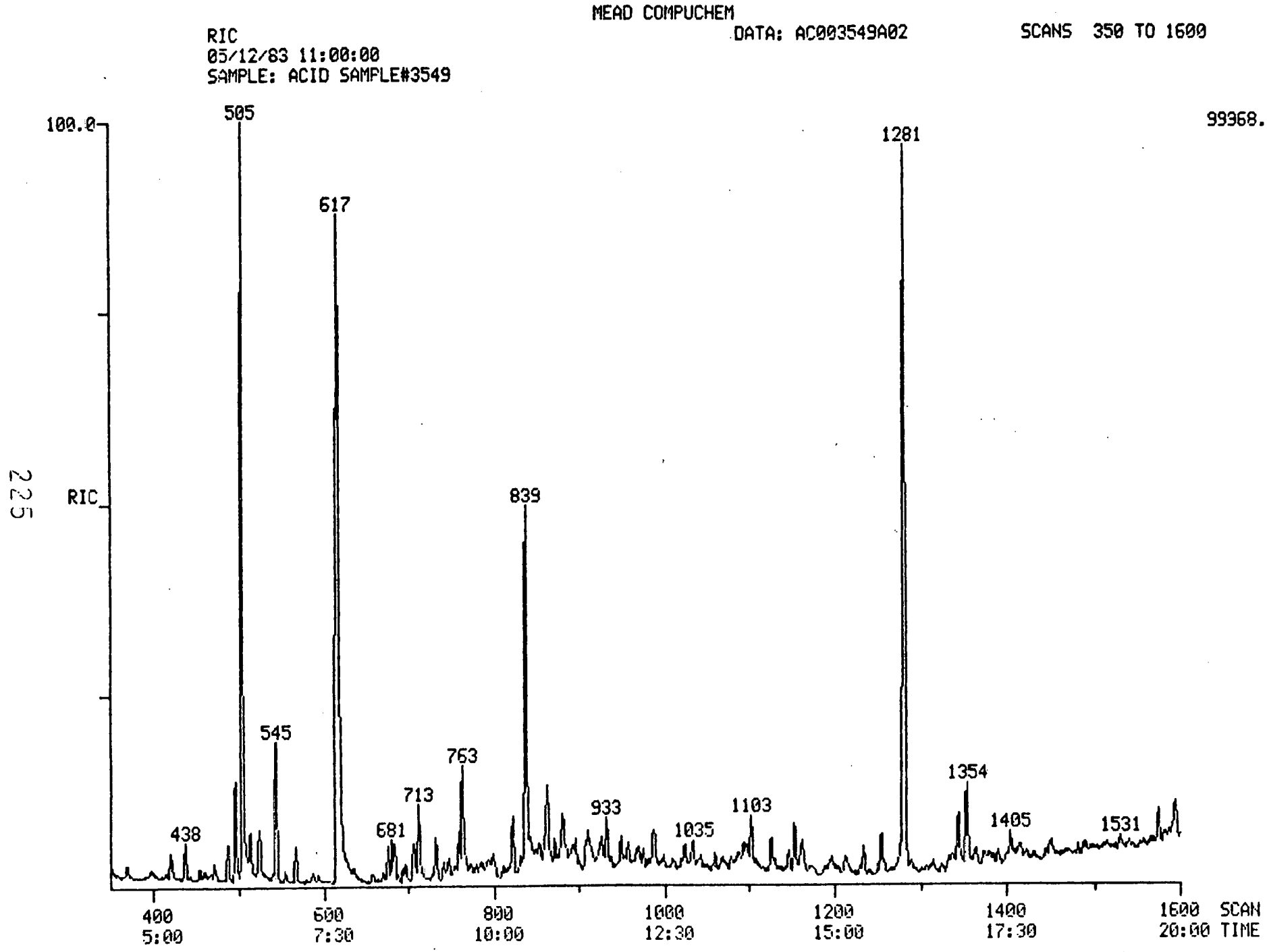
SCAN
TIME

224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1354
1405
1531
RIC
400
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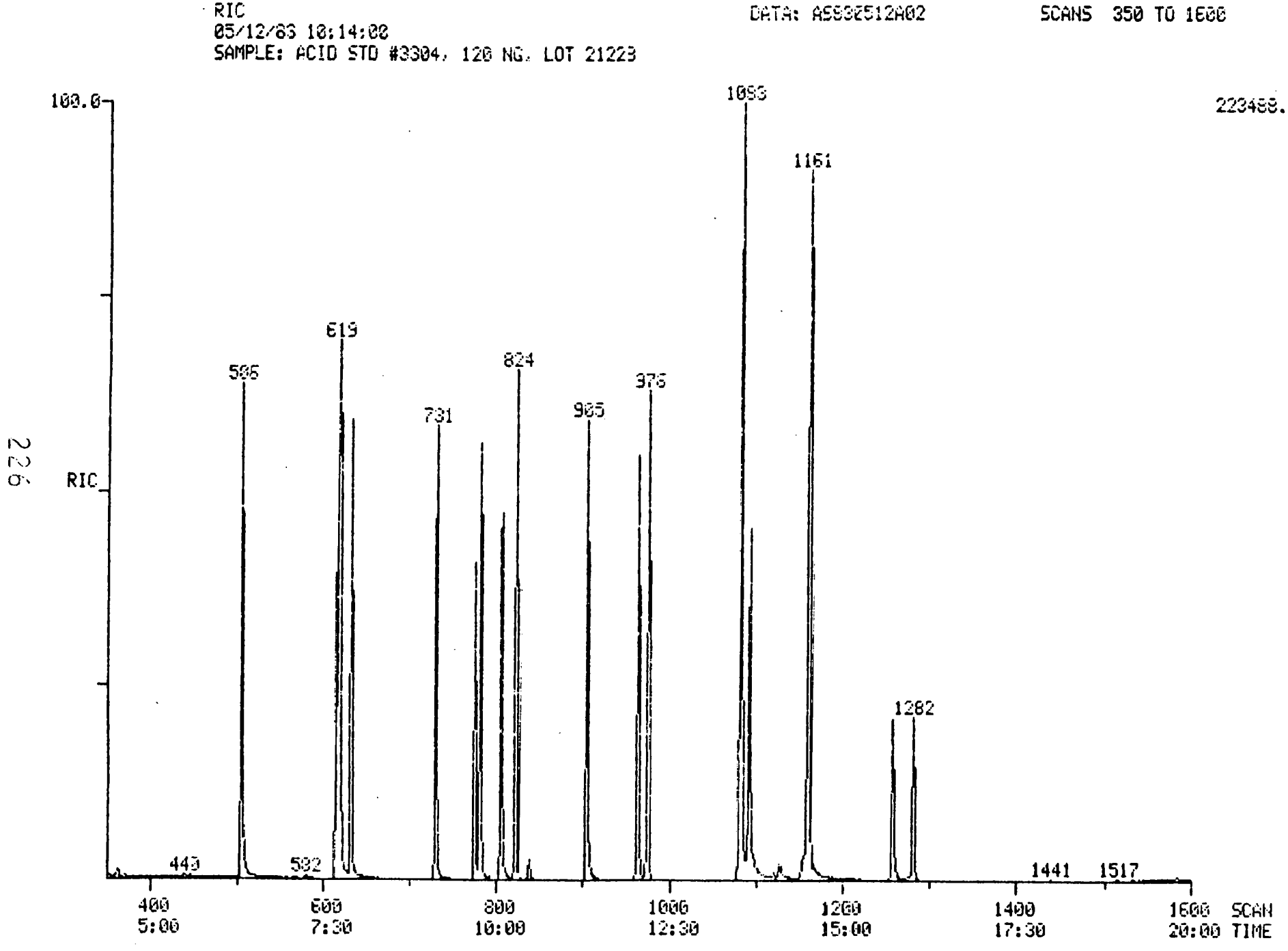
SCAN
TIME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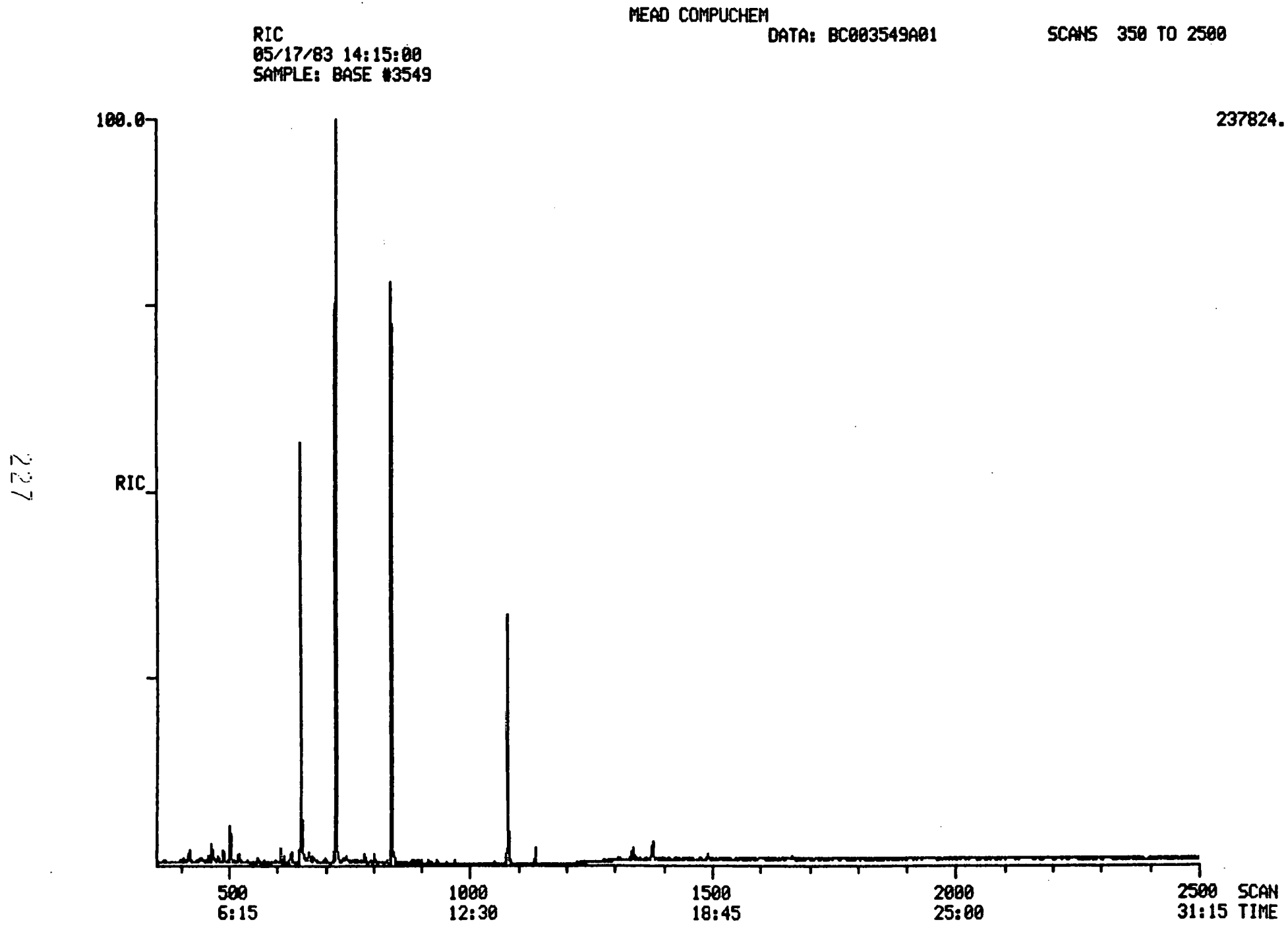
20:00
SCAN
TIME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RIC
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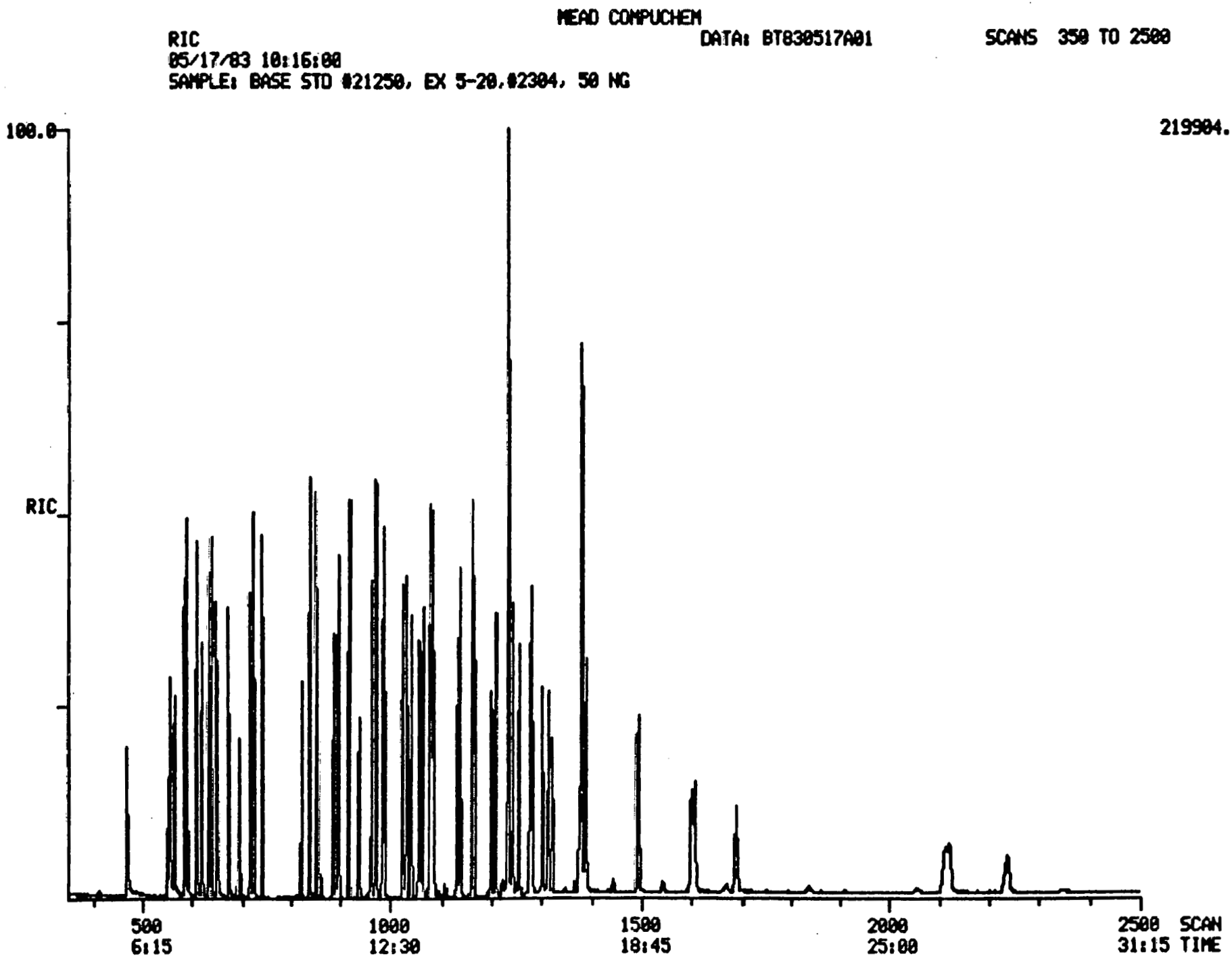
1500
18:45
2000
25:00
2500 SCAN
31:15 TIME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RIC
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6:15
1000
12:30
1500
18:45
2000
25:00
2500 SCAN
31:15 TIME

MeadCompuChem

1D. REPORT OF DATA

SAMPLE IDENTIFIER NUMBER: BIO UNIT 1B EFFLUENT

COMPUCHEM SAMPLE NUMBER: 3550

SUBMITTED TO:

Mr. W. M. Heintzelman
Catalytic Inc.
c/o ESD Lab
201 East 10th Street
Marcus Hook, PA 19061

Gerald D Wright

GERALD D. WRIGHT, CPIM
MANAGER, PRODUCTION PLANNING AND CONTROL

R. L. MYERS, PH.D.
PRESIDENT

PAUL E. MILLS
DIRECTOR OF QUALITY ASSURANCE

JAMES J. ZOLDAK
DIRECTOR OF LABORATORY OPERATIONS

EXHIBIT I - LABORATORY CHRONICLE

SAMPLE IDENTIFIER: BIO UNIT 1B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3550

	Date
Received/Refrigerated	05/02/83
Organics	
Extracted	05/04/83
Analyzed	
1. Volatiles	05/13/83
2. Acids	05/12/83
3. Base/Neutrals	05/16/83
4. Pesticides/PCBS	Not Requested
Inorganics	
1. Metals	Not Requested
2. Cyanides	Not Requested
3. Phenols	Not Requested

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 1B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3550

	VOLATILE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1V.	ACROLEIN	BDL	100	
2V.	ACRYLONITRILE	BDL	100	
3V.	BENZENE	BDL	10	
4V.	BIS (CHLOROMETHYL) ETHER	BDL	10	
5V.	BROMOFORM	BDL	10	
6V.	CARBON TETRACHLORIDE	BDL	10	
7V.	CHLOROBENZENE	BDL	10	
8V.	CHLORODIBROMOMETHANE	BDL	10	
9V.	CHLOROETHANE	BDL	10	
10V.	2-CHLOROETHYLVINYL ETHER	BDL	10	
11V.	CHLOROFORM	BDL	10	
12V.	DICHLOROBROMOMETHANE	BDL	10	
13V.	DICHLORODIFLUOROMETHANE	BDL	10	
14V.	1,1-DICHLOROETHANE	BDL	10	
15V.	1,2-DICHLOROETHANE	BDL	10	
16V.	1,1-DICHLOROETHYLENE	BDL	10	
17V.	1,2-DICHLOROPROPANE	BDL	10	
18V.	1,3-DICHLOROPROPYLENE	BDL	10	
19V.	ETHYLBENZENE	BDL	10	
20V.	METHYL BROMIDE	BDL	10	
21V.	METHYL CHLORIDE	BDL	10	
22V.	METHYLENE CHLORIDE	BDL	10	
23V.	1,1,2,2-TETRACHLOROETHANE	BDL	10	
24V.	TETRACHLOROETHYLENE	BDL	10	
25V.	TOLUENE	BDL	10	
26V.	1,2-TRANS-DICHLOROETHYLENE	BDL	10	
27V.	1,1,1-TRICHLOROETHANE	BDL	10	
28V.	1,1,2-TRICHLOROETHANE	BDL	10	
29V	TRICHLOROETHYLENE	BDL	10	
30V.	TRICHLOROFLUOROMETHANE	BDL	10	
31V.	VINYL CHLORIDE	BDL	10	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 1B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3550

	ACID EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1A.	2-CHLOROPHENOL	BDL	25	
2A.	2,4-DICHLOROPHENOL	BDL	25	
3A.	2,4-DIMETHYLPHENOL	BDL	25	
4A.	4,6-DINITRO-O-CRESOL	BDL	250	
5A.	2,4-DINITROPHENOL	BDL	250	
6A.	2-NITROPHENOL	BDL	25	
7A.	4-NITROPHENOL	BDL	25	
8A.	P-CHLORO-M-CRESOL	BDL	25	
9A.	PENTACHLOROPHENOL	BDL	25	
10A.	PHENOL	BDL	25	
11A.	2,4,6-TRICHLOROPHENOL	BDL	25	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 1B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3550

	BASE-NEUTRAL EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1B.	ACENAPHTHENE	BDL	10	
2B.	ACENAPHTHYLENE	BDL	10	
3B.	ANTHRACENE	BDL	10	
4B.	BENZIDINE	BDL	10	
5B.	BENZO (A) ANTHRACENE	BDL	10	
6B.	BENZO (A) PYRENE	BDL	10	
7B.	3,4-BENZOFLUORANTHENE	BDL	10	
8B.	BENZO (GHI) PERYLENE	BDL	25	
9B.	BENZO (K) FLUORANTHENE	BDL	10	
10B.	BIS (2-CHLOROETHOXY) METHANE	BDL	10	
11B.	BIS (2-CHLOROETHYL) ETHER	BDL	10	
12B.	BIS (2-CHLOROISOPROPYL) ETHER	BDL	10	
13B.	BIS (2-ETHYLHEXYL) PHTHALATE	BDL	10	
14B.	4-BROMOPHENYL PHENYL ETHER	BDL	10	
15B.	BUTYL BENZYL PHTHALATE	BDL	10	
16B.	2-CHLORONAPHTHALENE	BDL	10	
17B.	4-CHLOROPHENYL PHENYL ETHER	BDL	10	
18B.	CHRYSENE	BDL	10	
19B.	DIBENZO (A,H) ANTHRACENE	BDL	25	
20B.	1,2-DICHLOROBENZENE	BDL	10	
21B.	1,3-DICHLOROBENZENE	BDL	10	
22B.	1,4-DICHLOROBENZENE	BDL	10	
23B.	3,3'-DICHLOROBENZIDINE	BDL	10	
24B.	DIETHYL PHTHALATE	BDL	10	
25B.	DIMETHYL PHTHALATE	BDL	10	
26B.	DI-N-BUTYL PHTHALATE	BDL	10	
27B.	2,4-DINITROTOLUENE	BDL	10	
28B.	2,6-DINITROTOLUENE	BDL	10	
29B.	DI-N-OCTYL PHTHALATE	BDL	10	
30B.	1,2-DIPHENYLHYDRAZINE	BDL	10	
31B.	FLUORANTHENE	BDL	10	
32B.	FLUORENE	BDL	10	
33B.	HEXACHLOROBENZENE	BDL	10	
34B.	HEXACHLOROBUTADIENE	BDL	10	
35B.	HEXACHLOROCYCLOPENTADIENE	BDL	10	

Continued...

BDL = BELOW DETECTION LIMIT

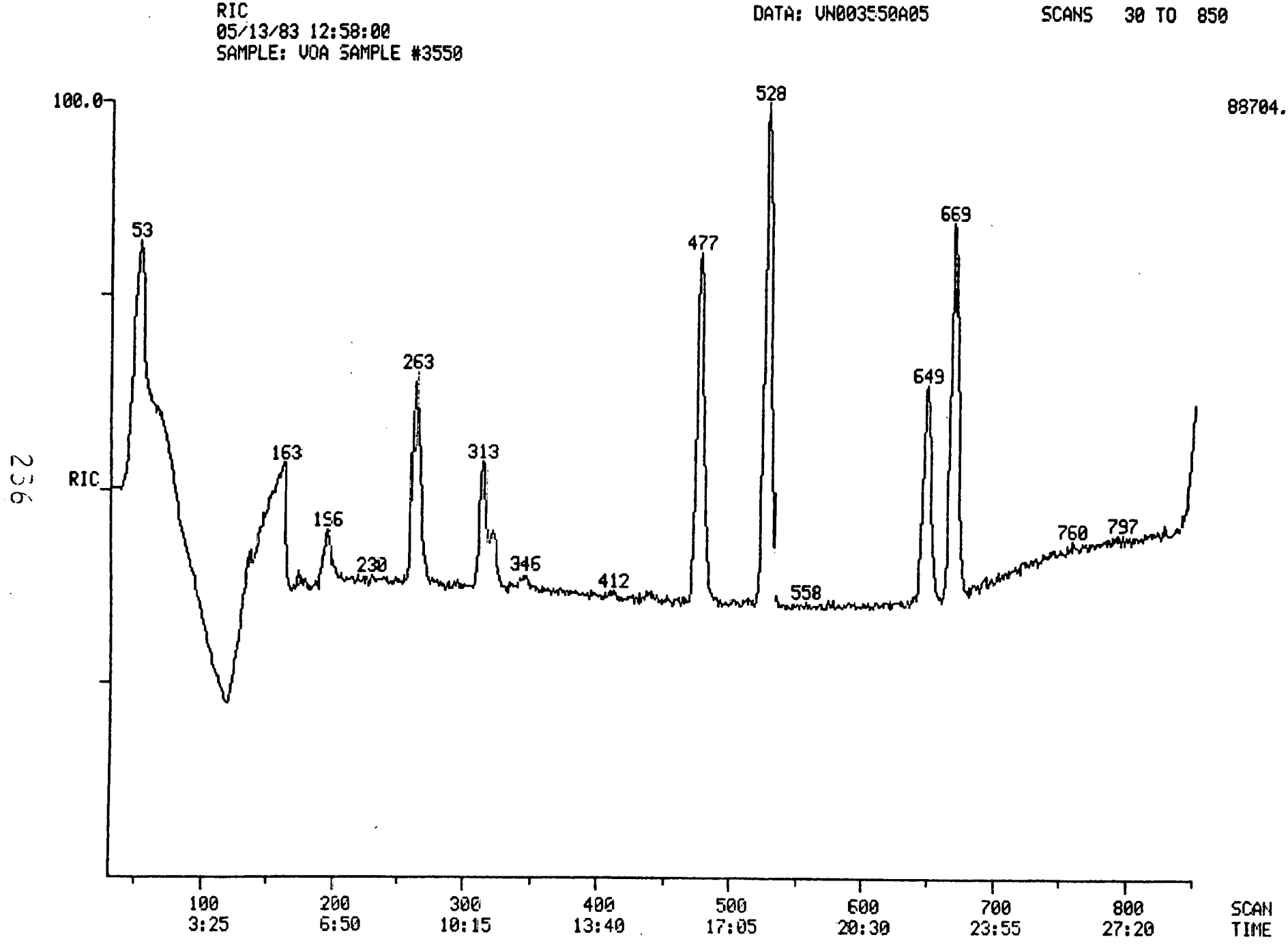
EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: BIO UNIT 1B EFFLUENT
COMPUCHEM SAMPLE NUMBER: 3550

	BASE-NEUTRAL EXTRACTABLE ORGANICS (Continued)	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
36B.	HEXACHLOROETHANE	BDL	10	
37B.	INDENO (1,2,3-CD) PYRENE	BDL	25	
38B.	ISOPHORONE	BDL	10	
39B.	NAPHTHALENE	BDL	10	
40B.	NITROBENZENE	BDL	10	
41B.	N-NITROSODIMETHYLAMINE	BDL	10	
42B.	N-NITROSODI-N-PROPYLAMINE	BDL	10	
43B.	N-NITROSODIPHENYLAMINE	BDL	10	
44B.	PHENANTHRENE	BDL	10	
45B.	PYRENE	BDL	10	
46B.	1,2,4-TRICHLOROBENZENE	BDL	10	

BDL = BELOW DETECTION LIMIT

CompuChem employs Methods 624 and 625 for priority pollutant analysis. These methods were proposed by the U.S. E.P.A. in Volume 44 of the Federal Register on December 3, 1979. As these methods are currently in a "proposed" status, all aspects of the methods may not be validated until the U.S. E.P.A. promulgates the methods in "final" form.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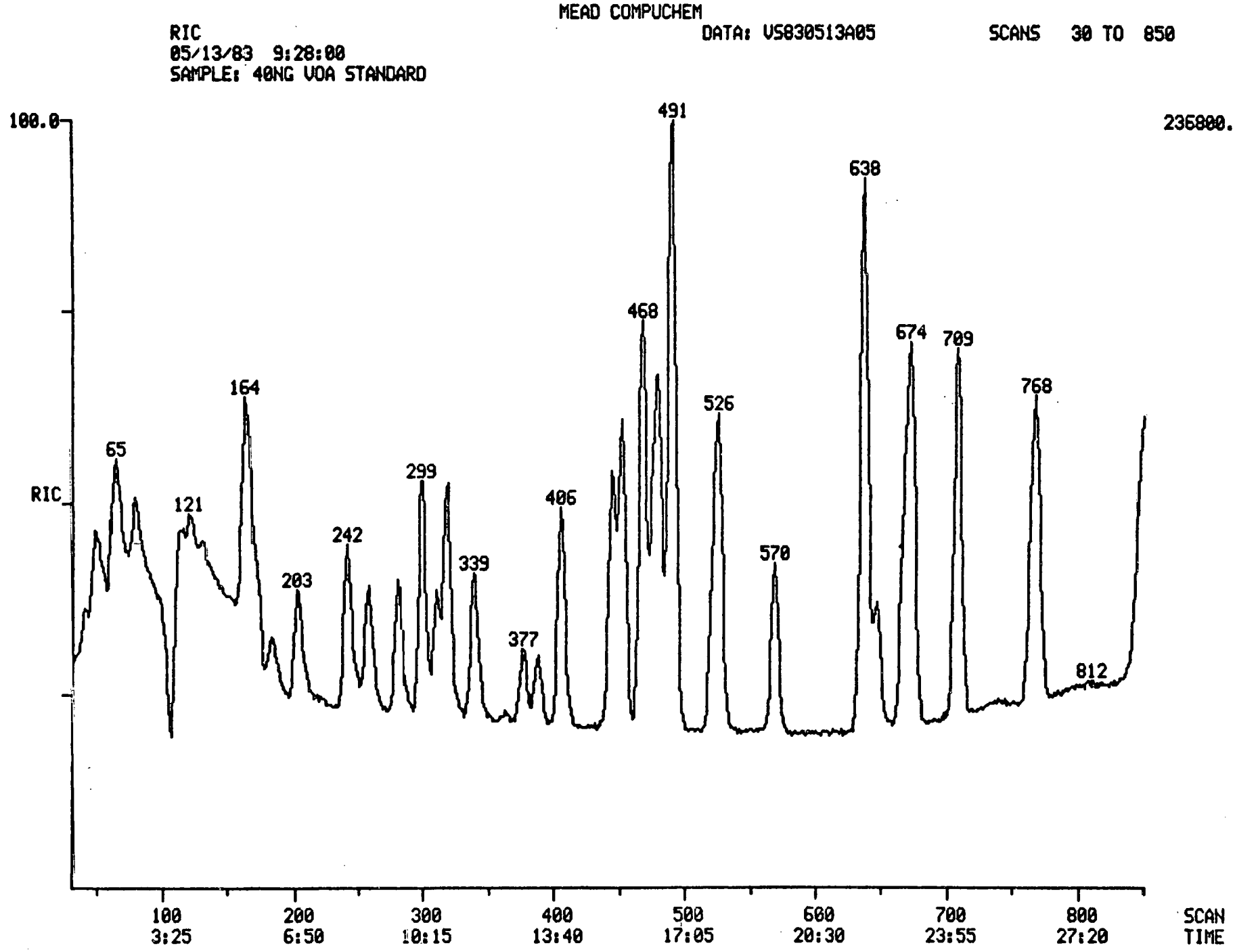
SCAN
TIME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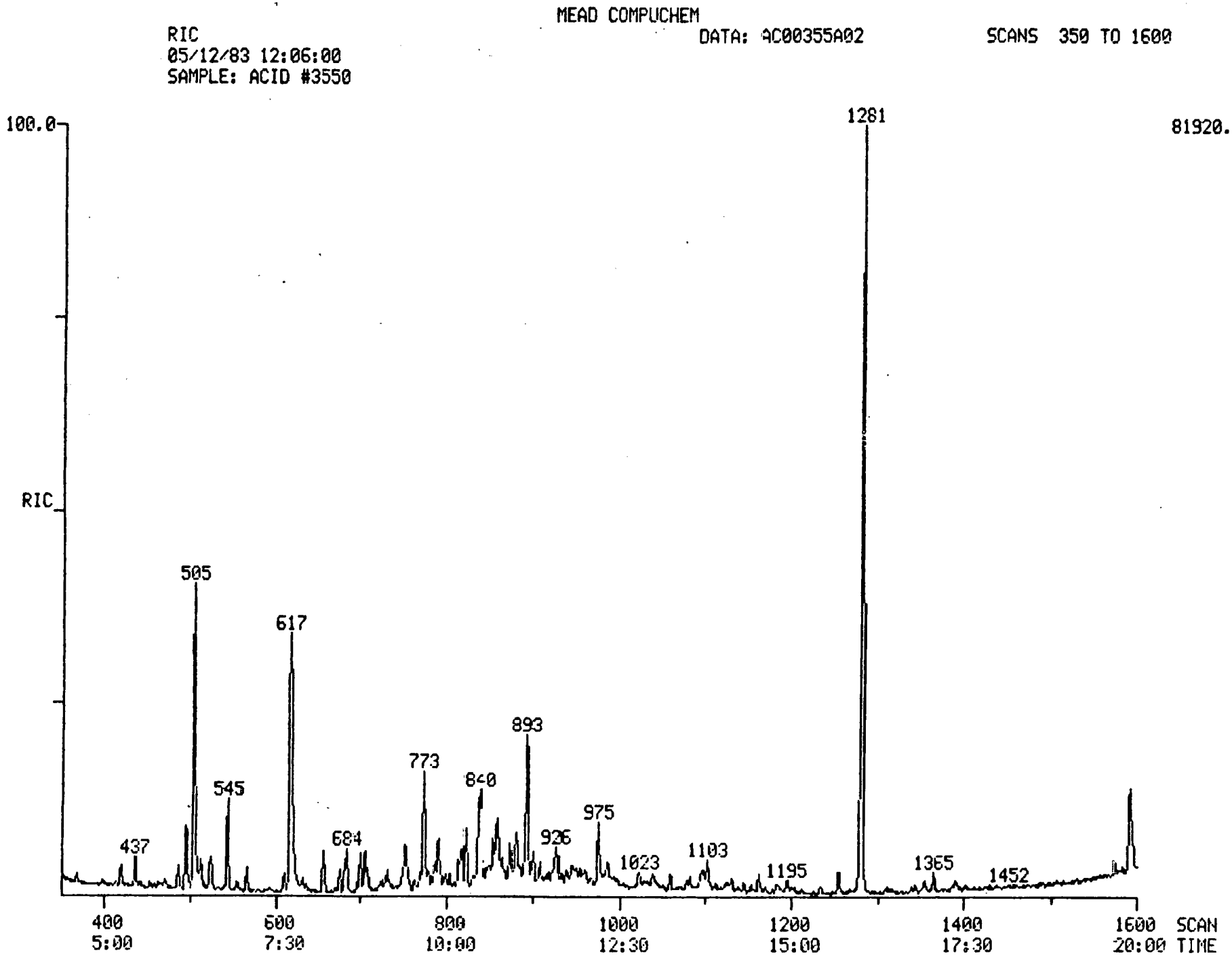
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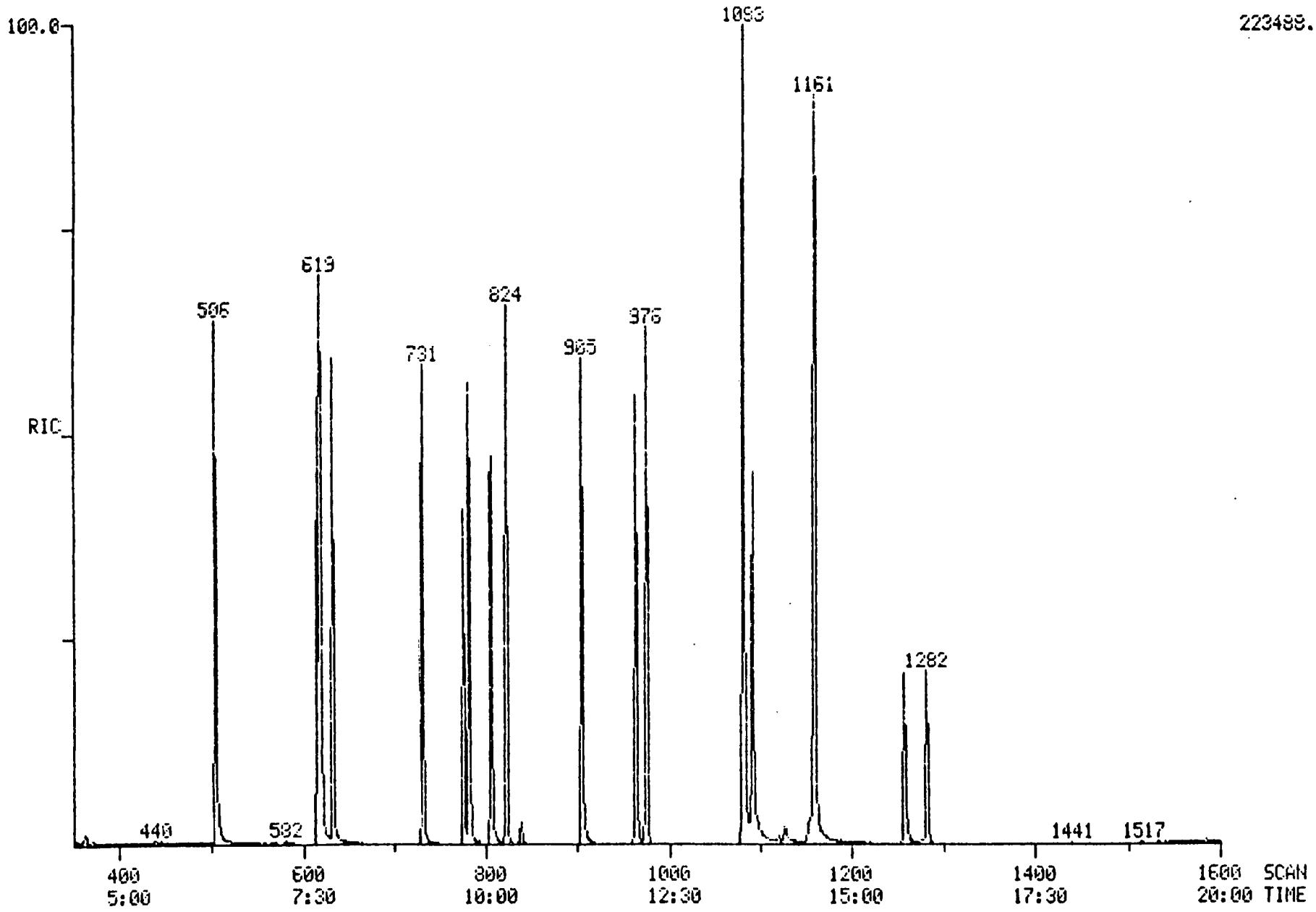
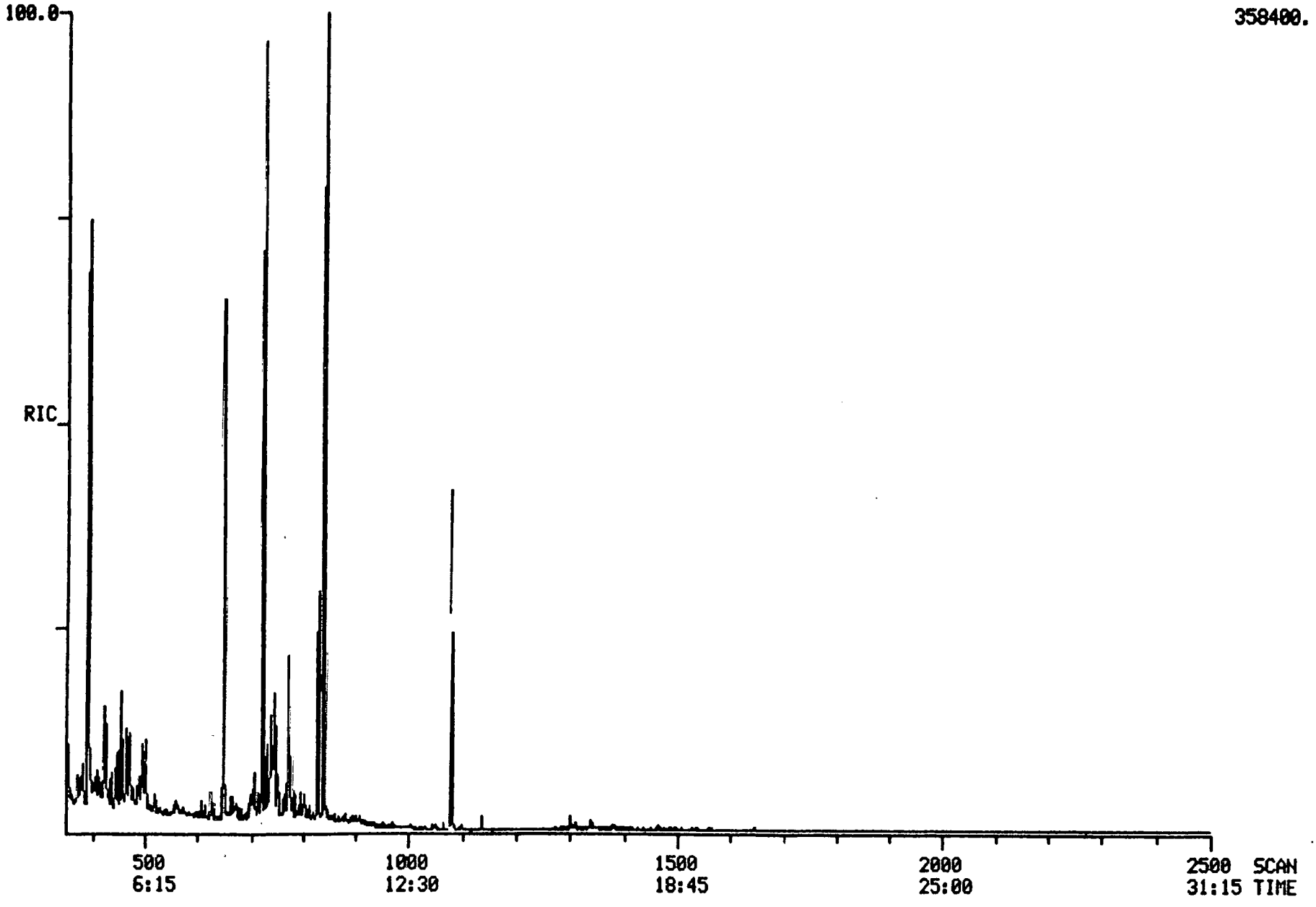
20:00
SCAN
TIME

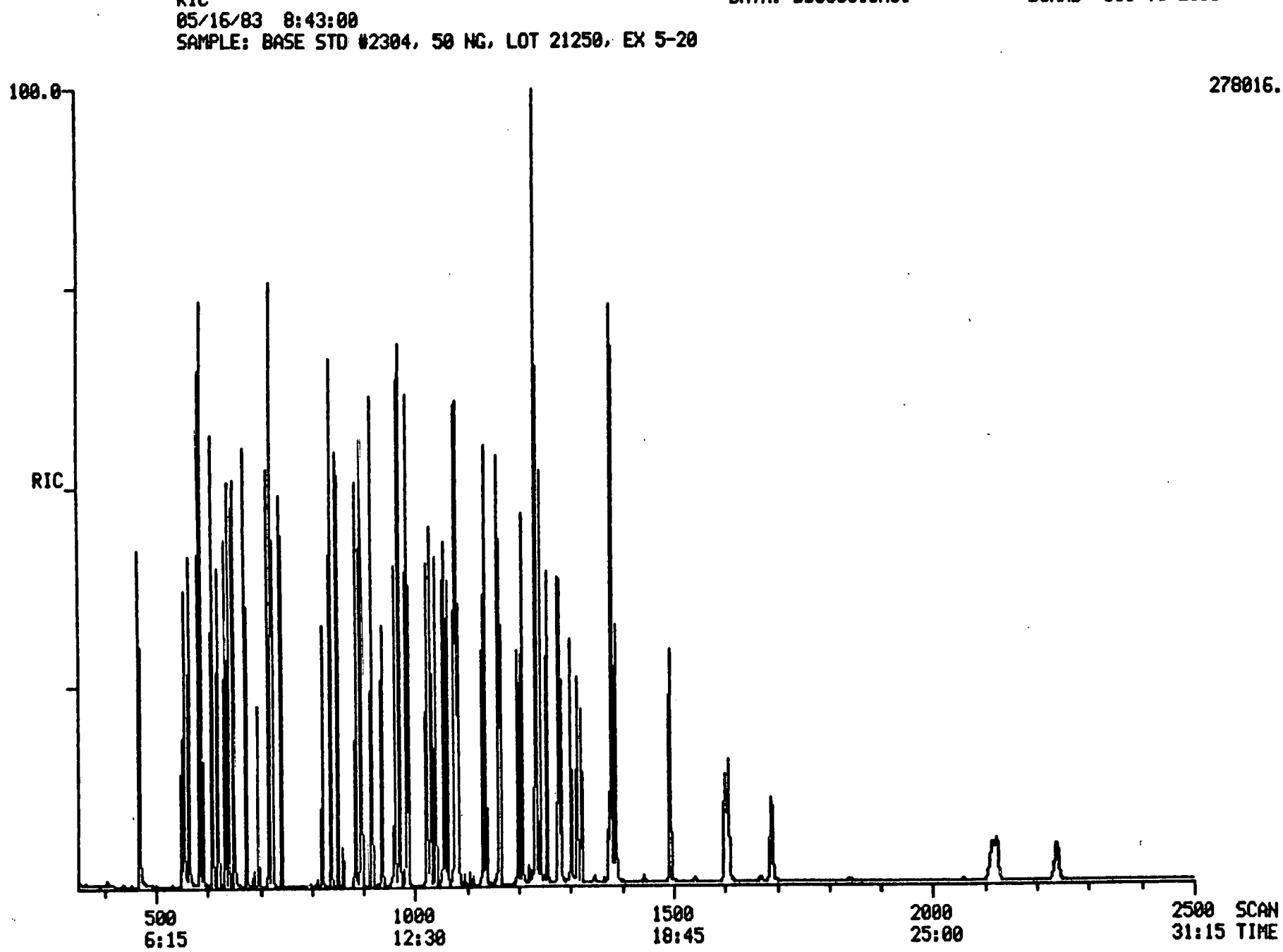

MEAD COMPUCHEM
RIC
DATA: AS830512A02
SCANS 350 TO 1600
05/12/83 10:14:00
SAMPLE: ACID STD #3304, 120 NG, LOT 21228
100.0
223488.
RIC
1093
1161
619
506
824
731
985
876
1282
440
582
1441
1517
400
5:00
600
7:30
800
10:00
1000
12:30
1200
15:00
1400
17:30
1600
20:00
SCAN
TIME

MEAD COMPUCHEM

RIC
05/16/83 16:27:00
SAMPLE: BN SAMPLE #3550

DATA: BC003550A01 SCANS 350 TO 2500




MEAD COMPUCHEM
RIC
DATA: BS830516A01
SCANS 350 TO 2500
05/16/83 8:43:00
SAMPLE: BASE STD #2304, 50 NG, LOT 21250, EX 5-20
278016.
100.0
RIC
500
6:15
1000
12:30
1500
18:45
2000
25:00
2500 SCAN
31:15 TIME

MeadCompuChem

1E. REPORT OF DATA

SAMPLE IDENTIFIER NUMBER: DEPHENOLATED FEED

COMPUCHEM SAMPLE NUMBER: 3551

SUBMITTED TO:

Mr. W. M. Heintzelman
Catalytic Inc.
c/o ESD Lab
201 East 10th Street
Marcus Hook, PA 19061

Gerald D Wright

GERALD D. WRIGHT, CPIM
MANAGER, PRODUCTION PLANNING AND CONTROL

R. L. MYERS, PH.D.
PRESIDENT

PAUL E. MILLS
DIRECTOR OF QUALITY ASSURANCE

JAMES J. ZOLDAK
DIRECTOR OF LABORATORY OPERATIONS

EXHIBIT I - LABORATORY CHRONICLE

SAMPLE IDENTIFIER: DEPHENOLATED FEED
COMPUCHEM SAMPLE NUMBER: 3551

	Date
Received/Refrigerated	05/02/83
Organics	
Extracted	05/06/83
Analyzed	
1. Volatiles	05/13/83
2. Acids	05/19/83
3. Base/Neutrals	05/17/83
4. Pesticides/PCBS	Not Requested
Inorganics	
1. Metals	Not Requested
2. Cyanides	Not Requested
3. Phenols	Not Requested

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: DEPHENOLATED FEED
COMPUCHEM SAMPLE NUMBER: 3551

	VOLATILE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1V.	ACROLEIN	BDL	100	
2V.	ACRYLONITRILE	BDL	100	
3V.	BENZENE	BDL	10	
4V.	BIS (CHLOROMETHYL) ETHER	BDL	10	
5V.	BROMOFORM	BDL	10	
6V.	CARBON TETRACHLORIDE	BDL	10	
7V.	CHLOROBENZENE	BDL	10	
8V.	CHLORODIBROMOMETHANE	BDL	10	
9V.	CHLOROETHANE	BDL	10	
10V.	2-CHLOROETHYLVINYL ETHER	BDL	10	
11V.	CHLOROFORM	10	10	294
12V.	DICHLOROBROMOMETHANE	BDL	10	
13V.	DICHLORODIFLUOROMETHANE	BDL	10	
14V.	1,1-DICHLOROETHANE	BDL	10	
15V.	1,2-DICHLOROETHANE	BDL	10	
16V.	1,1-DICHLOROETHYLENE	BDL	10	
17V.	1,2-DICHLOROPROPANE	BDL	10	
18V.	1,3-DICHLOROPROPYLENE	BDL	10	
19V.	ETHYLBENZENE	BDL	10	
20V.	METHYL BROMIDE	BDL	10	
21V.	METHYL CHLORIDE	BDL	10	
22V.	METHYLENE CHLORIDE	BDL	10	
23V.	1,1,2,2-TETRACHLOROETHANE	BDL	10	
24V.	TETRACHLOROETHYLENE	BDL	10	
25V.	TOLUENE	BDL	10	
26V.	1,2-TRANS-DICHLOROETHYLENE	BDL	10	
27V.	1,1,1-TRICHLOROETHANE	BDL	10	
28V.	1,1,2-TRICHLOROETHANE	BDL	10	
29V	TRICHLOROETHYLENE	BDL	10	
30V.	TRICHLOROFLUOROMETHANE	BDL	10	
31V.	VINYL CHLORIDE	BDL	10	

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: DEPHENOLATED FEED
COMPUCHEM SAMPLE NUMBER: 3551

	ACID EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION 1 LIMIT (UG/L)	SCAN NUMBER
1A.	2-CHLOROPHENOL	BDL	250	
2A.	2,4-DICHLOROPHENOL	BDL	250	
3A.	2,4-DIMETHYLPHENOL	BDL	250	
4A.	4,6-DINITRO-O-CRESOL	BDL	2500	
5A.	2,4-DINITROPHENOL	BDL	2500	
6A.	2-NITROPHENOL	BDL	250	
7A.	4-NITROPHENOL	BDL	250	
8A.	P-CHLORO-M-CRESOL	BDL	250	
9A.	PENTACHLOROPHENOL	BDL	250	
10A.	PHENOL	2,500 2	250	563
11A.	2,4,6-TRICHLOROPHENOL	BDL	250	

1 Sample extract could not be concentrated to 1.0 ml, thus the detection limits are higher than normal.

2 Sample analysis using a 1:10 dilution.

BDL = BELOW DETECTION LIMIT

EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: DEPHENOLATED FEED
COMPUCHEM SAMPLE NUMBER: 3551

	BASE-NEUTRAL EXTRACTABLE ORGANICS	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
1B.	ACENAPHTHENE	BDL	10	
2B.	ACENAPHTHYLENE	BDL	10	
3B.	ANTHRACENE	BDL	10	
4B.	BENZIDINE	BDL	10	
5B.	BENZO (A) ANTHRACENE	BDL	10	
6B.	BENZO (A) PYRENE	BDL	10	
7B.	3,4-BENZOFLUORANTHENE	BDL	10	
8B.	BENZO (GHI) PERYLENE	BDL	25	
9B.	BENZO (K) FLUORANTHENE	BDL	10	
10B.	BIS (2-CHLOROETHOXY) METHANE	BDL	10	
11B.	BIS (2-CHLOROETHYL) ETHER	BDL	10	
12B.	BIS (2-CHLOROISOPROPYL) ETHER	BDL	10	
13B.	BIS (2-ETHYLHEXYL) PHTHALATE	BDL	10	
14B.	4-BROMOPHENYL PHENYL ETHER	BDL	10	
15B.	BUTYL BENZYL PHTHALATE	BDL	10	
16B.	2-CHLORONAPHTHALENE	BDL	10	
17B.	4-CHLOROPHENYL PHENYL ETHER	BDL	10	
18B.	CHRYSENE	BDL	10	
19B.	DIBENZO (A,H) ANTHRACENE	BDL	25	
20B.	1,2-DICHLOROBENZENE	BDL	10	
21B.	1,3-DICHLOROBENZENE	BDL	10	
22B.	1,4-DICHLOROBENZENE	BDL	10	
23B.	3,3'-DICHLOROBENZIDINE	BDL	10	
24B.	DIETHYL PHTHALATE	BDL	10	
25B.	DIMETHYL PHTHALATE	BDL	10	
26B.	DI-N-BUTYL PHTHALATE	BDL	10	
27B.	2,4-DINITROTOLUENE	BDL	10	
28B.	2,6-DINITROTOLUENE	BDL	10	
29B.	DI-N-OCTYL PHTHALATE	BDL	10	
30B.	1,2-DIPHENYLHYDRAZINE	BDL	10	
31B.	FLUORANTHENE	BDL	10	
32B.	FLUORENE	BDL	10	
33B.	HEXACHLOROBENZENE	BDL	10	
34B.	HEXACHLOROBUTADIENE	BDL	10	
35B.	HEXACHLOROCYCLOPENTADIENE	BDL	10	

Continued...

BDL = BELOW DETECTION LIMIT

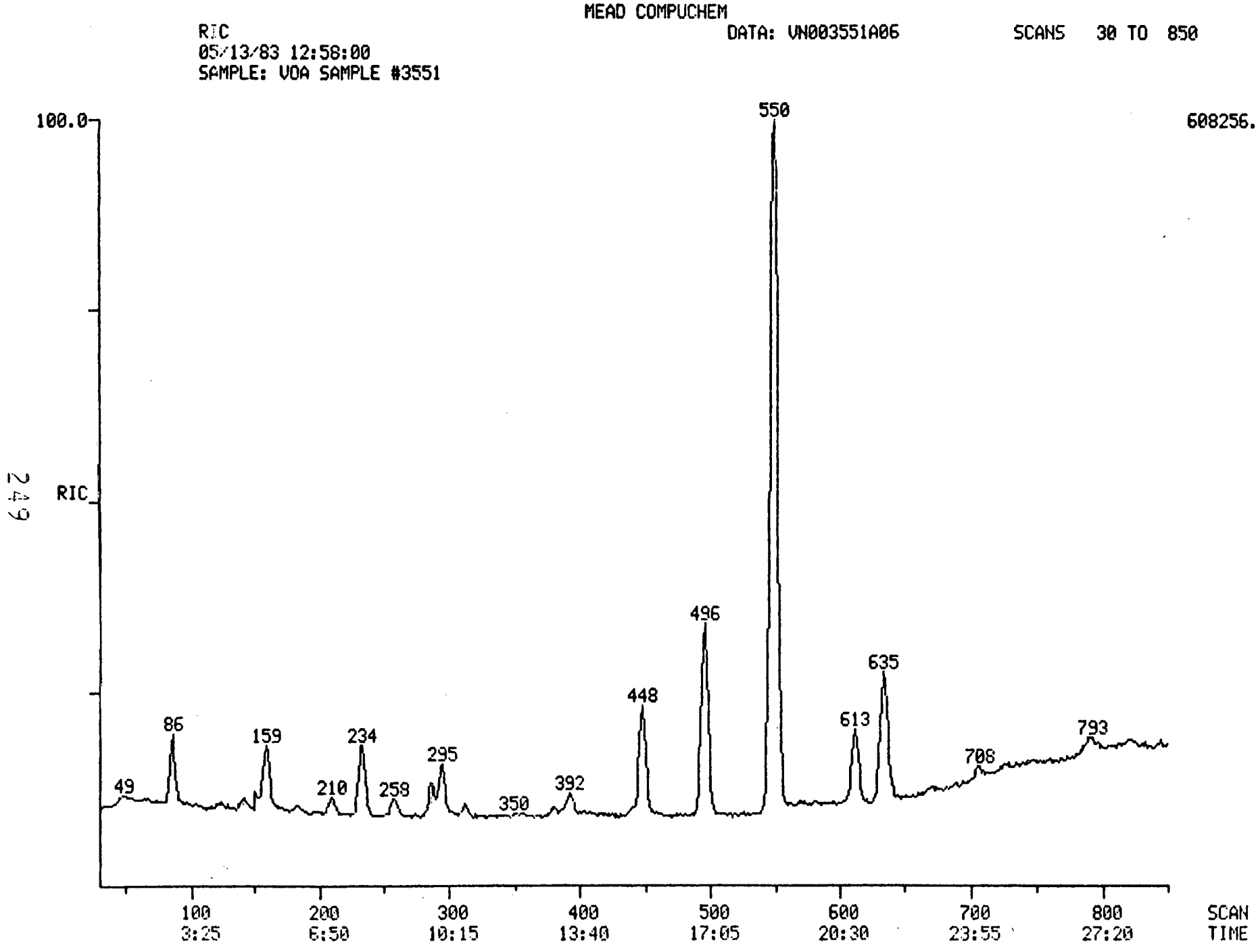
EXHIBIT II - COMPOUND LIST

SAMPLE IDENTIFIER: DEPHENOLATED FEED
COMPUCHEM SAMPLE NUMBER: 3551

	BASE-NEUTRAL EXTRACTABLE ORGANICS (Continued)	CONCENTRATION (UG/L)	DETECTION LIMIT (UG/L)	SCAN NUMBER
36B.	HEXACHLOROETHANE	BDL	10	
37B.	INDENO (1,2,3-CD) PYRENE	BDL	25	
38B.	ISOPHORONE	BDL	10	
39B.	NAPHTHALENE	BDL	10	
40B.	NITROBENZENE	BDL	10	
41B.	N-NITROSODIMETHYLAMINE	BDL	10	
42B.	N-NITROSODI-N-PROPYLAMINE	BDL	10	
43B.	N-NITROSODIPHENYLAMINE	BDL	10	
44B.	PHENANTHRENE	BDL	10	
45B.	PYRENE	BDL	10	
46B.	1,2,4-TRICHLOROBENZENE	BDL	10	

BDL = BELOW DETECTION LIMIT

CompuChem employs Methods 624 and 625 for priority pollutant analysis. These methods were proposed by the U.S. E.P.A. in Volume 44 of the Federal Register on December 3, 1979. As these methods are currently in a "proposed" status, all aspects of the methods may not be validated until the U.S. E.P.A. promulgates the methods in "final" form.

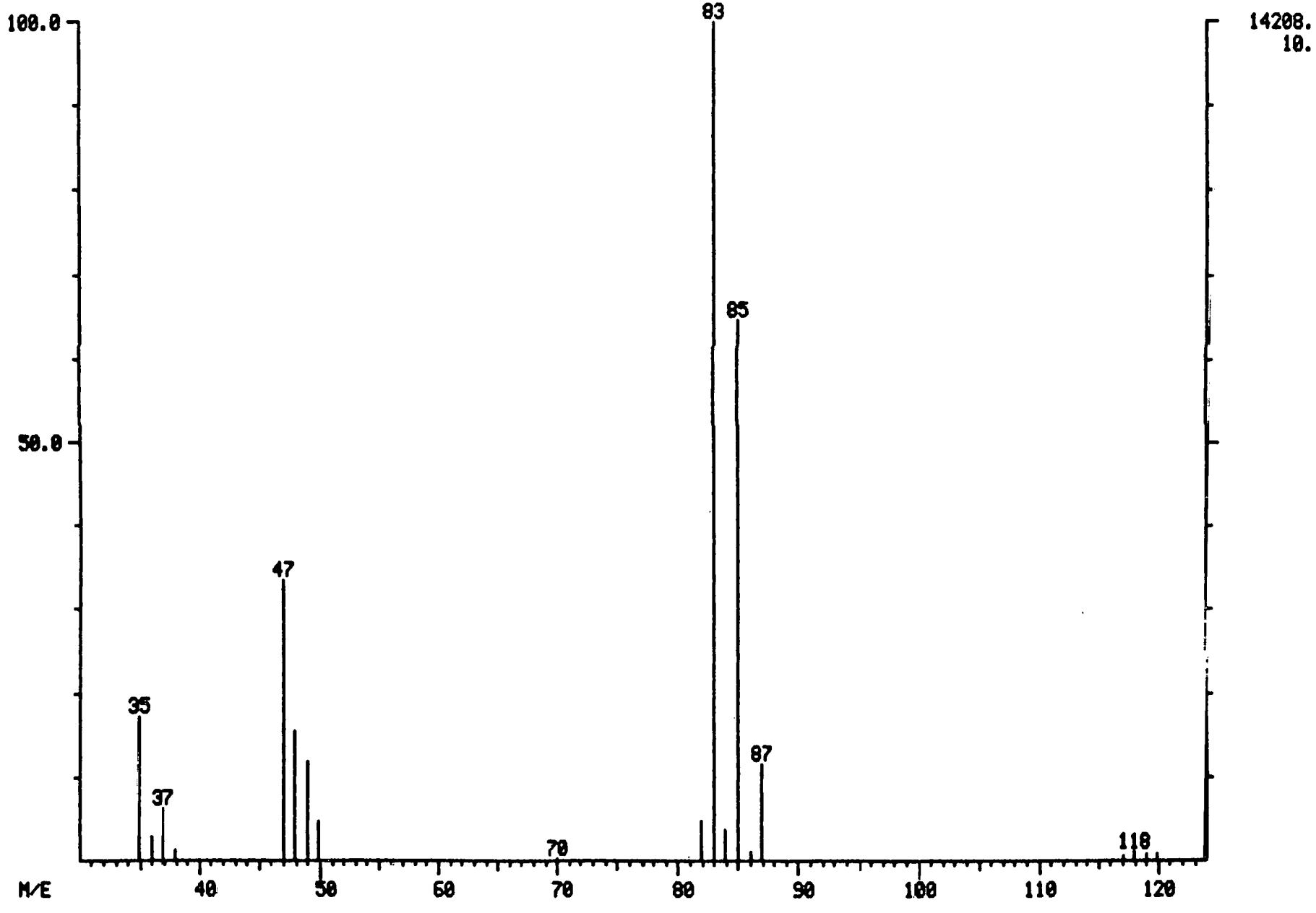

MEAD COMPUCHEM
RIC
05/13/83 12:58:00
SAMPLE: VOA SAMPLE #3551
DATA: VN003551A06
SCANS 30 TO 850
100.0
608256.
RIC
2469
550
496
448
635
613
793
708
86
159
234
295
258
210
392
350
49
100
3:25
200
6:50
300
10:15
400
13:40
500
17:05
600
20:30
700
23:55
800
27:20
SCAN
TIME

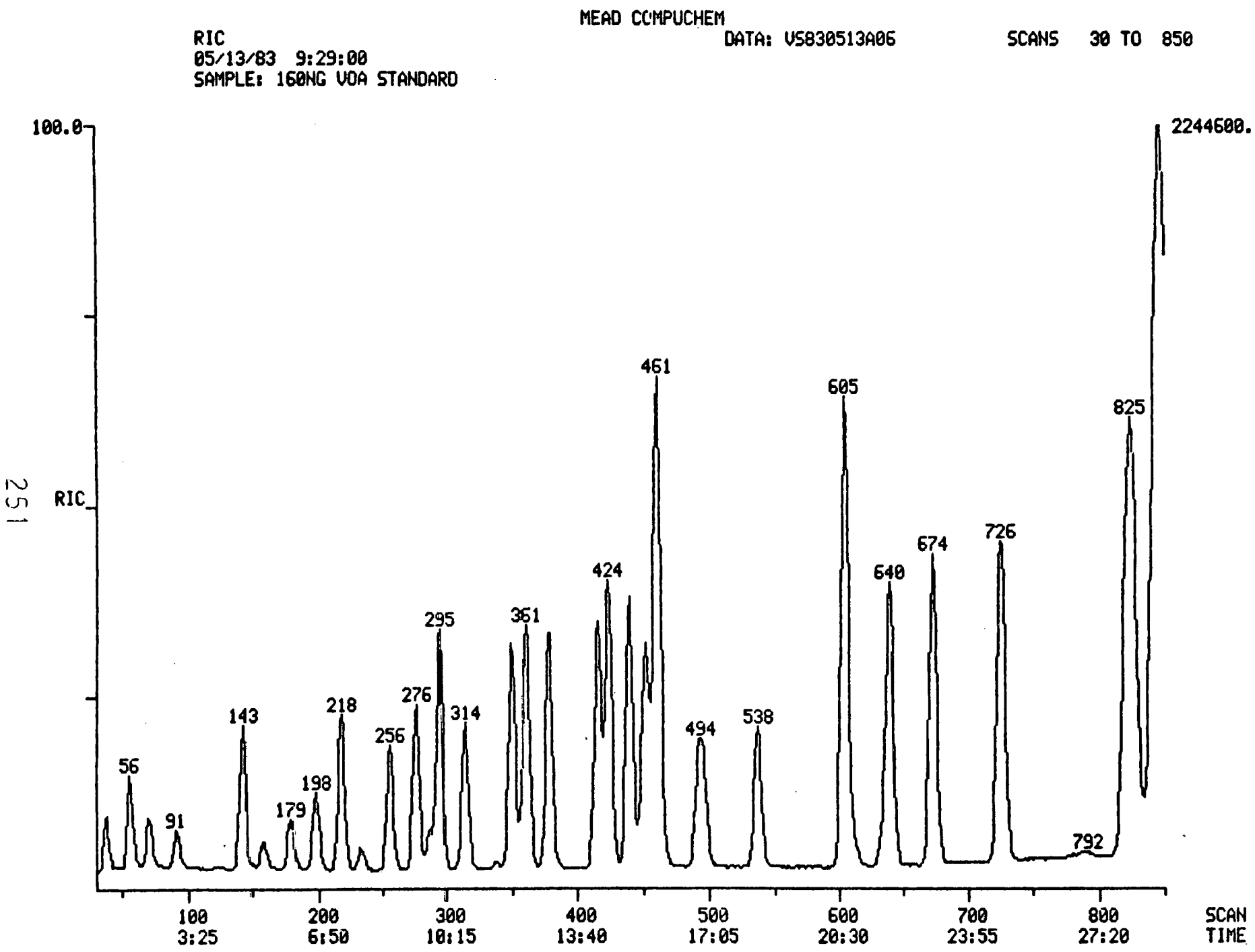
MEAD COMPUCHEM

MASS SPECTRUM
05/13/83 12:58:00 + 10:03
SAMPLE: VOA SAMPLE #3551
ENHANCED (S 15B 2N)

DATA: VN003551A06 #294

BASE M/E: 83
RIC: 40128.

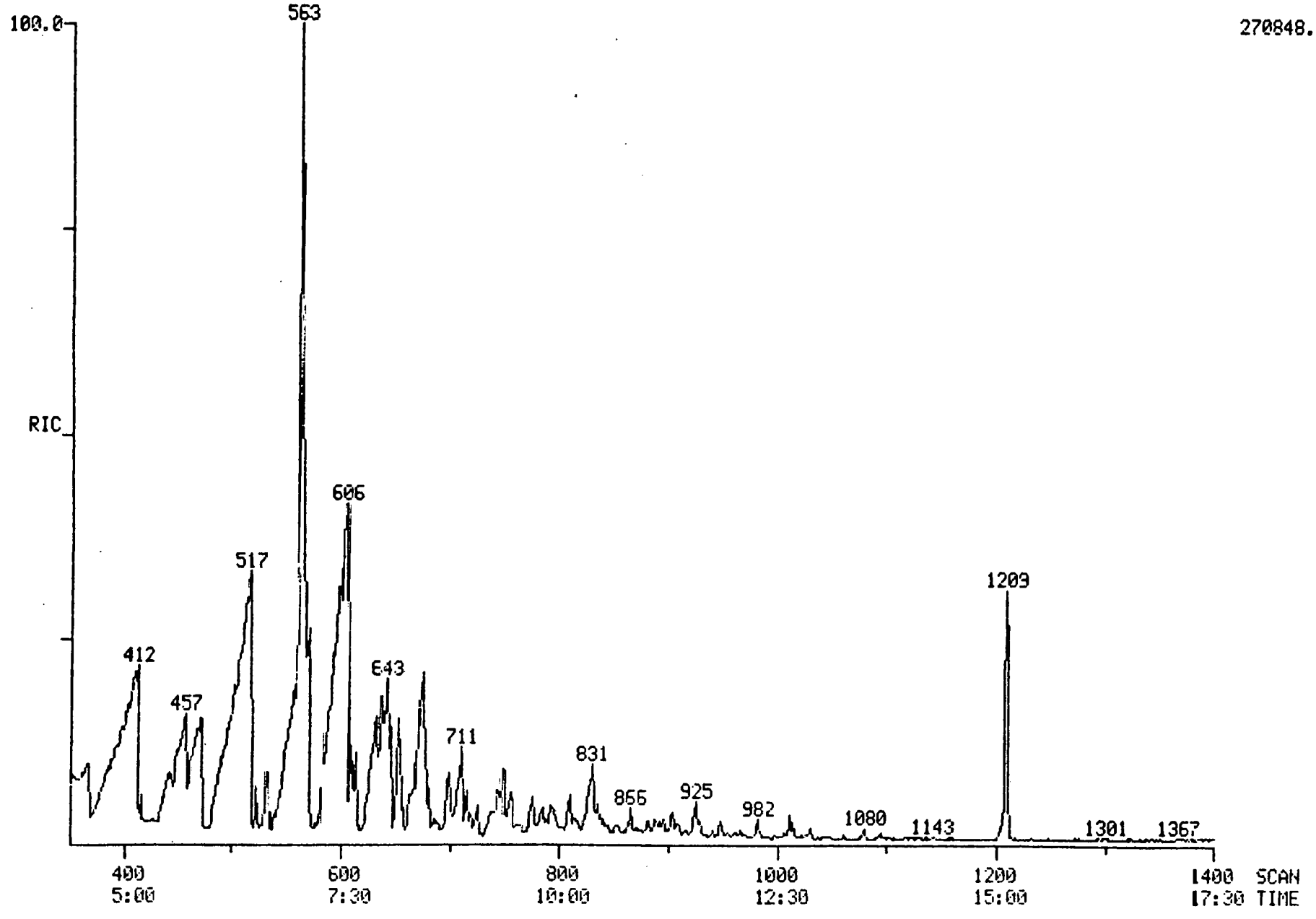



MEAD COMPUCHEM
RIC
DATA: VS830513A06
SCANS 30 TO 850
05/13/83 9:29:00
SAMPLE: 160NG VOA STANDARD
100.0
2244600.
RIC
56
91
143
179
198
218
256
276
295
314
361
424
461
494
538
605
640
674
726
792
825
100
3:25
200
6:50
300
10:15
400
13:40
500
17:05
600
20:30
700
23:55
800
27:20
SCAN
TIME

MEAD COMPUCHEM

RIC
05/19/83 11:43:00
SAMPLE: ACID #3551, 1:10 DIL

DATA: AC003551A02 SCANS 350 TO 1400

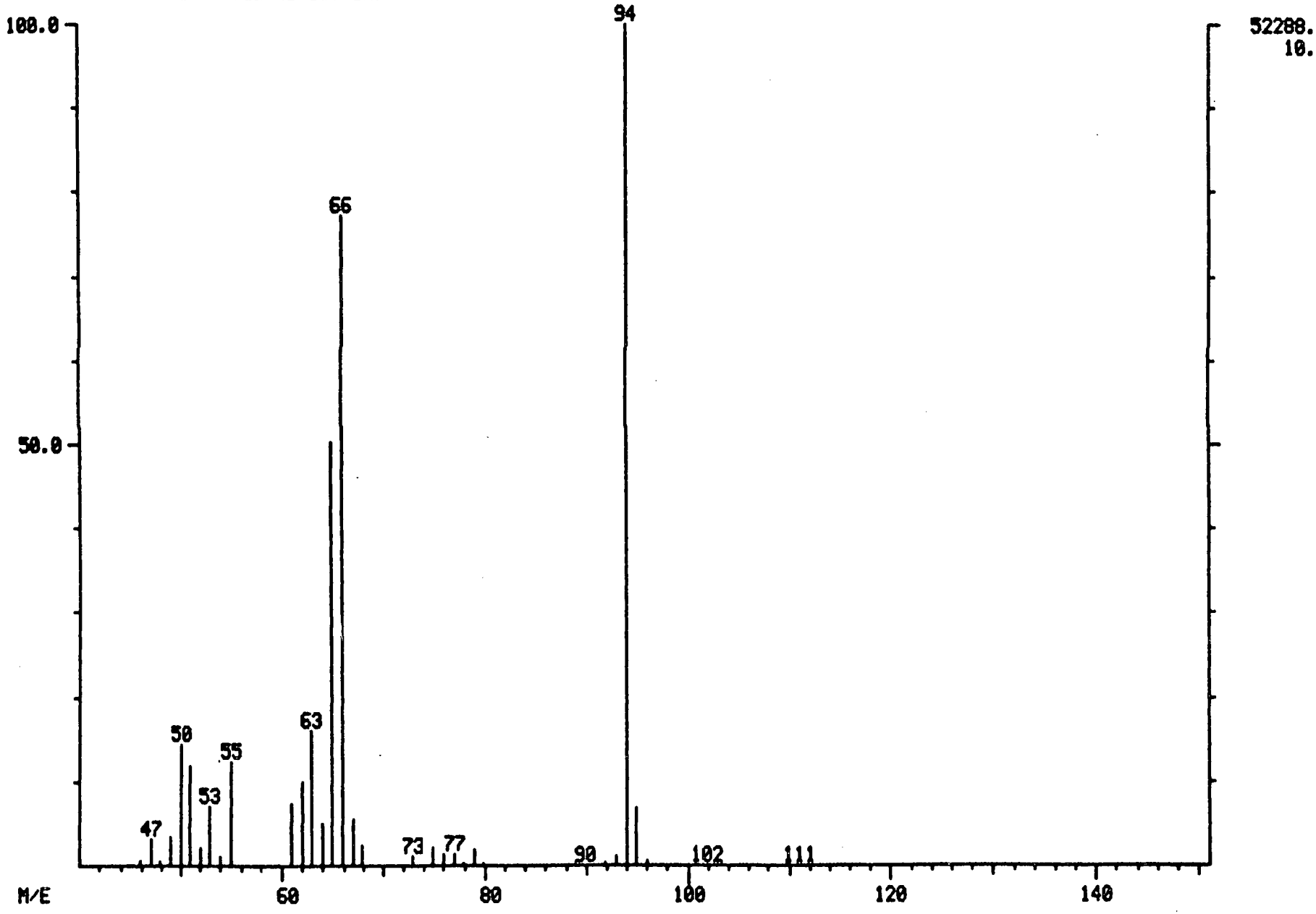


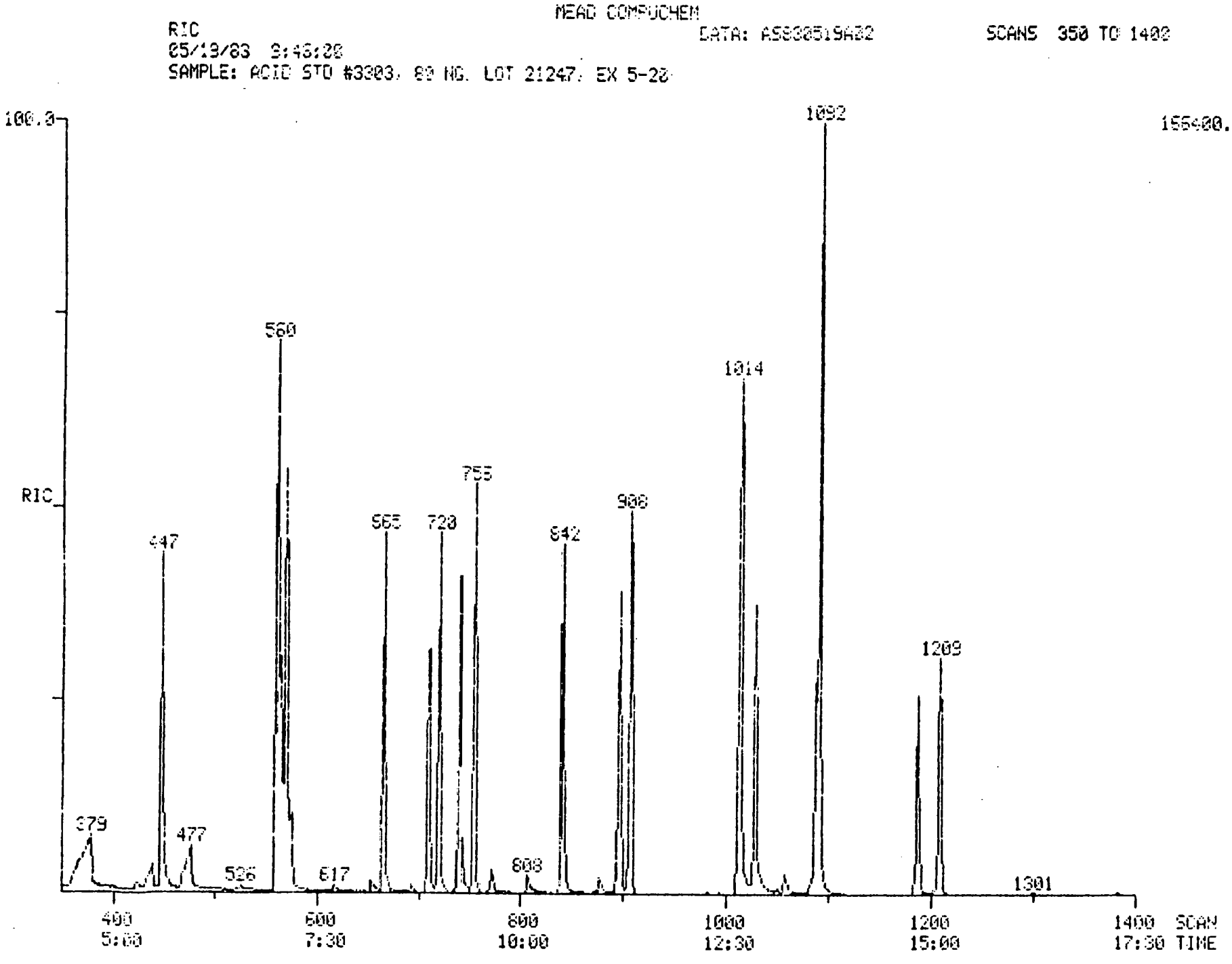
MEAD COMPUCHEM

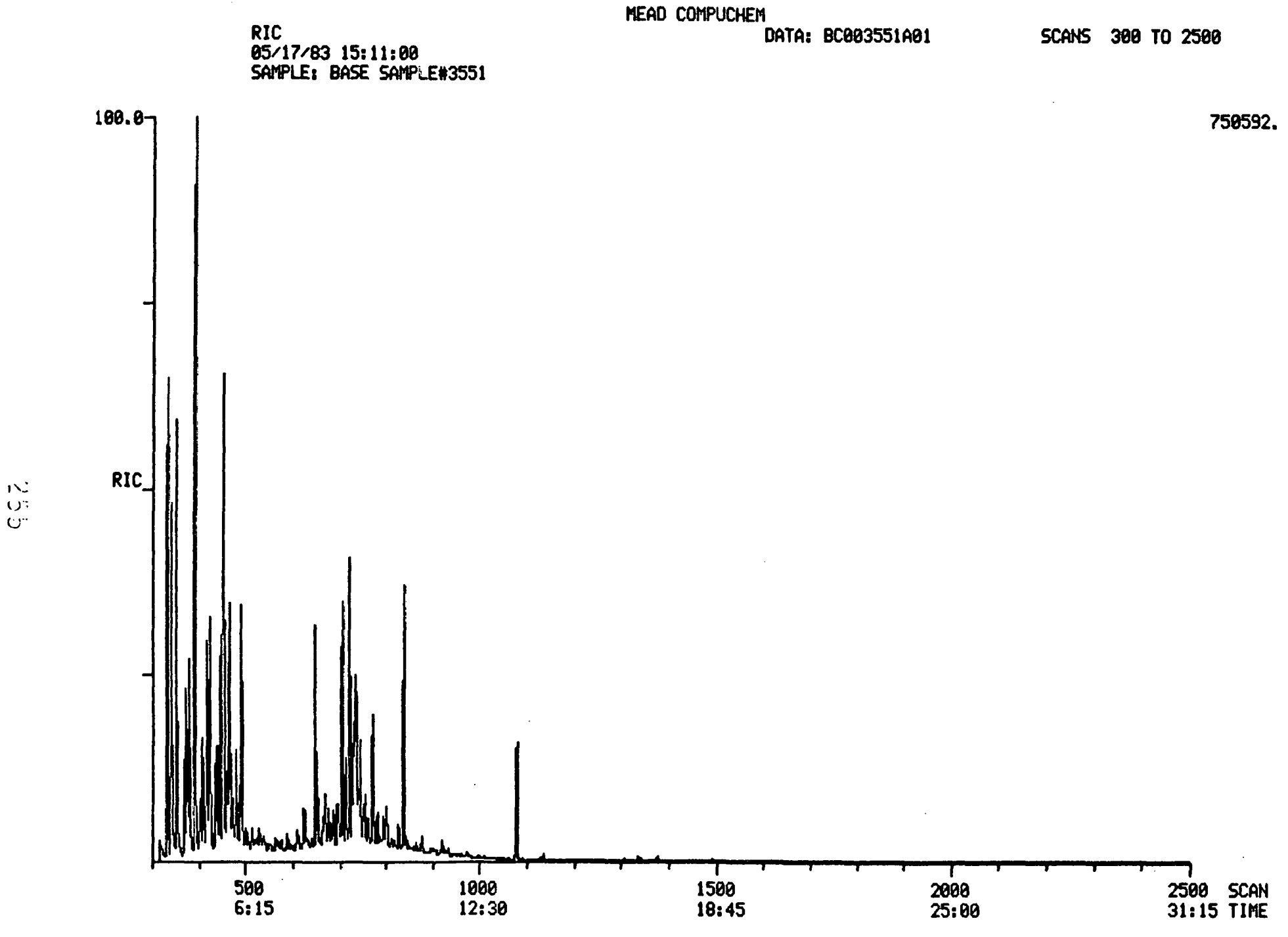
MASS SPECTRUM
05/19/83 11:43:00 + 7:02
SAMPLE: ACID #3551, 1:10 DIL
ENHANCED (S 158 2N)

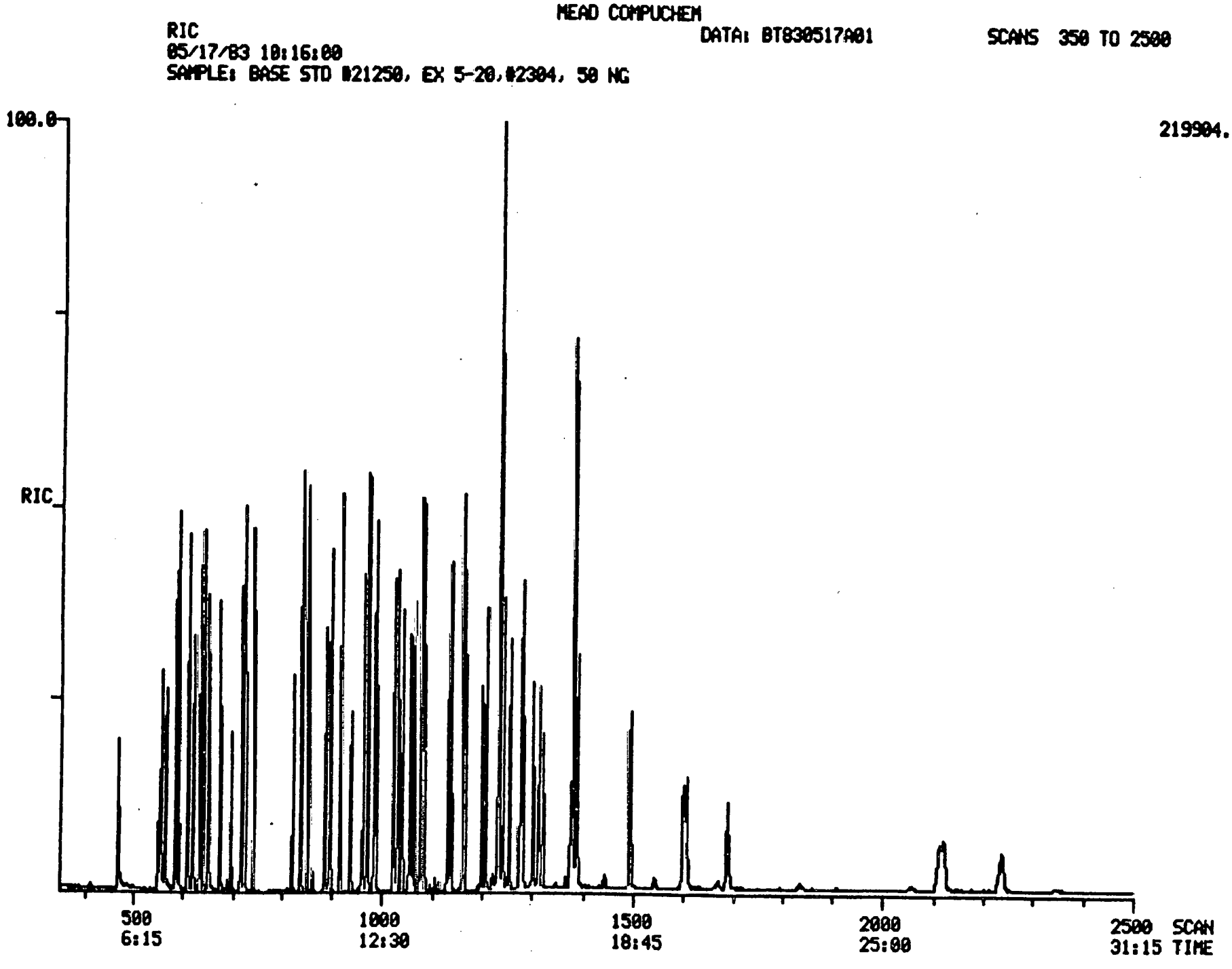
DATA: AC003551A02 #563

BASE M/E: 94
RIC: 181760.




MEAD COMPUCHEM
RIC
05/13/83 9:46:20
DATA: AS830519A02
SCANS 350 TO 1400
SAMPLE: ACID STD #3303, 80 NG. LOT 21247, EX 5-20
100.0
RIC
155400.
1092
560
1014
755
908
565
720
842
447
1209
379
477
536
617
808
1301
400
5:00
600
7:30
800
10:00
1000
12:30
1200
15:00
1400 SCAN
17:30 TIME


MEAD COMPUCHEM
RIC
05/17/83 15:11:00
SAMPLE: BASE SAMPLE#3551
DATA: BC003551A01
SCANS 300 TO 2500
100.0
750592.
RIC
500
6:15
1000
12:30
1500
18:45
2000
25:00
2500 SCAN
31:15 TIME


MEAD COMPUCHEM
RIC
05/17/83 10:16:00
SAMPLE: BASE STD #21250, EX 5-20,#2304, 50 NG
DATA: BT830517A01
SCANS 350 TO 2500
100.0
219904.
RIC
500
6:15
1000
12:30
1500
18:45
2000
25:00
2500 SCAN
31:15 TIME

2. ANALYTICAL METHODS, DEFINITIONS AND EXPLANATIONS

The CompuChem report contains not only the concentrations of the priority pollutant compounds identified but also additional supportive information which is useful in the review of this data. A complete report includes the following (if ordered):

Priority Pollutant Data
- GC/MS (VOA, B/N/P, Acid)
- Pesticides (Method 608)
- Inorganics

Other Analytical Data (EP Toxicity, etc.)
Conventional Permit Data

The GC/MS priority pollutant data is presented in summary form (concentration of each identified compound) along with the detection limits specified by EPA. In addition, a reconstructed total ion chromatogram (RIC) for each fraction and for the relevant instrument calibration (standards) runs are included.

Also included in the report are the spectra for all organic (except for certain pesticides) priority pollutant compounds identified above EPA specified detection limits, as well as a laboratory chronicle of completion dates.

To assist in the interpretation and utilization of this data, a Glossary of frequently used terms, a Compound Cross-Reference List and a typical Spectral Match Diagram with explanatory notation are also included.

If the Twenty Peak option has been ordered, the report also includes spectral match diagrams for as many as twenty (20) additional non-priority pollutant compounds with peaks greater than 25% of the intensity of the internal standard (d_{10}-anthracene).

If the Quality Control option has been ordered, the report also includes BFB and DFTPP tuning data for the GC/MS instruments, a summary of surrogate spike recovery data and the following:

Matrix Spike Data
Duplicate Data
Method Blank Data

Also included with the method blank is an RIC for each fraction plus spectra and spectral match diagrams for any compounds identified with concentrations greater than EPA specified detection limits found in the blank.

If the Chain-of-Custody option has been ordered, this information is included in the section with the sample data.

ANALYTICAL METHODS

The analytical methods used by CompuChem for priority pollutant, RCRA and NPDES permit analyses are based on those promulgated by EPA. These methods have appeared in the Federal Register as noted below.

In summary, gas chromatography/mass spectrometry (GC/MS) is the analytical technique employed for the analysis of organic compounds while atomic absorption spectrophotometry (AAS) is used for the analysis of metals.

On occasion CompuChem also performs analyses for other parameters which are not on the priority pollutant list. In these cases also, EPA methods are used if available, and if not methods are developed and verified along guidelines suggested by EPA.

References for Methods

Volatile Organics	(Method 624)	Federal Register 12-3-79
Acid Extractables	(Method 625)	" " "
Base/Neutral/Pesticide Extractables	(Method 625)	" " "
Pesticides	(Method 608)	" " "
Inorganics	EPA: Analysis of Water and Waste Water (1974, 1979)	
RCRA	Federal Register 5-19-80	

GLOSSARY OF TERMS

ACID FRACTION

Those compounds which solvent extract from the sample when it is pH-adjusted acidic (pH<2).

BFB TUNING

Each GC/MS instrument dedicated to VOA analyses is certified according to protocol prior to each 8-hour shift by injecting BFB (bromofluorobenzene) and comparing relationships between ion abundances for certain key mass numbers. If the prescribed relative ion abundances are not present, the instrument is adjusted until the criteria are met. With the available QC option, these parameters are included in the report for the BFB analysis following the specific sample analyzed.

B/N/P FRACTION

Those compounds which solvent extract from the sample when it is pH-adjusted basic (pH>11). This includes the pesticides (P), bases (B) and since this step is performed first, the neutral (N) compounds.

DFTPP TUNING

Each GC/MS instrument dedicated to Base/Neutral or Acid analyses is certified according to protocol prior to each 8-hour shift by injecting DFTPP (decafluorotriphenylphosphine) and comparing the relationships between ion abundances for certain key mass numbers. If the prescribed relative ion abundances are not present, the instrument is adjusted until the criteria are met. With the available QC option, these parameters are included in the report for the DFTPP analysis following the specific sample analyzed.

INDISTINGUISHABLE ISOMERS

Compounds with essentially the same mass spectrum and which have the same elution time from the gas chromatograph. An example is anthracene and phenanthrene.

INTERNAL STANDARD

CompuChem uses the internal standard method of quantitation. The same amount of d_{10}-anthracene is added to both the calibration standard and the sample. All calculations are referenced to a signal produced by this compound. Then all results are automatically corrected for any change in instrument sensitivity.

MATRIX SPIKES

Actual priority pollutants which are added to a second aliquot of the sample to determine the effect, if any, of the sample matrix on the analytical procedure.

METHOD BLANK

A sample of organic-free laboratory water which undergoes exactly the same extraction procedure at the same time as the actual samples. This monitors for possible contamination from glassware, solvents, or the extraction procedure.

PERCENT RECOVERY (SURROGATES AND MATRIX SPIKES)

The formula for determining percent recovery is:

$$\% \text{ Recovery (Spike)} = \frac{\text{Conc. in Spike} - \text{Conc. in Sample}}{\text{Amount of Spike Added}} \times 100\%$$

$$\% \text{ Recovery (Surrogate)} = \frac{\text{Amount found}}{\text{Amount added}} \times 100\%$$

PURITY VALUE (sometimes abbreviated PUR)

A mathematically devised index which indicates the "goodness of fit" between the spectrum in the sample and a compound in the library. The maximum value is 1000, and values greater than 800 indicate a high probability that the identification is correct. Values from 500 to 800 are only tentative and values less than 500 are not reliable. Also important is the relationship between purity values for the best, second and third matches; ideally the second and third purity scores are much lower than the first.

RIC - RECONSTRUCTED ION CHROMATOGRAM

A plot of the total ion current of the mass spectrometer during the analysis. The plot is analogous to a gas chromatogram where a peak indicates that a compound was detected at that time. The vertical axis is intensity and the horizontal axis is time (both minutes and mass spectral scan marks are labelled).

HOW TO INTERPRET "DATA: BN3436A4 #640"

In addition to the actual data, the headers of all RIC's, spectra, and spectral match diagrams contain informatin on the date, the sample and the instrumentation. Some of this information is coded in the following format:

DATA: BN3436A4 #640

BN

In this particular example, BN indicates that the sample analyzed was the base/neutral fraction. Other codes which are used are listed below:

VOA	Volatile Fraction	
AC	Acid Fraction	
BN	Base/Neutral Fraction	(Also includes Pesticides)
VOASTD	Volatile Standard	(sometimes VOASD)
ACSTD	Acid Standard	(sometimes ACSD)
BNSTD	Base/Neutral Standard	(sometimes BNSD)
VOABK	Volatile Blank	(sometimes VOAB)
ACBK	Acid Blank	(sometimes ACB)
BNBK	Base/Neutral Blank	(sometimes BNB)

3436

This is the CompuChem sample number. (In the case of a blank or standard, the number represents the date: two digits for month followed by two digits for day.)

A4

In this particular example, A4 indicates that the sample was run on the first shift (A) and on instrument #4. Other codes which are used include A, B, and C to denote the first, second and third shift respectively and instrument numbers 1 through 18.

From this information, CompuChem management also knows the chemist who performed the measurement, which senior spectroscopist reviewed the data, and which laboratory manager had the overall responsibility for the analysis.

#640

This is the scan number of the peak (or the compound). A specific peak on a RIC will be labelled with this number, and it will also appear in the header of the corresponding spectrum and/or the spectral match diagram.

COMPOUND CROSS-REFERENCE LIST

COMPOUND	NPDES PERMIT	STORET	CAS	EPA CONTRACTORS
VOLATILES				
acrolein	1V	34210	107-02-8	2V
acrylonitrile	2V	34215	107-13-1	3V
benzene	3V	34236	71-43-2	4V
bis (chloromethyl) ether	4V	N/A	542-88-1	N/A
bromoform	5V	32104	75-25-2	47V
carbon tetrachloride	6V	32102	56-23-5	6V
chlorobenzene	7V	34301	108-90-7	7V
chlorodibromomethane	8V	34105	124-48-1	51V
chloroethane	9V	34311	75-00-3	16V
2-chloroethylvinyl ether	10V	34576	110-75-8	19V
chloroform	11V	32106	67-66-3	23V
dichlorobromomethane	12V	32101	75-27-4	48V
dichlorodifluoromethane*	13V	N/A	75-71-8	50V
1,2-dichloroethane	14V	34496	75-34-3	13V
1,1-dichloroethane	15V	34531	107-06-2	10V
1,1-dichloroethylene	16V	34501	75-35-4	29V
1,2-dichloropropane	17V	34541	78-87-5	32V
1,2-dichloropropylene	18V	34561	542-75-6	33V
ethylbenzene	19V	34371	100-41-4	38V
methyl bromide	20V	34413	74-83-9	46V
methyl chloride	21V	34418	74-87-3	45V
methylene chloride	22V	34423	75-09-2	44V
1,1,2,2-tetrachloroethane	23V	34516	79-34-5	15V
tetrachloroethylene	24V	34475	127-18-4	85V
toluene	25V	34010	108-88-3	86V
1,2-trans-dichloroethylene	26V	34546	156-60-5	30V
1,1,1-trichloroethane	27V	34506	71-55-6	11V
1,1,2-trichloroethane	28V	34511	79-00-5	14V
trichloroethylene	29V	39180	79-01-6	87V
trichlorofluoromethane*	30V	34488	75-69-4	49V
vinyl chloride	31V	39175	75-01-4	88V

* Recently removed from list (Fed. Register 46, 5, January 8, 1981)

COMPOUND CROSS-REFERENCE LIST (Continued)

COMPOUND	NPDES PERMIT	STORET	CAS	EPA CONTRACTORS
ACIDS				
2-chlorophenol	1A	34586	95-57-8	24A
2,4-dichlorophenol	2A	34601	120-83-2	31A
2,4-dimethylphenol	3A	34606	105-67-9	34A
4,6-dinitro-o-cresol	4A	34657	534-52-1	60A
2,4-dinitrophenol	5A	34616	51-28-5	59A
2-nitrophenol	6A	34591	88-75-5	57A
4-nitrophenol	7A	34646	100-02-7	58A
p-chloro-m-cresol	8A	34452	59-50-7	22A
pentachlorophenol	9A	39094	87-86-5	64A
phenol	10A	34694	108-95-2	65A
2,4,6-trichlorophenol	11A	34621	88-06-2	21A
BASE/NEUTRALS				
acenaphthene	1B	34205	83-32-9	1B
acenaphthylene	2B	34200	208-96-8	77B
anthracene	3B	34220	120-12-7	78B
benzidine	4B	39120	92-87-5	5B
benzo (a) anthracene	5B	34526	56-55-3	72B
benzo (a) pyrene	6B	34247	50-32-8	73B
3,4-benzofluoranthene	7B	34230	205-99-2	74B
benzo (g,h,i) perylene	8B	34521	191-24-2	79B
benzo (k) fluoranthene	9B	34242	207-08-9	75B
bis (2-chloroethoxy) methane	10B	34278	111-91-1	43B
bis (2-chloroethyl) ether	11B	34273	111-44-4	18B
bis (2-chloroisopropyl) ether	12B	34283	39638-32-9	42B
bis (2-ethylhexyl) phthalate	13B	39100	117-81-7	66B
4-bromophenyl phenyl ether	14B	34636	101-55-3	41B
butylbenzyl phthalate	15B	34292	85-68-7	67B
2-chloronaphthalene	16B	34581	91-58-7	20B
4-chlorophenyl phenyl ether	17B	34641	7005-72-3	40B
chrysene	18B	34320	-218-01-9	76B
dibenzo (a,h) anthracene	19B	34556	53-70-3	82B
1,2-dichlorobenzene	20B	34536	95-50-1	25B
1,3-dichlorobenzene	21B	34566	541-73-1	26B
1,4-dichlorobenzene	22B	34571	106-46-7	27B
3,3'-dichlorobenzidine	23B	34631	91-94-1	28B
diethyl phthalate	24B	34336	84-66-2	70B
dimethyl phthalate	25B	34341	131-11-3	71B
di-n-butyl phthalate	26B	39110	84-74-2	68B
2,4-dinitrotoluene	27B	34611	121-14-2	35B
2,6-dinitrotoluene	28B	34626	606-20-2	36B
di-n-octyl phthalate	29B	34596	117-84-0	69B

COMPOUND CROSS-REFERENCE LIST (Continued)

COMPOUND	NPDES PERMIT	STORET	CAS	EPA CONTRACTORS
BASE/NEUTRALS (Cont'd)				
1,2-diphenylhydrazine	30B	34346	122-66-7	37B
fluoranthene	31B	34376	206-44-0	39B
fluorene	32B	34381	86-73-7	80B
hexachlorobenzene	33B	39700	118-71-1	9B
hexachlorobutadiene	34B	34391	87-68-3	52B
hexachlorocyclopentadiene	35B	34386	77-47-4	53B
hexachloroethane	36B	34396	67-72-1	12B
indeno (1,2,3-cd) pyrene	37B	34403	193-39-5	83B
isophorone	38B	34408	78-59-1	54B
naphthalene	39B	39250	91-20-3	55B
nitrobenzene	40B	34447	98-95-3	56B
N-nitrosodimethylamine	41B	34438	62-75-9	61B
N-nitrosodi-n-propylamine	42B	34428	621-64-7	63B
N-nitrosodiphenylamine	43B	34433	86-30-6	62B
phenanthrene	44B	34461	85-01-8	81B
pyrene	45B	34469	129-00-0	84B
1,2,4-trichlorobenzene	46B	34551	120-82-1	8B
PESTICIDES				
aldrin	1P	39330	309-00-2	89P
alpha-BHC	2P	39337	319-84-6	102P
beta-BHC	3P	39338	319-85-7	103P
gamma-BHC	4P	34259	58-89-9	104P
delta-BHC	5P	39340	319-86-8	105P
chlordane	6P	39350	57-74-9	91P
4,4'-DDT	7P	39300	50-29-3	92P
4,4'-DDE	8P	39320	72-55-9	93P
4,4'-DDD	9P	39310	72-54-8	94P
dieldrin	10P	39380	60-57-1	90P
alpha-endosulfan	11P	34361	115-29-7	95P
beta-endosulfan	12P	34356	115-29-7	96P
endosulfan sulfate	13P	34351	1031-07-8	97P
endrin	14P	39390	72-20-8	98P
endrin aldehyde	15P	34366	7421-93-4	99P
heptachlor	16P	39410	76-44-8	100P
heptachlor epoxide	17P	39420	1024-57-3	101P
PCB-1242	18P	39496	53469-21-9	106P
PCB-1254	19P	39504	11097-69-1	107P
PCB-1221	20P	39488	11104-28-2	108P
PCB-1232	21P	39492	11141-16-5	109P
PCB-1248	22P	39500	12672-29-6	110P
PCB-1260	23P	39508	11096-82-5	111P
PCB-1016	24P	34671	12674-11-2	112P
toxaphene	25P	39400	8001-35-2	113P

COMPOUND CROSS-REFERENCE LIST (Continued)

COMPOUND	NPDES PERMIT	STORET	CAS	EPA CONTRACTORS
METALS, CYANIDE, and PHENOLS (ALL TOTAL)				
Antimony	1M		7440-36-0	
Arsenic	2M		7440-38-2	
Beryllium	3M		7440-41-7	
Cadmium	4M		7440-43-9	
Chromium	5M		7440-47-3	
Copper	6M		7550-50-8	
Lead	7M		7439-92-1	
Mercury	8M		7439-97-6	
Nickel	9M		7440-02-0	
Selenium	10M		7782-49-2	
Silver	11M		7440-22-4	
Thallium	12M		7440-28-0	
Zinc	13M		7440-66-6	
Cyanide	14M		57-12-5	
Phenols	15M		N/A	
DIOXIN				
2,3,7,8-tetrachlorodi-benzo-p-dioxin		34675	1764-01-6	129B

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7495	DATE ANALYZED	4/8/83
RMC I.D.	456	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	37400
2-chlorophenol	<6.0
2-nitrophenol	<9.0
2,4-dimethylphenol	5420
2,4-dichlorophenol	<8.0
4-chloro-3-methylphenol	<6.2
2,4,6-trichlorophenol	<9.9
2,4-dinitrophenol	<40.0
4-nitrophenol	<49.3
2-methyl-4,6-dinitrophenol	<15.5
pentachlorophenol	<31.1

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7495	DATE ANALYZED	4/8/84
RMC I.D.	456	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<17.1	4-chlorophenyl phenyl ether	<5.8
bis(2-chloroethyl)ether	<4.9	n-nitrosodiphenylamine	<4.6
1,3-dichlorobenzene	<5.2	1,2-diphenylhydrazine	<7.4
1,4-dichlorobenzene	<5.2	4-bromophenyl phenyl ether	<9.4
1,2-dichlorobenzene	<4.8	hexachlorobenzene	<7.2
bis(2-chloroisopropyl)ether	<13.3	phenanthrene	<1.8
hexachloroethane	<6.8	anthracene	<2.0
n-nitrosodi-n-propylamine	<5.8	di-n-butyl phthalate	<1.4
nitrobenzene	<5.9	fluoranthene	<1.8
isophorone	<2.2	benzidine	<83.9
bis(2-chloroethoxy)methane	<3.4	pyrene	<2.2
1,2,4-trichlorobenzene	<5.0	butyl benzyl phthalate	<2.8
naphthalene	<1.6	benz(a)anthracene	<8.0
hexachlorobutadiene	<9.7	3,3'-dichlorobenzidine	<31.1
hexachlorocyclopentadiene	<9.4	chrysene	<8.0
2-chloronaphthalene	<2.4	bis(2-ethylhexyl)phthalate	30.5
acenaphthylene	<1.6	di-n-octyl phthalate	<1.4
dimethyl phthalate	<2.2	benzo(b)fluoranthene	<6.4
2,6-dinitrotoluene	<8.4	benzo(k)fluoranthene	<3.6
acenaphthene	<2.6	benzo(a)pyrene	<5.0
2,4-dinitrotoluene	<7.2	indeno(1,2,3-c,d)pyrene	<10.7
fluorene	<2.4	dibenz(a,h)anthracene	<20.4
diethyl phthalate	<2.0	benz(g.h.i.)perylene	<46.6
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<19.8

Approved By: Richard S. Kodgis

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National Bureau of Standards Library Search of
Major Non-Priority Pollutant Peaks from the
Chromatogram of Catalytic Sample #7495

Peak Scan Number	Most Probable Compound Match	Total Abundance of Scan Number
294	2-methylphenol	54811
321	3-methylphenol and hexanoic acid	112937
404	3,4-dimethylphenol	16788
432	benzoic acid	10768
493	4-methylbenzoic acid	15478
509	3,4 or 2,4-dimethylbenzaldehyde	17156

Approved By: Richard S. Hodgson

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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7495	DATE ANALYZED	3/30/83
RMC I.D.	456	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.08
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.19
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	3.9	benzene	<0.05
acrolein	<80	dibromochloromethane	<0.09
acrylonitrile	<8	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.09	2-chloroethylvinyl ether	<1.6
1,1-dichloroethane	<0.10	bromoform	<0.19
trans-1,2-dichloroethene	<0.09	tetrachloroethene	<0.07
chloroform	0.4	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.03
1,1,1-trichloroethane	<0.05	chlorobenzene	<0.04
carbon tetrachloride	<0.04	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard L. Rodgers
Approved By

RMC Environmental Services
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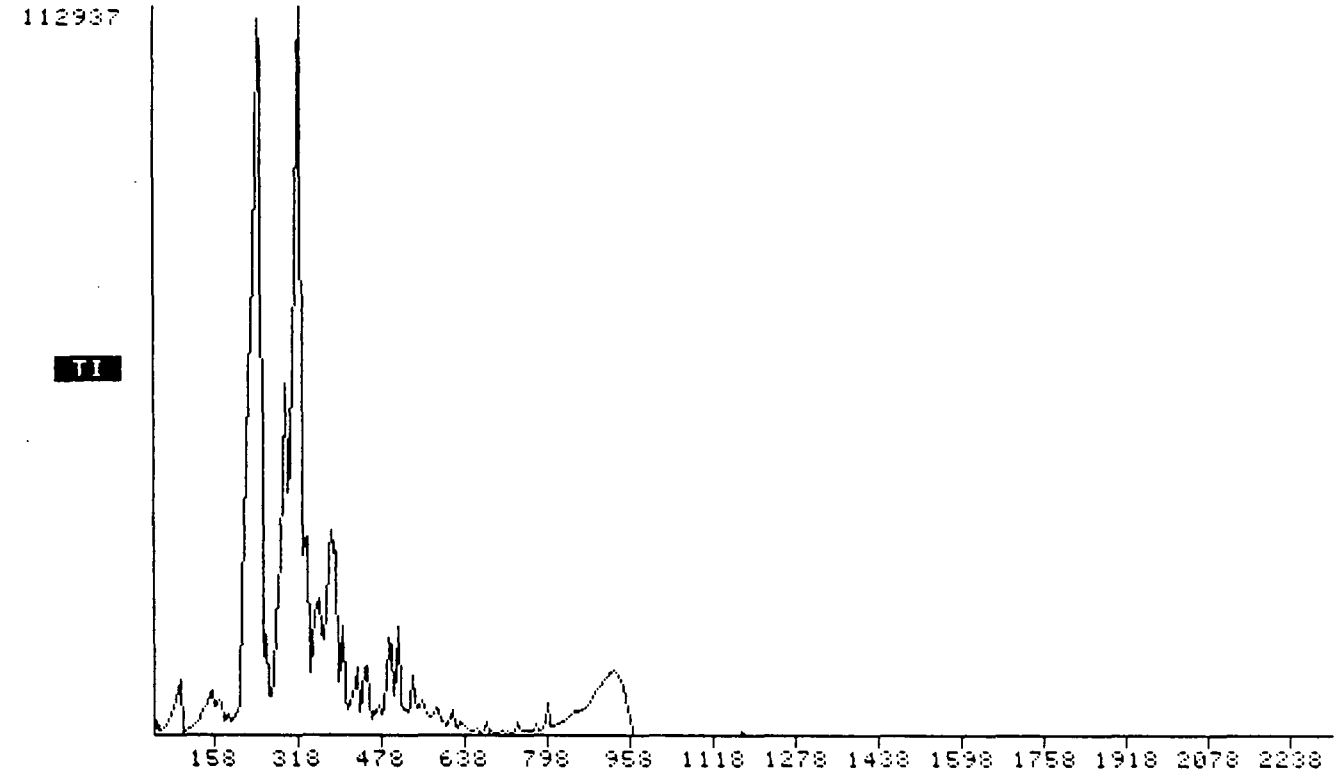
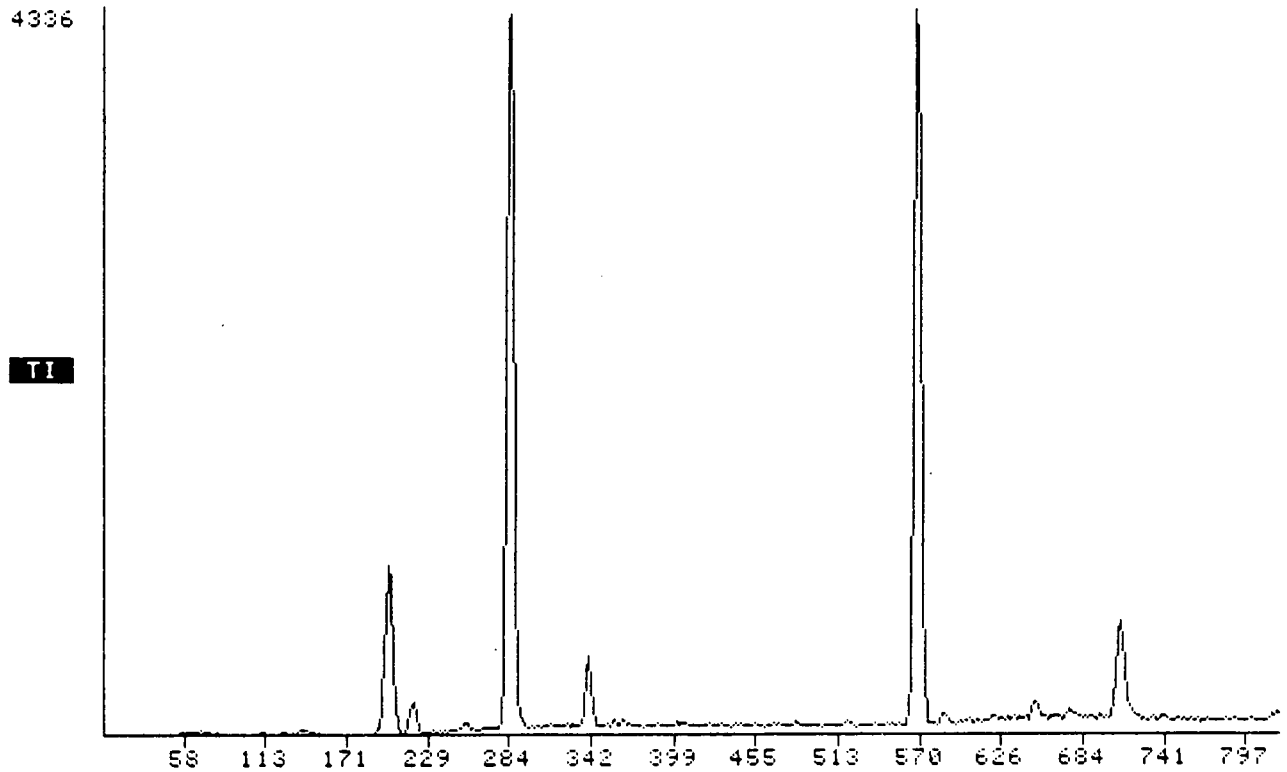
Pottstown, PA 19464

NAME CAP. CATALYTIC#7495 RMC#456(A-B/N)+20PPM D-10 FRN 5604
MISC 4/8/83 BTL#17 D5604



NAME VOL. CATALYTIC#7495 RMC#456+10PFB I.S. EM1800 FRN 5539
MISC 3/30/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7496	DATE ANALYZED	4/8/83
RMC I.D.	457	ANALYZED BY	KHG

ACID COMPOUNDS

	µg/l
phenol	<1.5
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.5
2,4-dinitrophenol	<10.2
4-nitrophenol	<12.6
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
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Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7496	DATE ANALYZED	4/8/83
RMC I.D.	457	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<1.9
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.4	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	12.9
nitrobenzene	<1.5	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.5
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	10.2
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<3.1	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.5	benz(g.h.i.)perylene	<11.9
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<2.8

Approved By: Richard L. Kodgis

RMC Environmental Services Division
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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7496	DATE ANALYZED	3/30/83
RMC I.D.	457	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.15
bromomethane	<0.5	1,2-dichloropropane	<0.5
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.4
chloroethane	<1.0	trichloroethene	<0.11
methylene chloride	16.2	benzene	<0.09
acrolein	<150	dibromochloromethane	<0.18
acrylonitrile	<14	1,1,2-trichloroethane	<0.5
1,1-dichloroethene	<0.17	2-chloroethylvinyl ether	<2.9
1,1-dichloroethane	<0.19	bromoform	<0.4
trans-1,2-dichloroethene	<0.17	tetrachloroethene	<0.13
chloroform	1.0	1,1,2,2-tetrachloroethane	<0.7
1,2-dichloroethane	<0.5	toluene	<0.06
1,1,1-trichloroethane	<0.10	chlorobenzene	<0.08
carbon tetrachloride	<0.08	ethylbenzene	<0.05

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Bodycomb
Approved By

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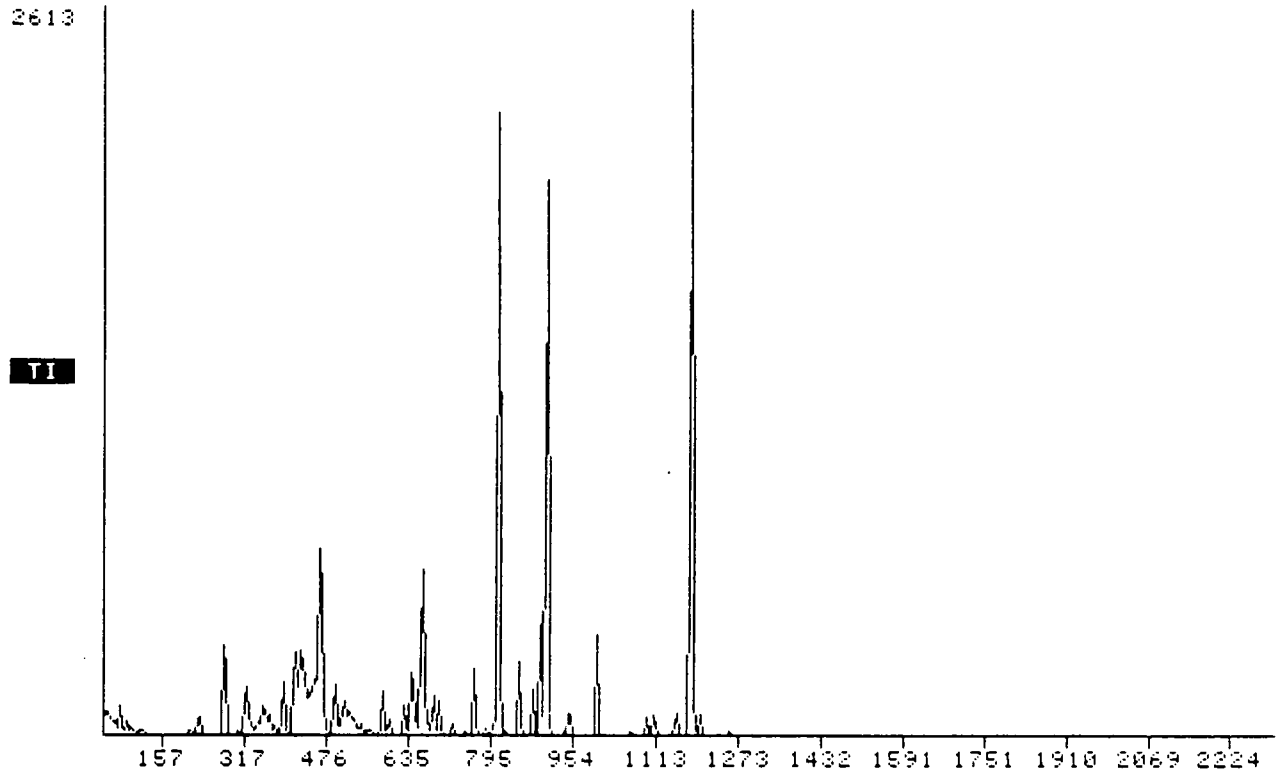
NAME CAP. CATALYTIC#7496 RMC#457(A-B/N)+20PPM D-10 FRN 5605
MISC 4/8/83 BTL#18 D5605



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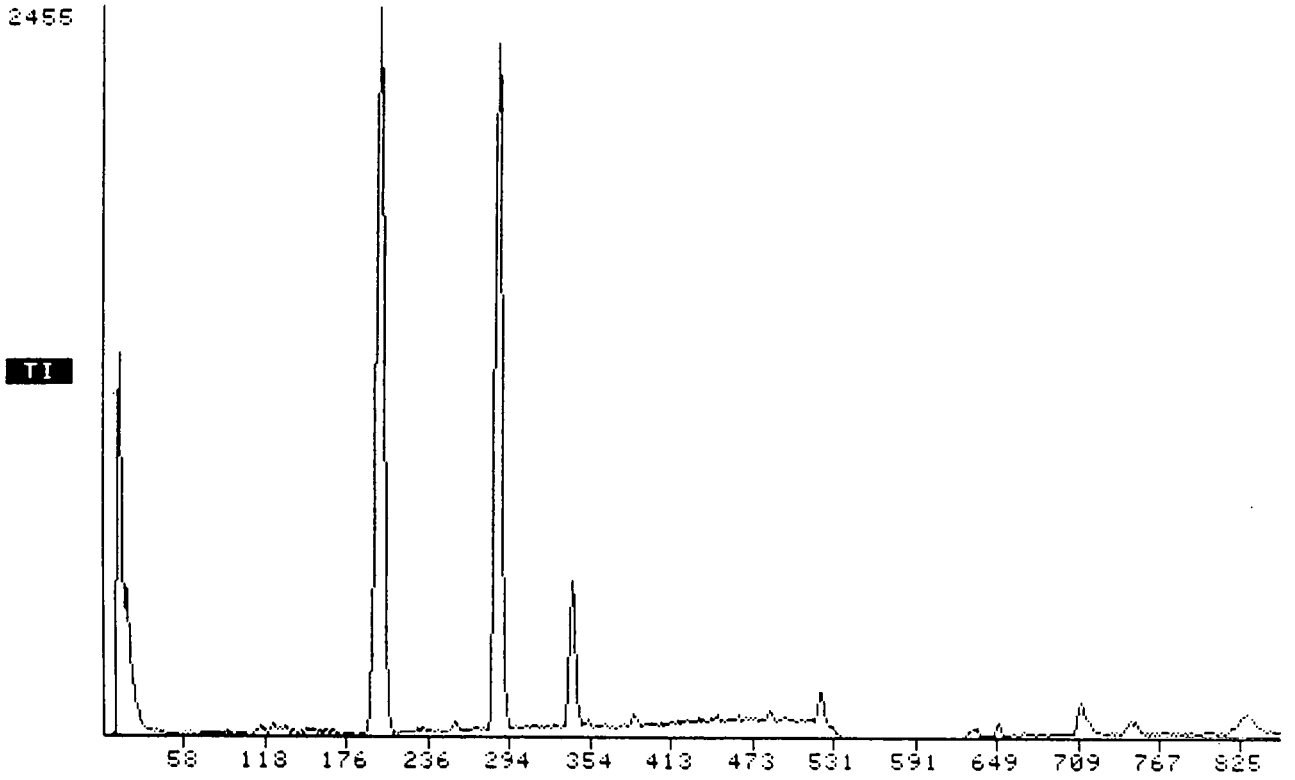
MISC 3/30/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7497	DATE ANALYZED	4/8/83
RMC I.D.	458	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.5
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.2
4-nitrophenol	<12.6
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: Richard S. Hodges

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7497	DATE ANALYZED	4/8/83
RMC I.D.	458	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<0.6
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<1.9
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.4	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	17.1
nitrobenzene	<1.5	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.4
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<0.6
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<11.9
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<1.7

Approved By: Richard L. Rodgers

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7497	DATE ANALYZED	3/31/83
RMC I.D.	458	ANALYZED BY	KFG

VOLATILES

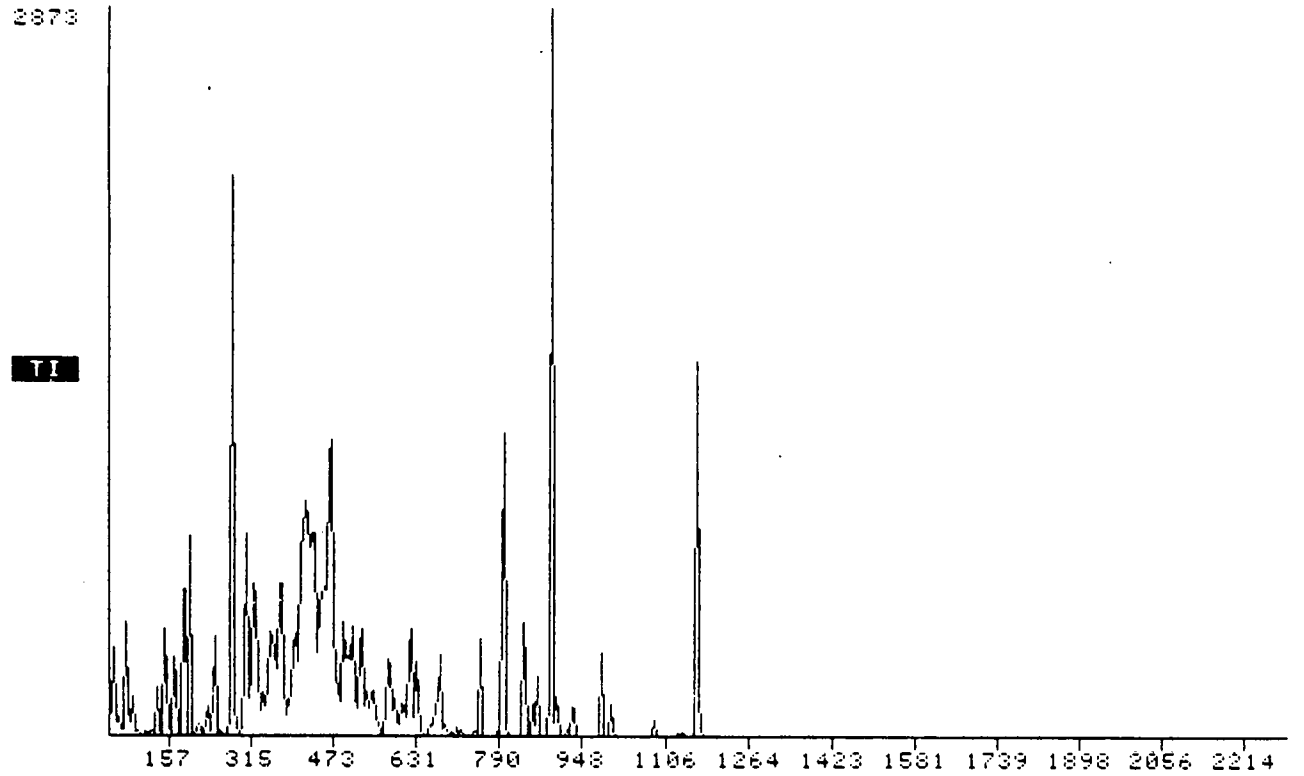
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.06
bromomethane	<0.5	1,2-dichloropropane	<0.19
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.14
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	<0.3	benzene	<0.04
acrolein	<80	dibromochloromethane	<0.09
acrylonitrile	<7	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.09	2-chloroethylvinyl ether	<1.1
1,1-dichloroethane	<0.09	bromoform	<0.16
trans-1,2-dichloroethene	<0.08	tetrachloroethene	<0.07
chloroform	10.8	1,1,2,2-tetrachloroethane	<0.3
1,2-dichloroethane	<0.18	toluene	<0.03
1,1,1-trichloroethane	<0.04	chlorobenzene	<0.04
carbon tetrachloride	<0.9	ethylbenzene	<0.02

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Rodgers
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7497 RMC#458(A-B/N)+20PPM D-10 FRN 5606
MISC 4/8/83 BTL#19 D5606



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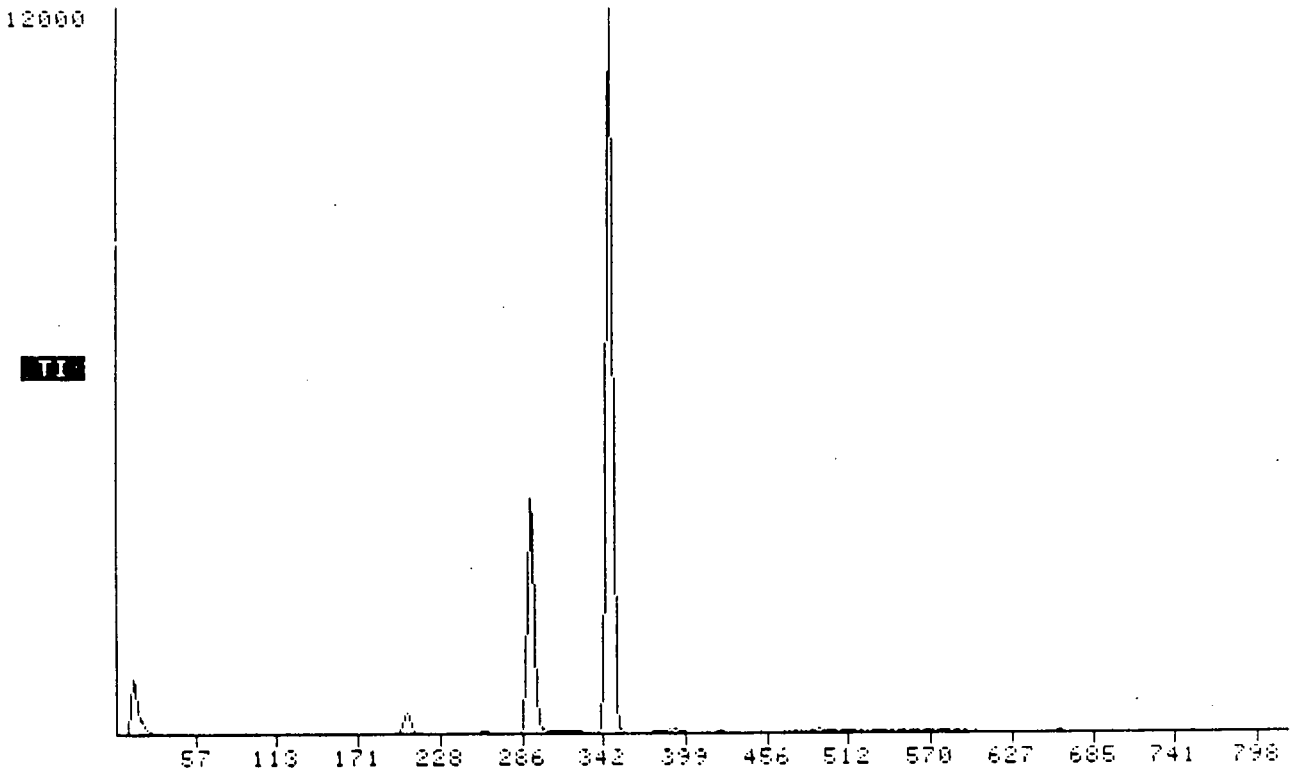
MISC 3/31/89



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7198	DATE ANALYZED	4/8/83
RMC I.D.	459	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.3
4-nitrophenol	<12.7
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: [signature]

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7498	DATE ANALYZED	4/8/83
RMC I.D.	459	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	5.7
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.6
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<1.7
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.2	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.6	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<12.0
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.0

Approved By: Richard S. Ledyard

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Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7498	DATE ANALYZED	3/31/83
RMC I.D.	459	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.05
bromomethane	<0.5	1,2-dichloropropane	<0.18
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.13
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	<0.2	benzene	<0.03
acrolein	<70	dibromochloromethane	<0.09
acrylonitrile	<7	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.09	2-chloroethylvinyl ether	<1.1
1,1-dichloroethane	<0.09	bromoform	<0.15
trans-1,2-dichloroethene	<0.07	tetrachloroethene	<0.07
chloroform	1.9	1,1,2,2-tetrachloroethane	<0.3
1,2-dichloroethane	<0.17	toluene	<0.03
1,1,1-trichloroethane	<0.04	chlorobenzene	<0.04
carbon tetrachloride	<0.9	ethylbenzene	<0.02

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

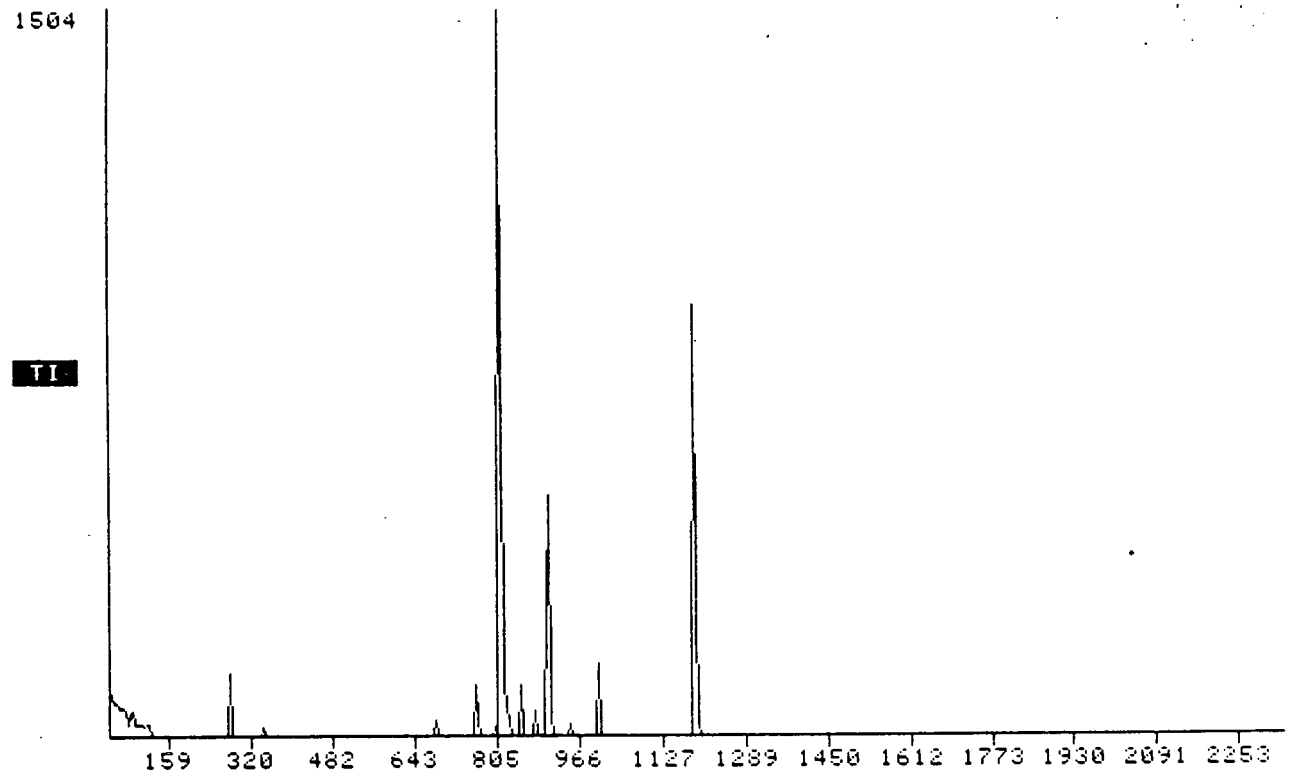
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

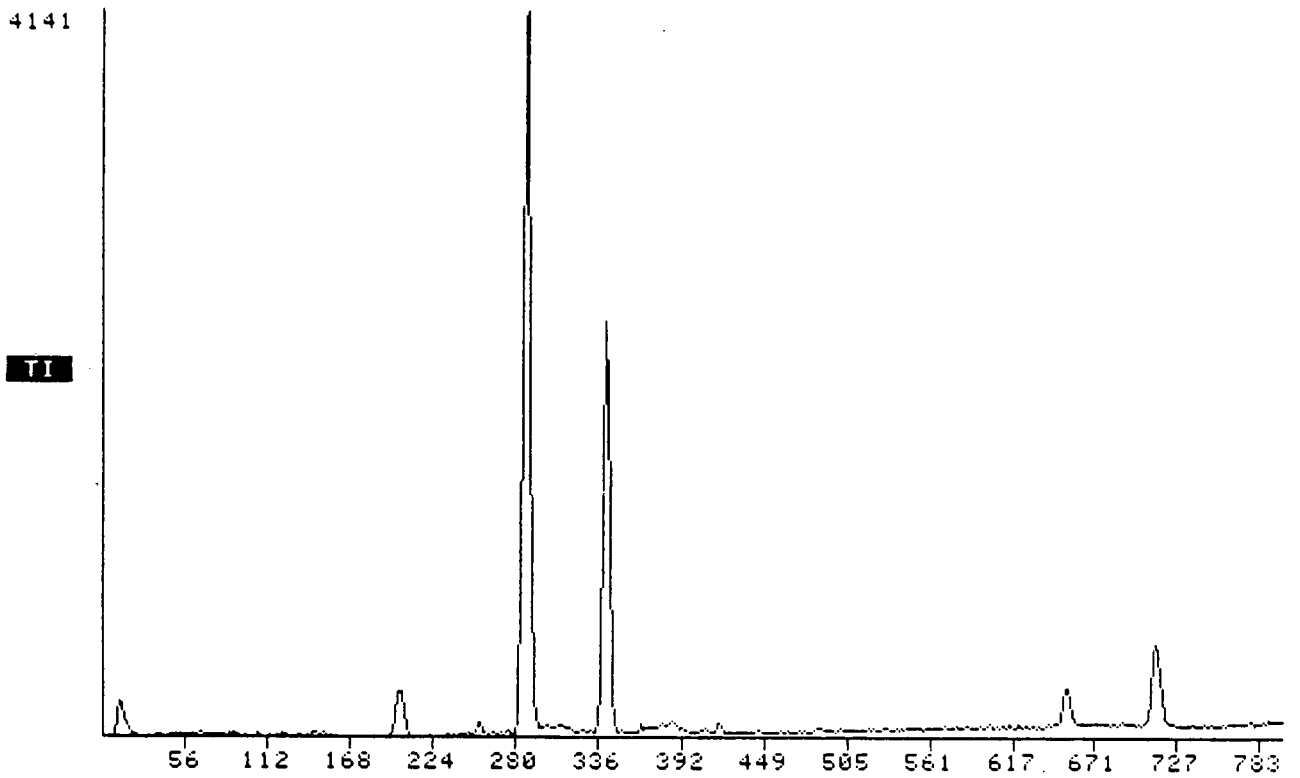
NAME 4/8/83
MISC CAT.#7498(A-B/BTL#20

D5607

FRN 5607



NAME VOL. CATALYTIC#7498 RMC#459+10PPB I.S. EM1800 FRN 5547
MISC 3/31/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7499	DATE ANALYZED	4/8/83
RMC I.D.	460	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.7
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.6
4-nitrophenol	<13.0
2-methyl-4,6-dinitrophenol	<4.1
pentachlorophenol	<8.2

Approved By: Richard S. Rodgers

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7499	DATE ANALYZED	4/8/83
RMC I.D.	460	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.6	4-chlorophenyl phenyl ether	<1.6
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	8.4
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<22.1
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.4	butyl benzyl phthalate	<0.8
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.2
hexachlorocyclopentadiene	<2.5	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.2	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.4
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.9
fluorene	<0.7	dibenz(a,h)anthracene	<5.4
diethyl phthalate	<0.6	benz(g.h.i.)perylene	<12.3
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.3

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Chemistry Laboratory
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Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7499	DATE ANALYZED	3/31/83
RMC I.D.	460	ANALYZED BY	KFG

VOLATILES

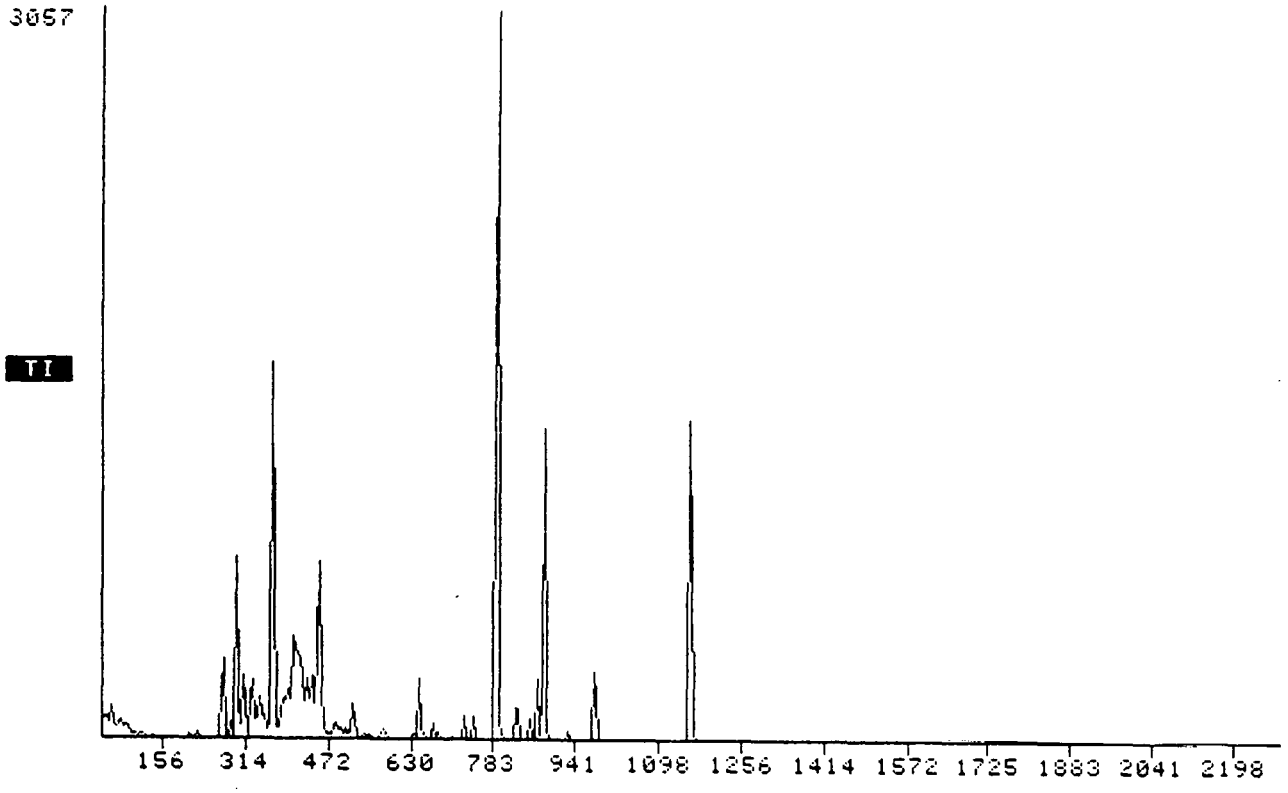
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.12
bromomethane	<0.5	1,2-dichloropropane	<0.5
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.3
chloroethane	<1.0	trichloroethene	<0.13
methylene chloride	<0.3	benzene	<0.08
acrolein	<160	dibromochloromethane	<0.19
acrylonitrile	<16	1,1,2-trichloroethane	<0.5
1,1-dichloroethene	<0.19	2-chloroethylvinyl ether	<2.4
1,1-dichloroethane	<0.19	bromoform	<0.4
trans-1,2-dichloroethene	<0.16	tetrachloroethene	<0.15
chloroform	2.0	1,1,2,2-tetrachloroethane	<0.7
1,2-dichloroethane	<0.4	toluene	<0.06
1,1,1-trichloroethane	<0.08	chlorobenzene	<0.09
carbon tetrachloride	<1.9	ethylbenzene	<0.04

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

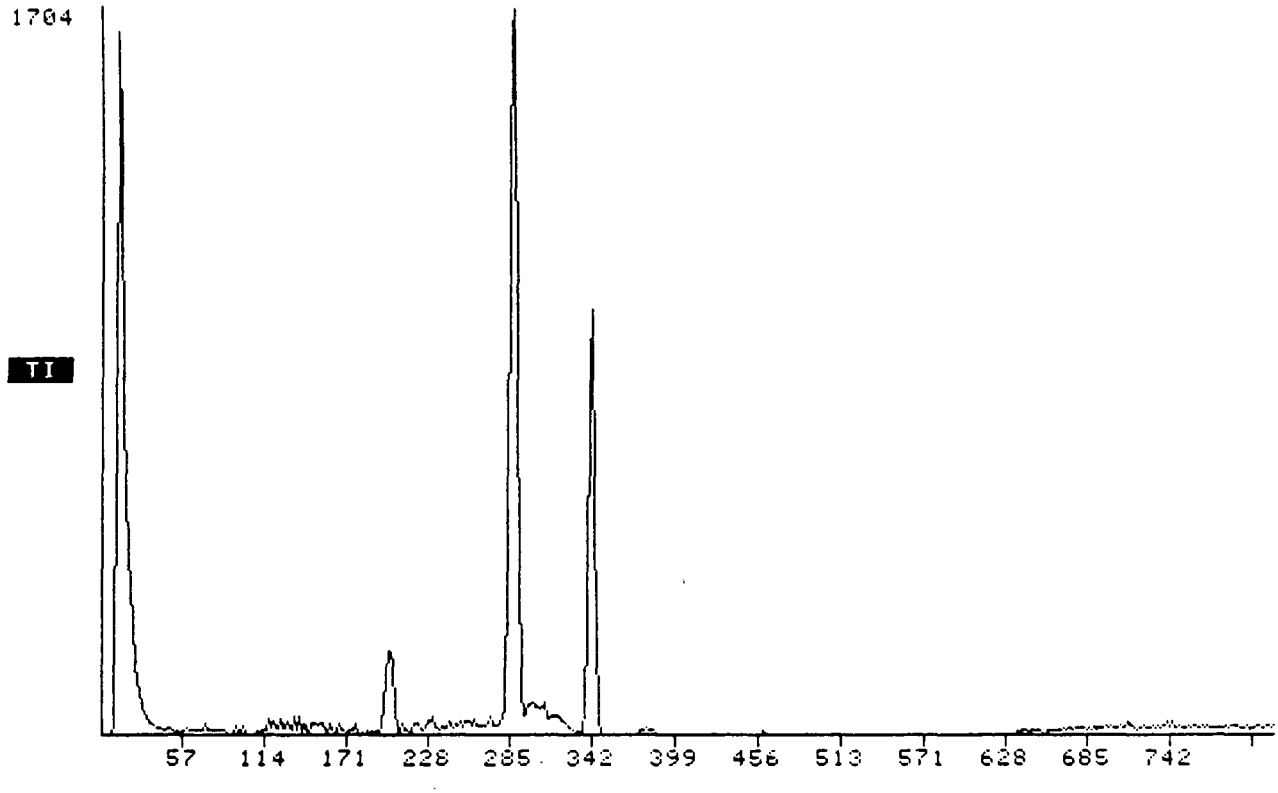
Richard S. Kobzina
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7499 RMC#460(A-B/N)+20PPM D-10 FRN 5608
MISC 4/8/83 BTL#21 D5608



NAME VOL. CATALYTIC#7499 RMC#460+10PPB I.S. EM1800 FRN 5548
MISC 3/31/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7500	DATE ANALYZED	4/8/83
RMC I.D.	461	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.3
4-nitrophenol	<12.7
2-methyl-4,6-dinitrophenol	<4.1
pentachlorophenol	<8.0

Approved By: Richard S. Kodis

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7500	DATE ANALYZED	4/8/83
RMC I.D.	461	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.6
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.0
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	8.4
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.6
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g.h.i.)perylene	<12.1
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.2

Approved By: Richard S. Kodzwa

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7500	DATE ANALYZED	3/31/83
RMC I.D.	461	ANALYZED BY	KFG

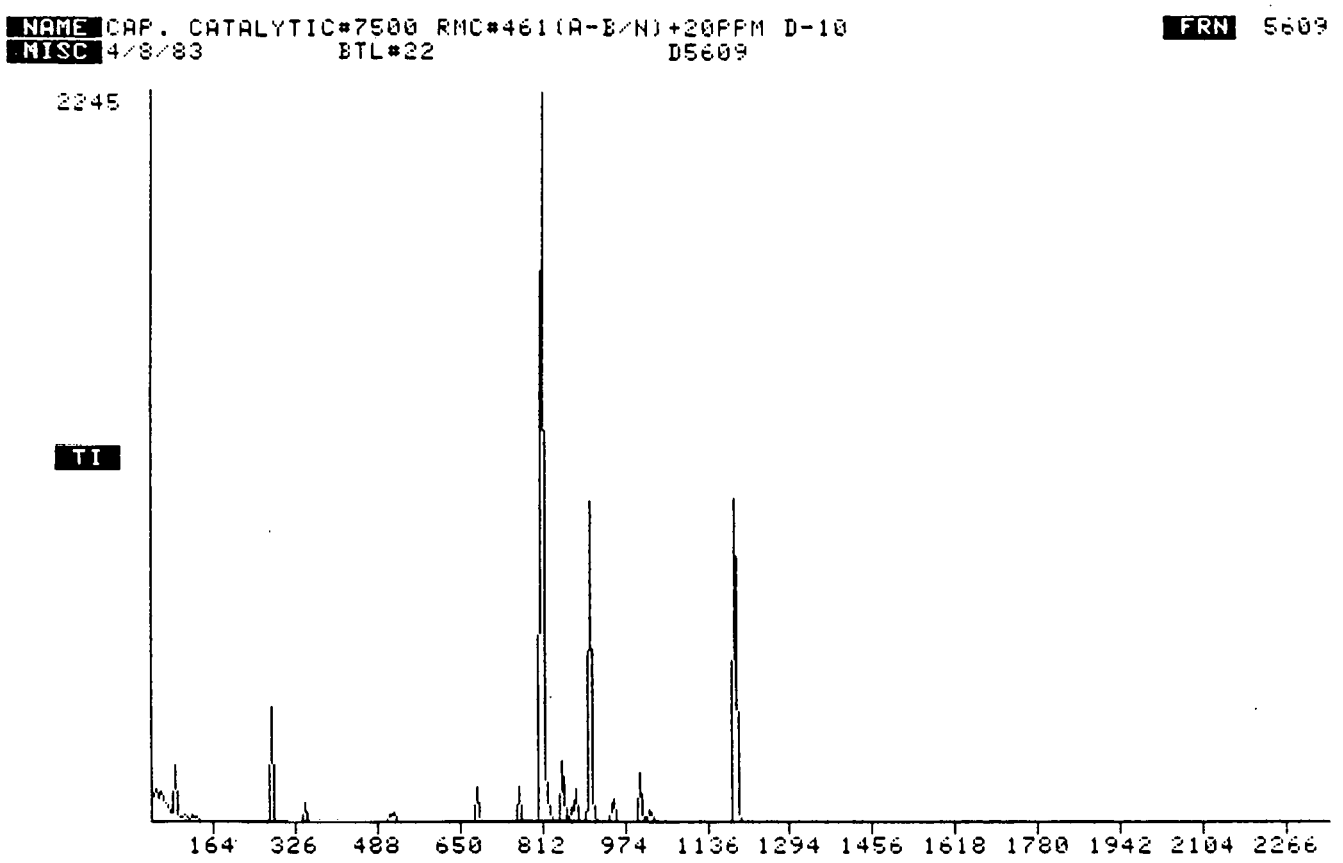
VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.11
bromomethane	<0.5	1,2-dichloropropane	<0.4
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.3
chloroethane	<1.0	trichloroethene	<0.12
methylene chloride	<0.3	benzene	<0.07
acrolein	<150	dibromochloromethane	<0.18
acrylonitrile	<14	1,1,2-trichloroethane	<0.5
1,1-dichloroethene	<0.17	2-chloroethylvinyl ether	<2.3
1,1-dichloroethane	<0.18	bromoform	<0.4
trans-1,2-dichloroethene	<0.15	tetrachloroethene	<0.14
chloroform	0.7	1,1,2,2-tetrachloroethane	<0.06
1,2-dichloroethane	<0.4	toluene	<0.05
1,1,1-trichloroethane	<0.08	chlorobenzene	<0.08
carbon tetrachloride	<1.7	ethylbenzene	<0.04

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Kodgers
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464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FRN 5609
MISC 4/8/83 BTL#22 D5609
2245
TI
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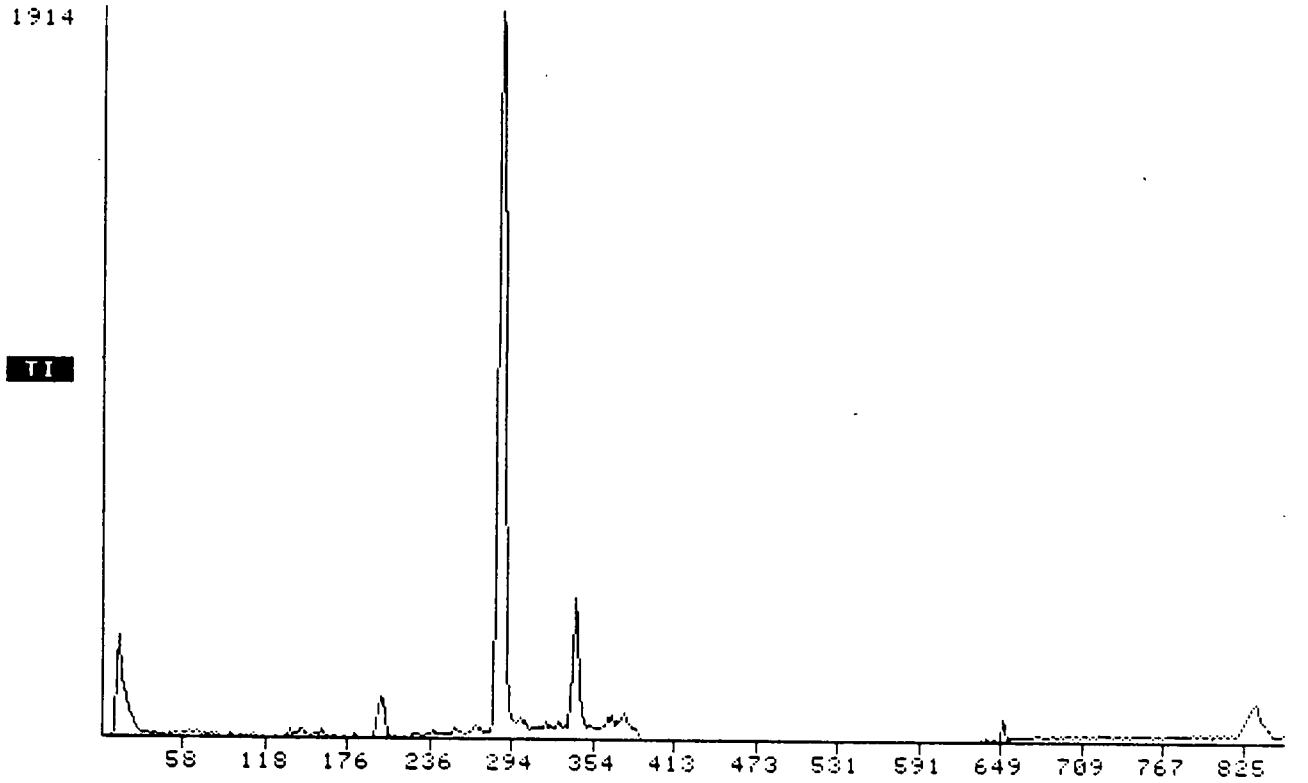
NAME VOL. CATALYTIC#7500 RMC#461+10PPB I.S. EM1800 FRN 5549
MISC 3/31/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7501	DATE ANALYZED	4/8/84
RMC I.D.	462	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.2
4-chloro-3-methylphenol	<1.7
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.6
4-nitrophenol	<13.0
2-methyl-4,6-dinitrophenol	<4.1
pentachlorophenol	<8.2

Approved By: Richard S. Hodges

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7501	DATE ANALYZED	4/8/83
RMC I.D.	462	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.5	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.3
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.6	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	<0.4
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<22.1
bis(2-chloroethoxy)methane	<1.0	pyrene	<0.6
1,2,4-trichlorobenzene	<1.4	butyl benzyl phthalate	<0.7
naphthalene	<0.6	benz(a)anthracene	<2.2
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.2
hexachlorocyclopentadiene	<2.5	chrysene	<2.2
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	5.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.2	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.4
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.9
fluorene	<0.7	dibenz(a,h)anthracene	<5.4
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<12.3
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<5.8

Approved By: Richard D. Hodgen

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7501	DATE ANALYZED	3/31/83
RMC I.D.	462	ANALYZED BY	KFG

VOLATILES

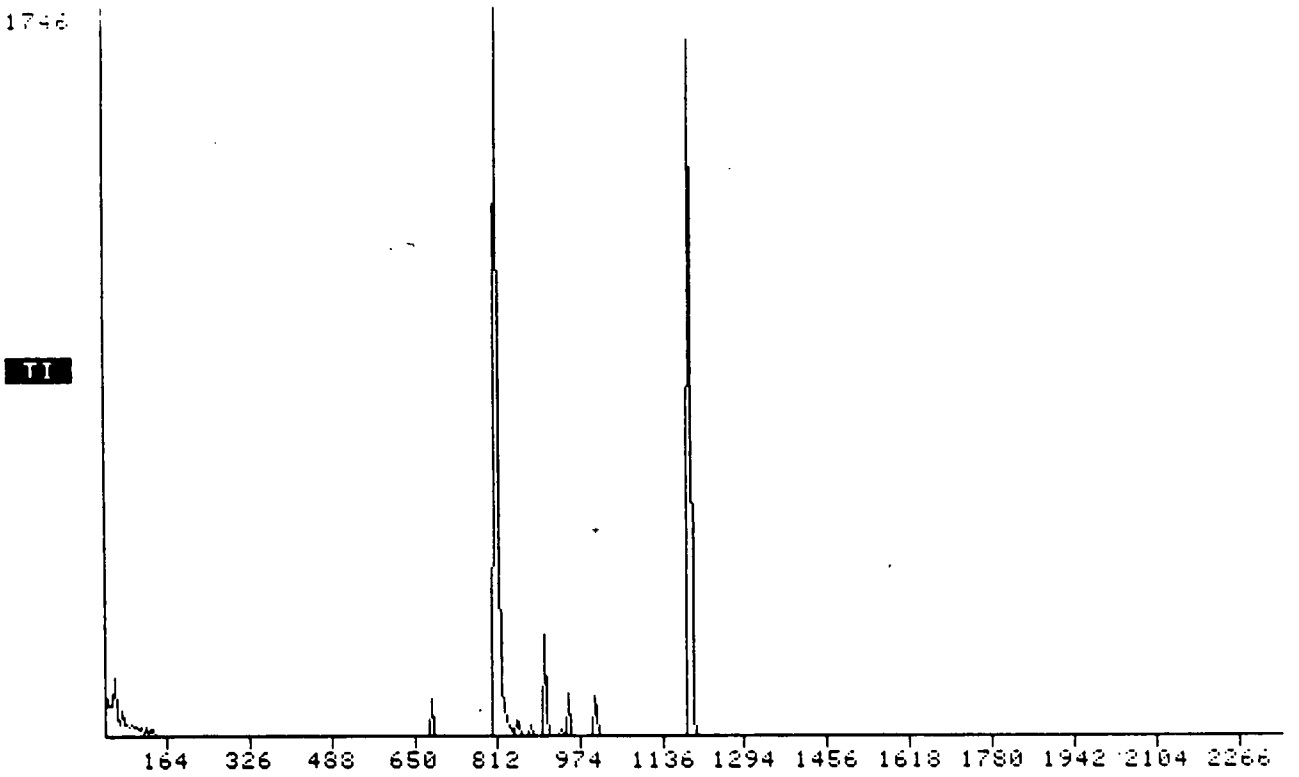
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.05
bromomethane	<0.5	1,2-dichloropropane	<0.16
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.11
chloroethane	<1.0	trichloroethene	<0.05
methylene chloride	<0.09	benzene	<0.03
acrolein	<60	dibromochloromethane	<0.07
acrylonitrile	<6	1,1,2-trichloroethane	<0.18
1,1-dichloroethene	<0.07	2-chloroethylvinyl ether	<0.9
1,1-dichloroethane	<0.07	bromoform	<0.13
trans-1,2-dichloroethene	<0.06	tetrachloroethene	<0.06
chloroform	<0.03	1,1,2,2-tetrachloroethane	<0.3
1,2-dichloroethane	<0.15	toluene	<0.02
1,1,1-trichloroethane	<0.03	chlorobenzene	<0.03
carbon tetrachloride	<0.8	ethylbenzene	<0.02

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Hodgson
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7501 RMC#462(A-B/N)+20PPM D-10 FRN 5610
MISC 4/8/83 BTL#23 D5610



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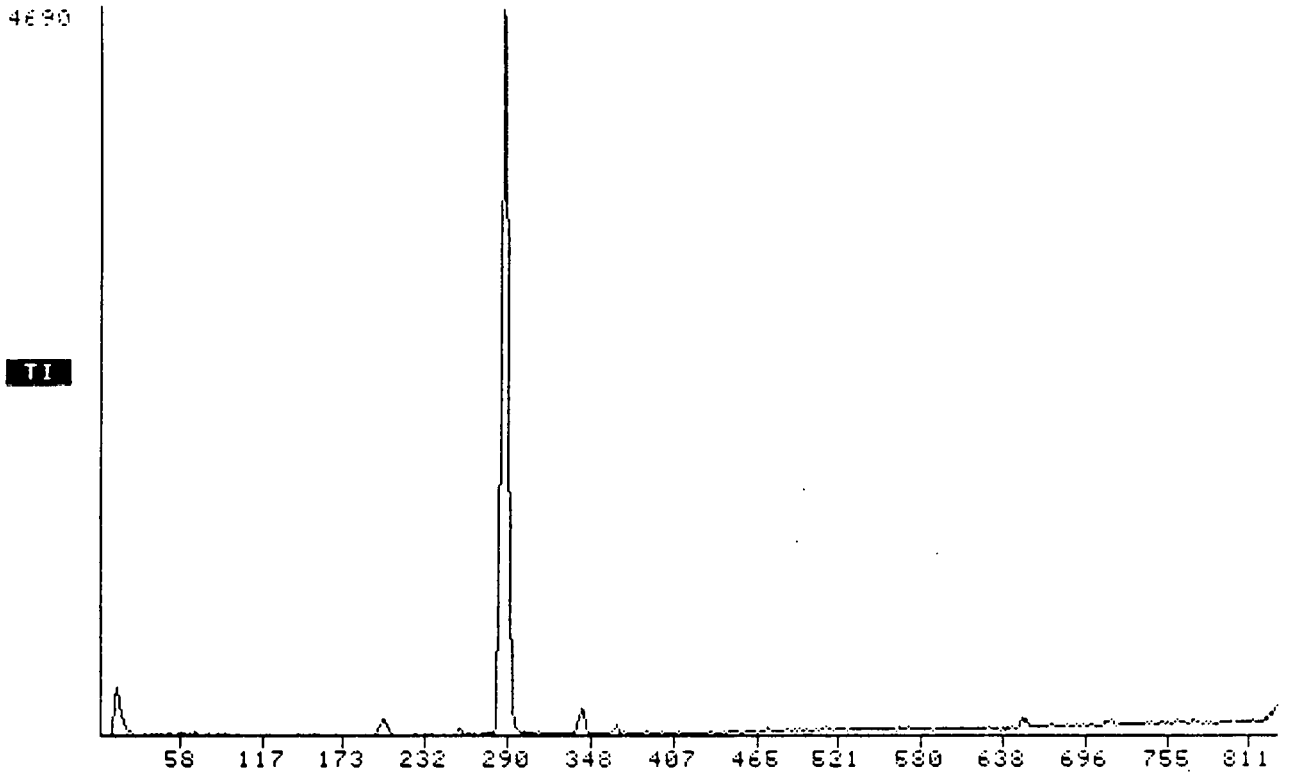
MISC 3/31/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7502	DATE ANALYZED	4/8/83
RMC I.D.	463	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.7
2-chlorophenol	<1.7
2-nitrophenol	<2.5
2,4-dimethylphenol	<1.6
2,4-dichlorophenol	<2.3
4-chloro-3-methylphenol	<1.8
2,4,6-trichlorophenol	<2.8
2,4-dinitrophenol	<11.2
4-nitrophenol	<13.8
2-methyl-4,6-dinitrophenol	<4.4
pentachlorophenol	<8.7

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7502	DATE ANALYZED	4/8/83
RMC I.D.	463	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.8	4-chlorophenyl phenyl ether	<1.7
bis(2-chloroethyl)ether	<1.4	n-nitrosodiphenylamine	<1.3
1,3-dichlorobenzene	<1.5	1,2-diphenylhydrazine	<2.1
1,4-dichlorobenzene	<1.5	4-bromophenyl phenyl ether	<2.7
1,2-dichlorobenzene	<1.4	hexachlorobenzene	<2.2
bis(2-chloroisopropyl)ether	<3.8	phenanthrene	<0.5
hexachloroethane	<1.9	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.6	di-n-butyl phthalate	16.0
nitrobenzene	<1.7	fluoranthene	<0.6
isophorone	<0.6	benzidine	<23.4
bis(2-chloroethoxy)methane	<1.0	pyrene	<0.7
1,2,4-trichlorobenzene	<1.4	butyl benzyl phthalate	<0.8
naphthalene	<0.5	benz(a)anthracene	<2.3
hexachlorobutadiene	<2.8	3,3'-dichlorobenzidine	<8.7
hexachlorocyclopentadiene	<2.7	chrysene	<2.3
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	10.2
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.7	benzo(b)fluoranthene	<1.8
2,6-dinitrotoluene	<2.3	benzo(k)fluoranthene	<1.1
acenaphthene	<0.8	benzo(a)pyrene	<1.4
2,4-dinitrotoluene	<2.0	indeno(1,2,3-c,d)pyrene	<1.0
fluorene	<0.7	dibenz(a,h)anthracene	<5.7
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<13.0
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<1.9

Approved By: Richard D. Hodgens

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7502	DATE ANALYZED	3/31/83
RMC I.D.	463	ANALYZED BY	KFG

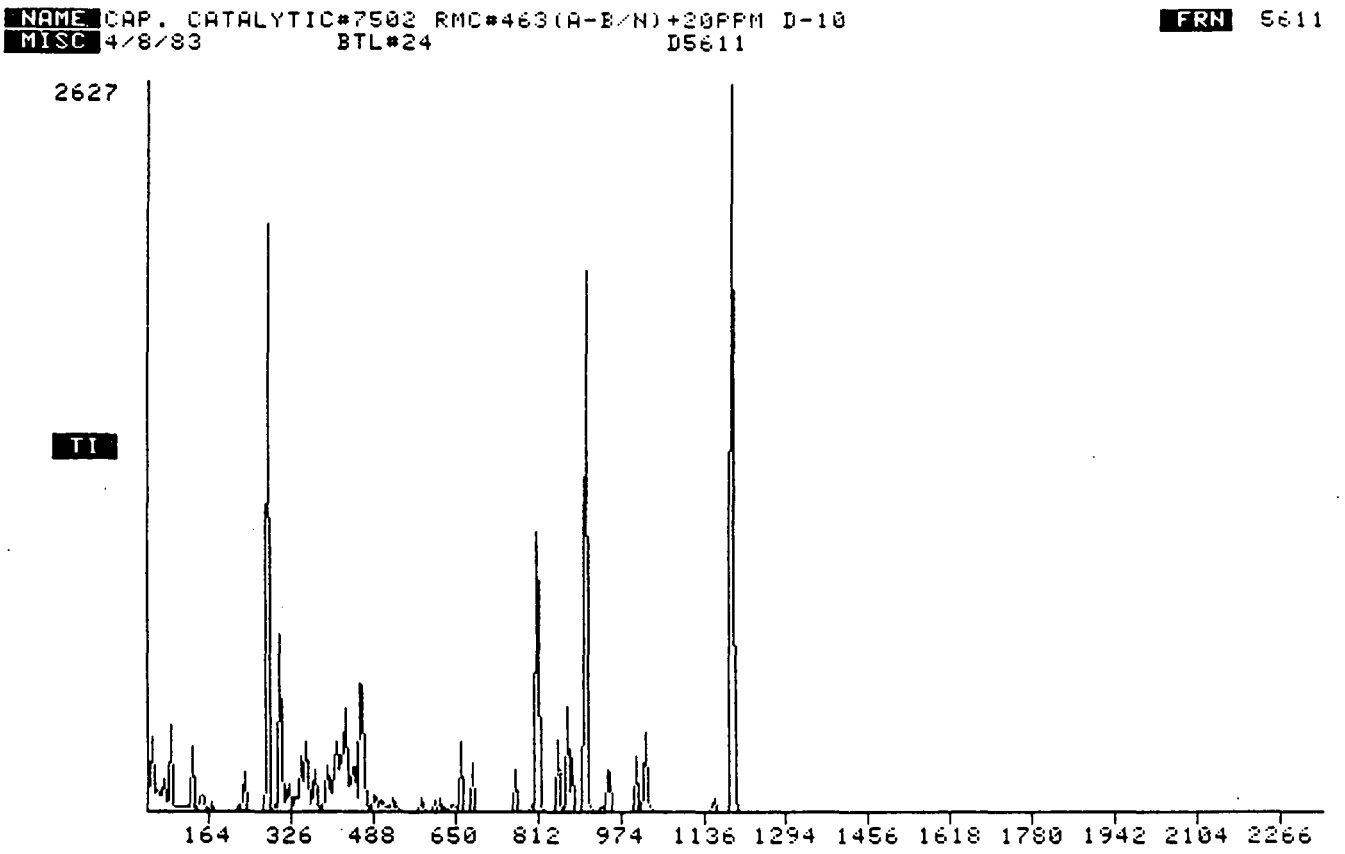
VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.08
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.2
chloroethane	<1.0	trichloroethene	<0.09
methylene chloride	<0.4	benzene	<0.05
acrolein	<110	dibromochloromethane	<0.13
acrylonitrile	<11	1,1,2-trichloroethane	<0.4
1,1-dichloroethene	<0.13	2-chloroethylvinyl ether	<1.6
1,1-dichloroethane	<0.13	bromoform	<0.3
trans-1,2-dichloroethene	<0.11	tetrachloroethene	<0.10
chloroform	0.9	1,1,2,2-tetrachloroethane	<0.5
1,2-dichloroethane	<0.3	toluene	<0.04
1,1,1-trichloroethane	<0.06	chlorobenzene	<0.06
carbon tetrachloride	<1.3	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard D. Kolyer
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464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MISC 4/8/83 BTL#24 D5611
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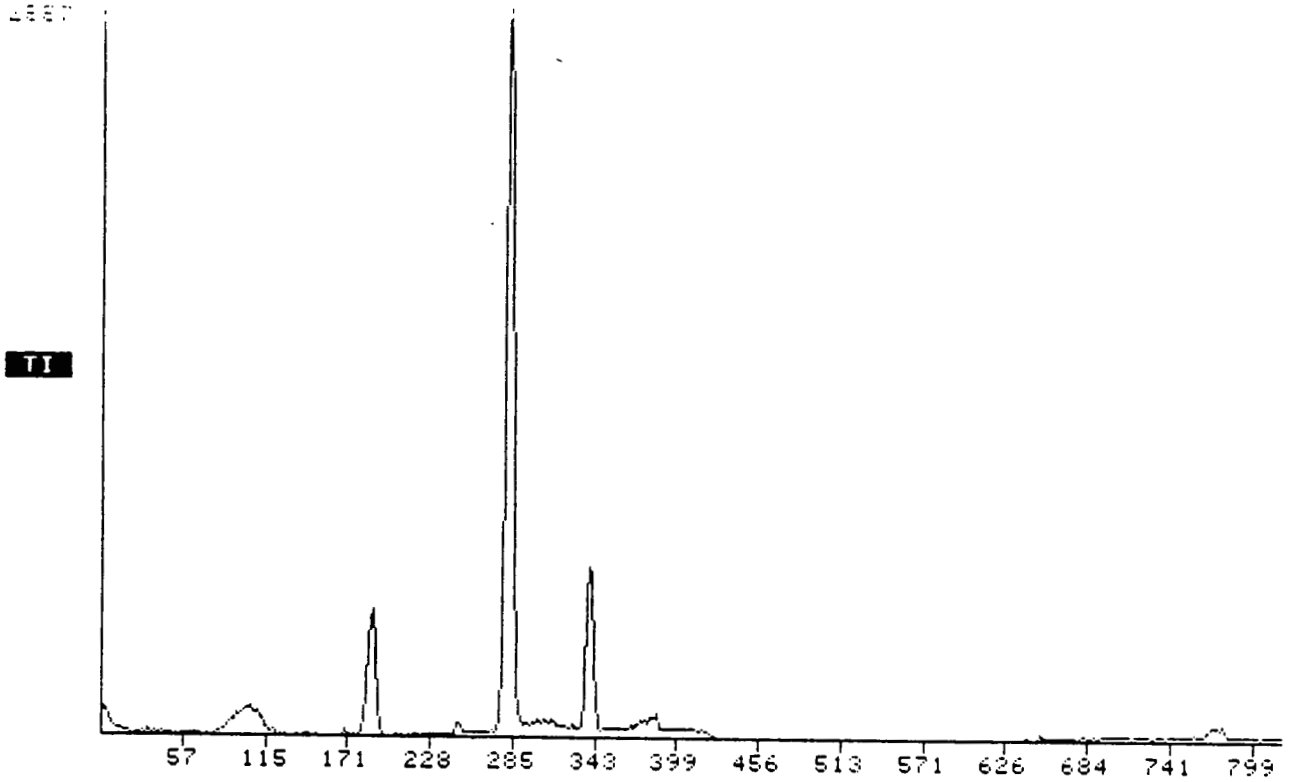
164 326 488 650 812 974 1136 1294 1456 1618 1780 1942 2104 2266

NAME VOL. CATALYTIC#7502 RMC#463+10PPB I.S. EM1800 FRN 5551
MISC 3/31/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7503	DATE ANALYZED	4/8/83
RMC I.D.	464	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.4
4-nitrophenol	<12.9
2-methyl-4,6-dinitrophenol	<4.1
pentachlorophenol	<8.1

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7503	DATE ANALYZED	4/8/83
RMC I.D.	464	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<7.1	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	<0.4
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.8
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.4	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.1
hexachlorocyclopentadiene	<2.5	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	7.1
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.2	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.4
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<12.1
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.3

Approved By: Richard S. Fiedler

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7503	DATE ANALYZED	3/31/83
RMC I.D.	464	ANALYZED BY	KFG

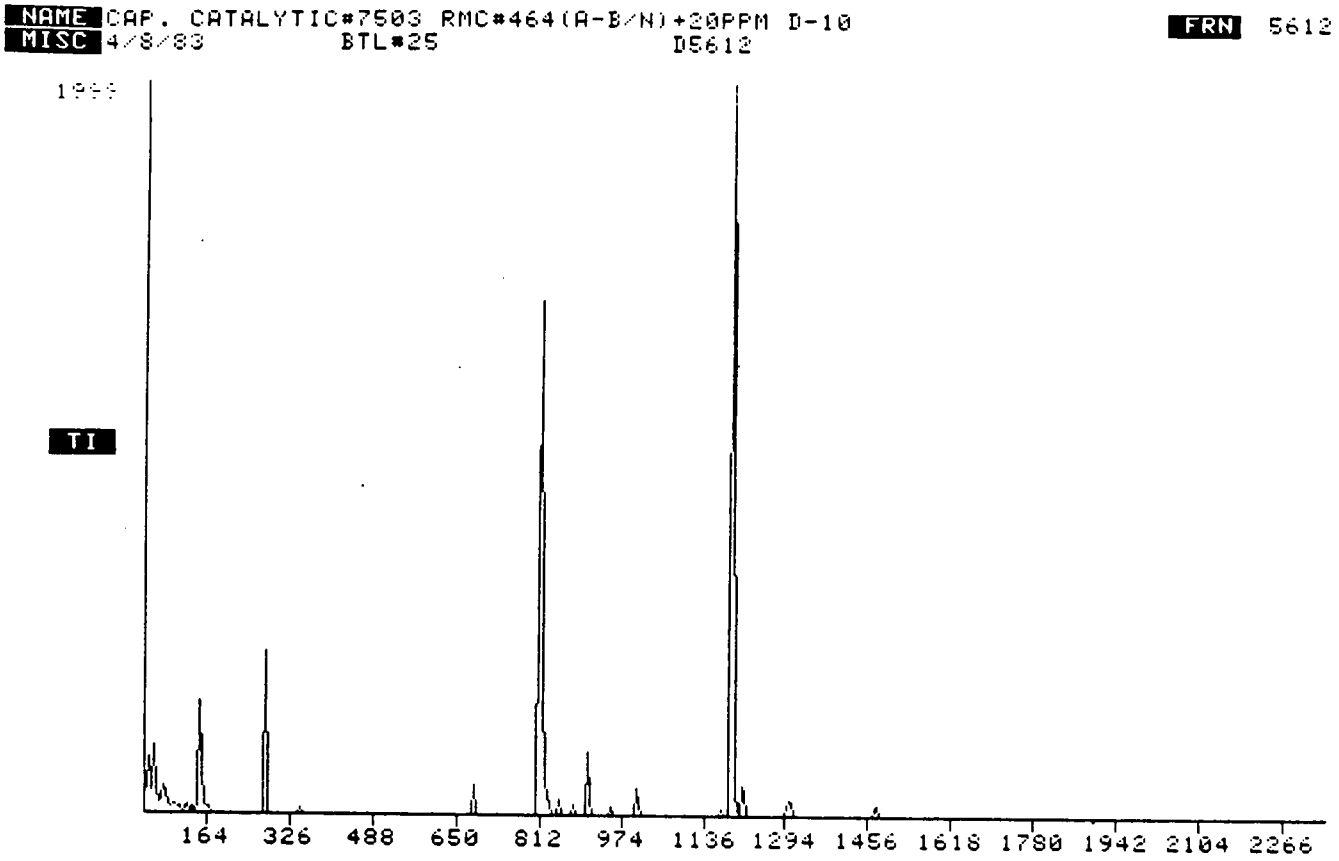
VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.05
bromomethane	<0.5	1,2-dichloropropane	<0.18
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.13
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	<0.3	benzene	<0.03
acrolein	<70	dibromochloromethane	<0.08
acrylonitrile	<7	1,1,2-trichloroethane	<0.2
1,1-dichloroethene	<0.08	2-chloroethylvinyl ether	<1.0
1,1-dichloroethane	<0.08	bromoform	<0.15
trans-1,2-dichloroethene	<0.07	tetrachloroethene	<0.06
chloroform	3.6	1,1,2,2-tetrachloroethane	<0.3
1,2-dichloroethane	<0.17	toluene	0.2
1,1,1-trichloroethane	<0.04	chlorobenzene	<0.04
carbon tetrachloride	<0.8	ethylbenzene	<0.02

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Hodgson
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464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FRN 5612
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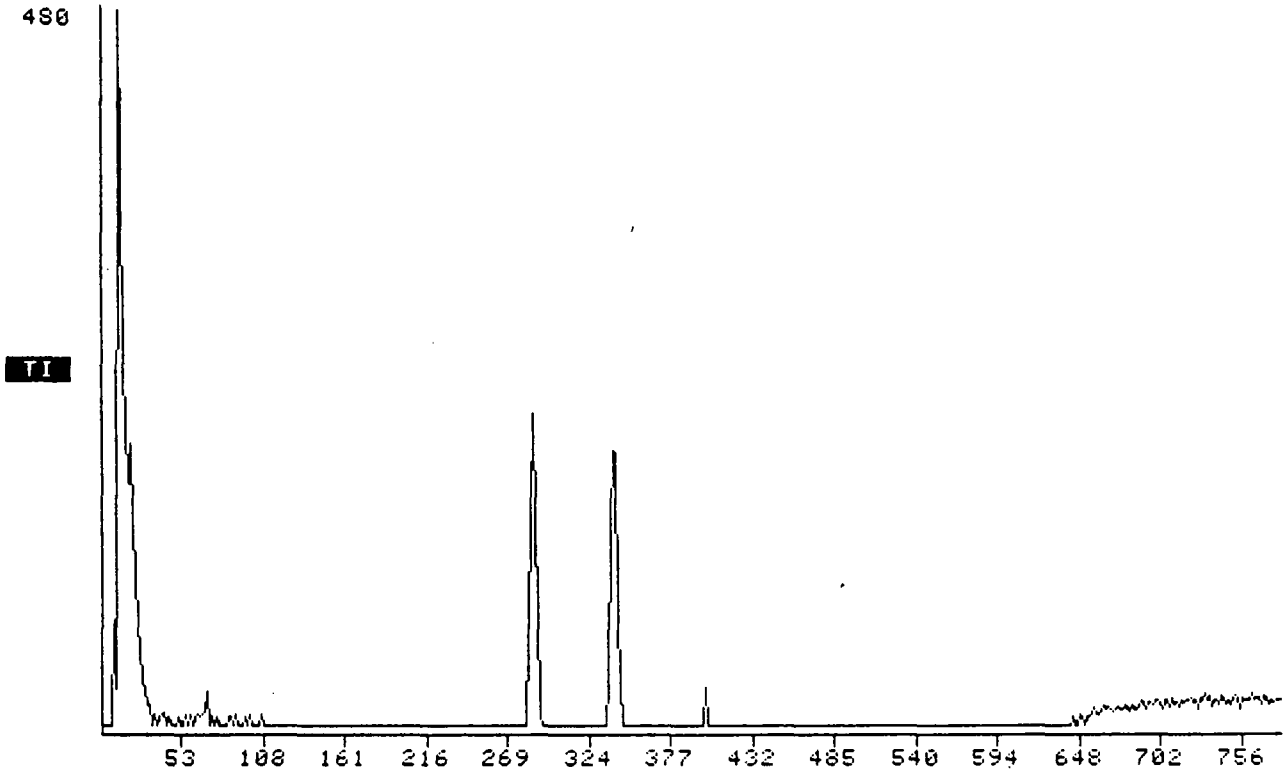
164 326 488 650 812 974 1136 1294 1456 1618 1780 1942 2104 2266

NAME VOL. CATALYTIC#7503 RMC#464+10PPB I.S. EM1800 FRN 5552
MISC 3/31/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7504	DATE ANALYZED	4/8/83
RMC I.D.	465	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.4
4-nitrophenol	<12.9
2-methyl-4,6-dinitrophenol	<4.1
pentachlorophenol	<8.1

Approved By: K. L. Kodgers

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7504	DATE ANALYZED	4/8/83
RMC I.D.	465	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.5	4-chlorophenyl phenyl ether	<1.6
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	6.7
nitrobenzene	<1.6	fluoranthene	<0.6
isophorone	<0.6	benzidine	<21.8
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.4	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.1
hexachlorocyclopentadiene	<2.5	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.2	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.4
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.4
diethyl phthalate	<0.5	benz(g.h.i.)perylene	<12.1
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.0

Approved By: Richard S. Kolgas

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7504	DATE ANALYZED	3/31/83
RMC I.D.	465	ANALYZED BY	KFG

VOLATILES

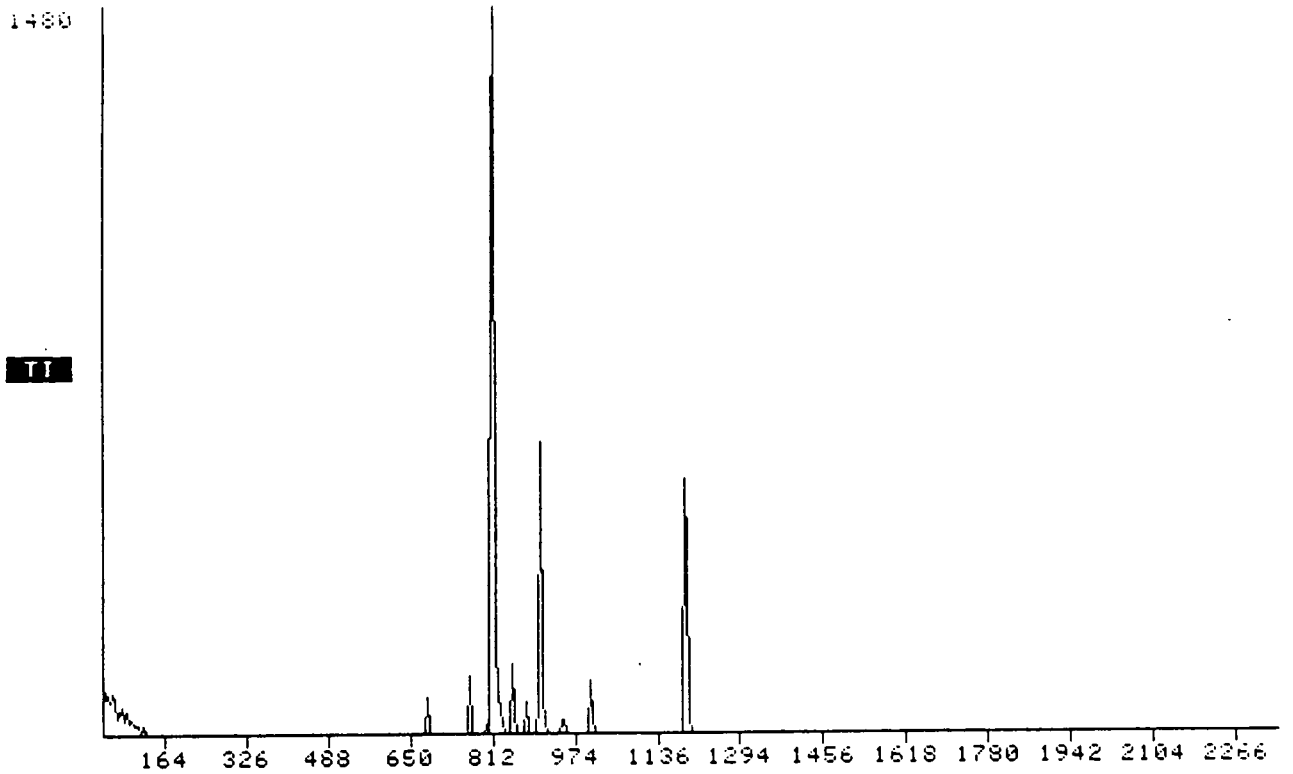
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.07
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.17
chloroethane	<1.0	trichloroethene	<0.07
methylene chloride	<0.3	benzene	<0.04
acrolein	<90	dibromochloromethane	<0.11
acrylonitrile	<9	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.11	2-chloroethylvinyl ether	<1.4
1,1-dichloroethane	<0.11	bromoform	<0.2
trans-1,2-dichloroethene	<0.09	tetrachloroethene	<0.09
chloroform	<0.05	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.03
1,1,1-trichloroethane	<0.05	chlorobenzene	<0.05
carbon tetrachloride	<1.1	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

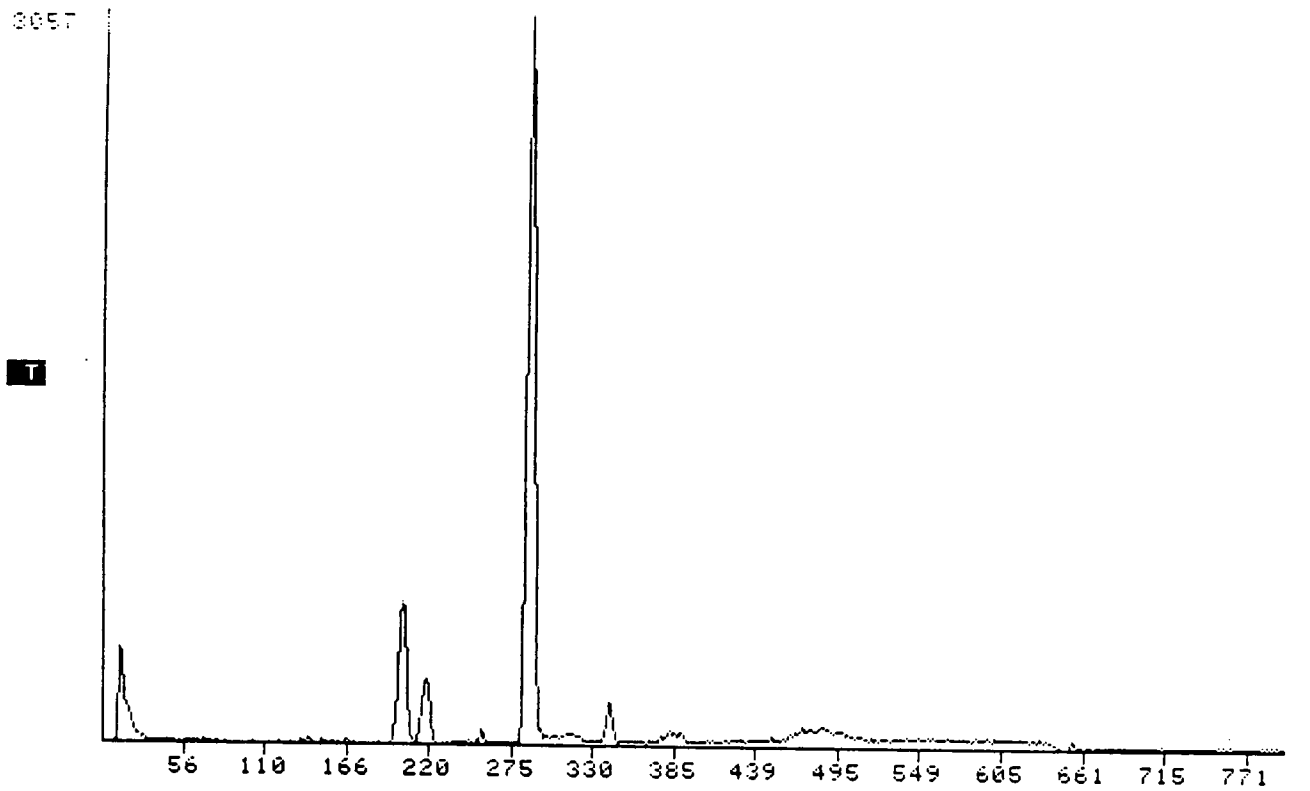
Richard S. Kadyan
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7504 RMC#465(A-B/N)+20PPM D-10 FRN 5613
MISC 4/8/83 BTL#26 D5613



NAME VOL. CATALYTIC#7504 RMC#465+10PPB I.S. EM1800 FRN 5553
MISC 3/31/83



CANBERRA RMC
Environmental Services Division, Fricks Lock Rd., RD #1, Pottstown, PA 19464 (215) 326-9662

22 July 1983

Dr. William Cowen
Catalytic, Inc.
P. O. Box 434
Marcus Hook, PA 19061

Dear Bill:

Enclosed please find the results of the GC/MS analyses performed on the samples you submitted 3 June 1983. I apologize for the delay, but we had some equipment problems which set us back several weeks.

If you have any questions concerning these data, please feel free to contact me.

Sincerely yours,

Richard S. Rodgers

Richard S. Rodgers
Manager
Environmental Chemistry
Laboratory

Enc.
gjs

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	2B Effluent #143	DATE ANALYZED	7/5/83
RMC I.D.	1005	ANALYZED BY	J. Good

VOLATILES

	µg/l		µg/l
chloromethane	<5	bromodichloromethane	<5
bromomethane	<5	1,2-dichloropropane	<5
vinyl chloride	<5	1,3-dichloropropene[1]	<5
chloroethane	<5	trichloroethene	<5
methylene chloride	14.5	benzene	<5
acrolein	<80	dibromochloromethane	<5
acrylonitrile	<6	1,1,2-trichloroethane	<5
1,1-dichloroethene	<5	2-chloroethylvinyl ether	<5
1,1-dichloroethane	<5	bromoform	<5
trans-1,2-dichloroethene	<5	tetrachloroethene	<5
chloroform	<5	1,1,2,2-tetrachloroethane	<5
1,2-dichloroethane	<5	toluene	<5
1,1,1-trichloroethane	<5	chlorobenzene	<5
carbon tetrachloride	<5	ethylbenzene	<5

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	2B Effluent #143	DATE ANALYZED	6/17/83
RMC I.D.	1005	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	< 1.0
2-chlorophenol	< 0.9
2-nitrophenol	< 1.3
2,4-dimethylphenol	< 0.8
2,4-dichlorophenol	< 1.2
4-chloro-3-methylphenol	< 0.9
2,4,6-trichlorophenol	< 1.9
2,4-dinitrophenol	< 4.6
4-nitrophenol	< 4.2
2-methyl-4,6-dinitrophenol	< 8.5
pentachlorophenol	< 6.9

Approved By: Richard S. Fodyn

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	2B Effluent #143	DATE ANALYZED	6/17/83
RMC I.D.	1005	ANALYZED BY	KFG

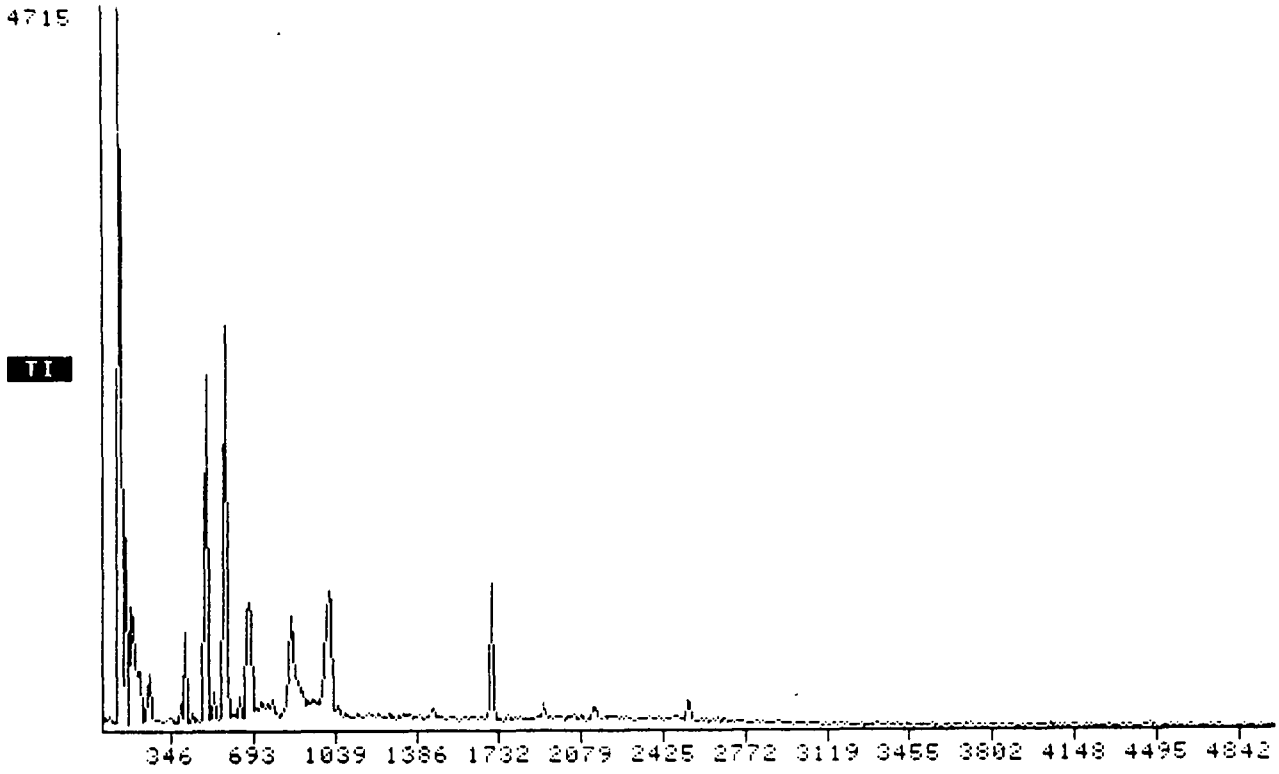
BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	< 3.2	4-chlorophenyl phenyl ether	< 1.6
bis(2-chloroethyl)ether	< 0.9	n-nitrosodiphenylamine	<37.3
1,3-dichlorobenzene	< 0.7	1,2-diphenylhydrazine	< 5.9
1,4-dichlorobenzene	< 0.7	4-bromophenyl phenyl ether	< 1.9
1,2-dichlorobenzene	< 0.8	hexachlorobenzene	< 3.1
bis(2-chloroisopropyl)ether	< 3.7	phenanthrene	< 0.5
hexachloroethane	< 1.1	anthracene	< 0.6
n-nitrosodi-n-propylamine	< 1.7	di-n-butyl phthalate	< 0.4
nitrobenzene	< 1.1	fluoranthene	< 0.8
isophorone	< 0.4	benzidine	<110
bis(2-chloroethoxy)methane	< 0.8	pyrene	< 0.8
1,2,4-trichlorobenzene	< 1.0	butyl benzyl phthalate	< 0.9
naphthalene	< 0.3	benz(a)anthracene	< 1.2
hexachlorobutadiene	< 1.6	3,3'-dichlorobenzidine	< 9.2
hexachlorocyclopentadiene	< 2.0	chrysene	<12.2
2-chloronaphthalene	< 0.5	bis(2-ethylhexyl)phthalate	< 0.8
acenaphthylene	< 0.3	di-n-octyl phthalate	< 0.4
dimethyl phthalate	< 0.5	benzo(b)fluoranthene	< 3.7
2,6-dinitrotoluene	<36.1	benzo(k)fluoranthene	<52
acenaphthene	< 0.5	benzo(a)pyrene	< 1.6
2,4-dinitrotoluene	< 1.8	indeno(1,2,3-c,d)pyrene	< 7.5
fluorene	< 0.6	dibenz(a,h)anthracene	<55
diethyl phthalate	< 0.6	benz(g.h.i.)perylene	<22
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<20

Approved By: Richard D. Hodgson

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME A-B/N CATALYTIC#143:PMC#1005 FRN 5696
MISC 6/17 83 BTL#18 D5696



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	D&P Feed #144	DATE ANALYZED	6/17/83
RMC I.D.	1006	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	< 5	bromodichloromethane	< 5
bromomethane	< 5	1,2-dichloropropane	< 5
vinyl chloride	< 5	1,3-dichloropropene[1]	< 5
chloroethane	< 5	trichloroethene	< 5
methylene chloride	13.5	benzene	< 5
acrolein	<80	dibromochloromethane	< 5
acrylonitrile	< 5	1,1,2-trichloroethane	< 5
1,1-dichloroethene	< 5	2-chloroethylvinyl ether	< 5
1,1-dichloroethane	< 5	bromoform	< 5
trans-1,2-dichloroethene	< 5	tetrachloroethene	< 5
chloroform	6.23	1,1,2,2-tetrachloroethane	< 5
1,2-dichloroethane	< 5	toluene	< 5
1,1,1-trichloroethane	< 5	chlorobenzene	< 5
carbon tetrachloride	< 5	ethylbenzene	< 5

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Ridgway
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	D&P Feed #144	DATE ANALYZED	6/17/83
RMC I.D.	1006	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	< 3.0
2-chlorophenol	< 1.0
2-nitrophenol	< 1.5
2,4-dimethylphenol	< 0.9
2,4-dichlorophenol	< 1.3
4-chloro-3-methylphenol	< 1.1
2,4,6-trichlorophenol	< 2.1
2,4-dinitrophenol	< 5.3
4-nitrophenol	< 4.8
2-methyl-4,6-dinitrophenol	< 9.7
pentachlorophenol	< 7.9

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	D&P Feed #144	DATE ANALYZED	6/17/83
RMC I.D.	1006	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	< 3.7	4-chlorophenyl phenyl ether	< 1.8
bis(2-chloroethyl)ether	< 1.1	n-nitrosodiphenylamine	<42.4
1,3-dichlorobenzene	< 0.8	1,2-diphenylhydrazine	< 6.7
1,4-dichlorobenzene	< 0.8	4-bromophenyl phenyl ether	< 2.2
1,2-dichlorobenzene	< 0.9	hexachlorobenzene	< 3.5
bis(2-chloroisopropyl)ether	< 4.2	phenanthrene	< 0.6
hexachloroethane	< 1.3	anthracene	< 0.6
n-nitrosodi-n-propylamine	< 1.9	di-n-butyl phthalate	< 0.5
nitrobenzene	< 1.3	fluoranthene	< 0.9
isophorone	< 0.5	benzidine	<123
bis(2-chloroethoxy)methane	< 0.9	pyrene	< 0.9
1,2,4-trichlorobenzene	< 1.2	butyl benzyl phthalate	< 1.0
naphthalene	< 0.3	benz(a)anthracene	< 1.4
hexachlorobutadiene	< 1.9	3,3'-dichlorobenzidine	<10.4
hexachlorocyclopentadiene	< 2.3	chrysene	<13.8
2-chloronaphthalene	< 0.5	bis(2-ethylhexyl)phthalate	< 0.9
acenaphthylene	< 0.3	di-n-octyl phthalate	< 0.4
dimethyl phthalate	< 0.6	benzo(b)fluoranthene	< 4.2
2,6-dinitrotoluene	<41.0	benzo(k)fluoranthene	<59
acenaphthene	< 0.5	benzo(a)pyrene	< 1.8
2,4-dinitrotoluene	< 2.0	indeno(1,2,3-c,d)pyrene	< 8.5
fluorene	< 0.7	dibenz(a,h)anthracene	<62
diethyl phthalate	< 0.6	benz(g.h.i.)perylene	<25
		2,3,7,8-tetrachlorodibenzo-p-dioxin	< 20

Approved By: Richard I. Rodgers

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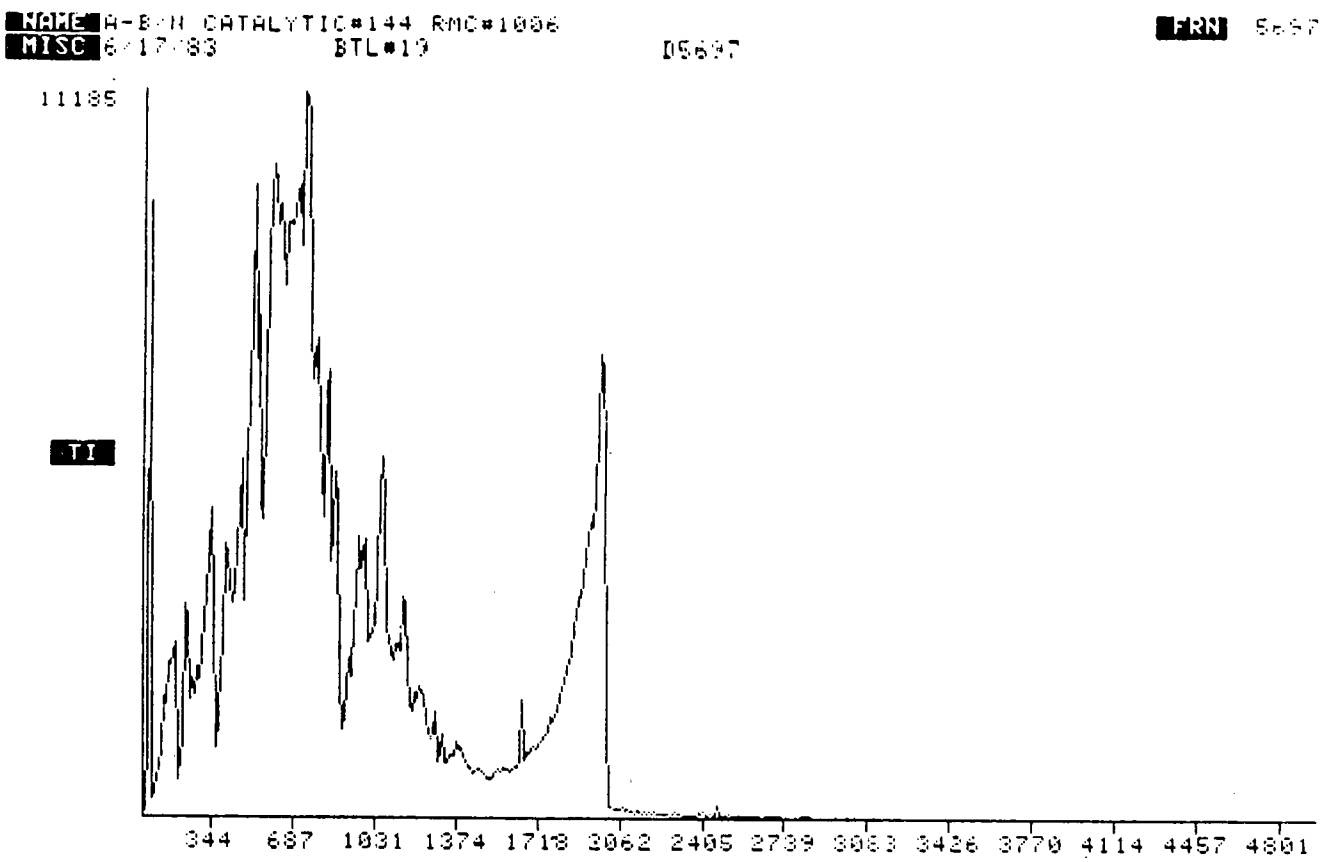
Fricks Lock Road, R.D. 1
Pottstown, PA 19464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FRN 5e57
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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE SAMPLED	6/3/83
CLIENT I.D.	#145 Tapwater	DATE ANALYZED	7/5/83
RMC I.D.	1007	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	< 5	bromodichloromethane	< 5
bromomethane	< 5	1,2-dichloropropane	< 5
vinyl chloride	< 5	1,3-dichloropropene[1]	< 5
chloroethane	< 5	trichloroethene	< 5
methylene chloride	12.6	benzene	< 5
acrolein	<80	dibromochloromethane	< 5
acrylonitrile	< 5	1,1,2-trichloroethane	< 5
1,1-dichloroethene	< 5	2-chloroethylvinyl ether	< 5
1,1-dichloroethane	< 5	bromoform	< 5
trans-1,2-dichloroethene	< 5	tetrachloroethene	< 5
chloroform	60.9	1,1,2,2-tetrachloroethane	< 5
1,2-dichloroethane	< 5	toluene	< 5
1,1,1-trichloroethane	< 5	chlorobenzene	< 5
carbon tetrachloride	< 5	ethylbenzene	< 5

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Kodys
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	#145	DATE ANALYZED	6/17/83
RMC I.D.	1007	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	< 0.6
2-chlorophenol	< 0.5
2-nitrophenol	< 0.7
2,4-dimethylphenol	< 0.4
2,4-dichlorophenol	< 0.7
4-chloro-3-methylphenol	< 0.5
2,4,6-trichlorophenol	< 1.1
2,4-dinitrophenol	< 2.6
4-nitrophenol	< 2.4
2-methyl-4,6-dinitrophenol	< 4.9
pentachlorophenol	< 4.0

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	6/3/83
CLIENT I.D.	#145	DATE ANALYZED	6/17/83
RMC I.D.	1007	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	< 1.8	4-chlorophenyl phenyl ether	< 0.9
bis(2-chloroethyl)ether	< 0.5	n-nitrosodiphenylamine	<21.3
1,3-dichlorobenzene	< 0.4	1,2-diphenylhydrazine	< 3.4
1,4-dichlorobenzene	< 0.4	4-bromophenyl phenyl ether	< 1.1
1,2-dichlorobenzene	< 0.4	hexachlorobenzene	< 1.8
bis(2-chloroisopropyl)ether	< 2.1	phenanthrene	< 0.3
hexachloroethane	< 0.6	anthracene	< 0.3
n-nitrosodi-n-propylamine	< 1.0	di-n-butyl phthalate	< 3.8
nitrobenzene	< 0.6	fluoranthene	< 0.5
isophorone	< 0.2	benzidine	<110
bis(2-chloroethoxy)methane	< 0.5	pyrene	< 0.5
1,2,4-trichlorobenzene	< 0.6	butyl benzyl phthalate	< 0.5
naphthalene	< 0.2	benz(a)anthracene	< 0.7
hexachlorobutadiene	< 0.9	3,3'-dichlorobenzidine	< 5.2
hexachlorocyclopentadiene	< 1.1	chrysene	< 0.9
2-chloronaphthalene	< 0.3	bis(2-ethylhexyl)phthalate	< 0.5
acenaphthylene	< 0.2	di-n-octyl phthalate	< 0.2
dimethyl phthalate	< 0.3	benzo(b)fluoranthene	< 2.1
2,6-dinitrotoluene	<20.6	benzo(k)fluoranthene	<30
acenaphthene	< 0.3	benzo(a)pyrene	< 0.9
2,4-dinitrotoluene	< 1.0	indeno(1,2,3-c,d)pyrene	< 4.3
fluorene	< 0.3	dibenz(a,h)anthracene	<31
diethyl phthalate	< 0.3	benz(g,h,i,)perylene	<13
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<20

Approved By: Richard S. Lodyga

RMC Environmental Services Division
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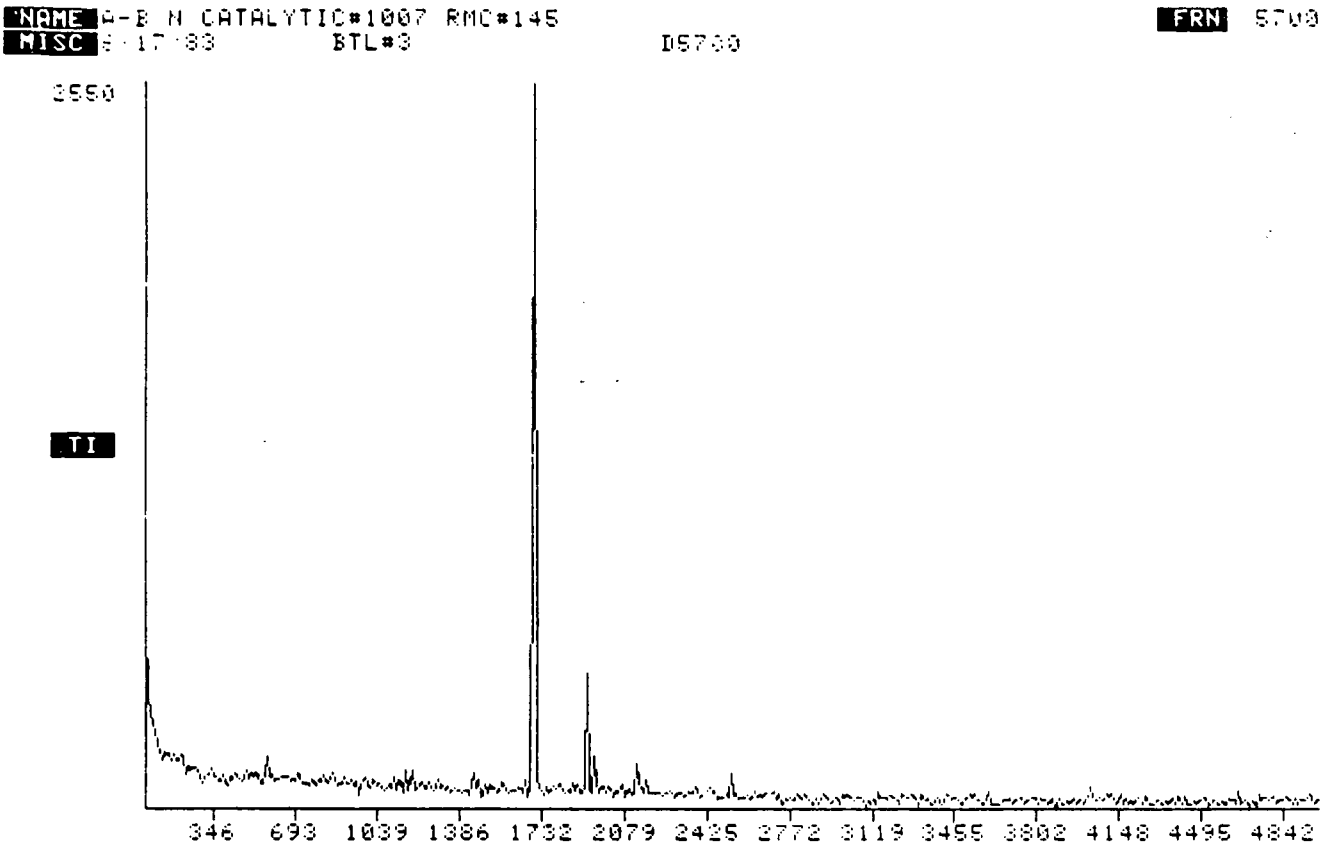
Pottstown, PA 19464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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7487	DATE ANALYZED	4/8/83
RMC I.D.	448	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	2420000
2-chlorophenol	<59
2-nitrophenol	<87
2,4-dimethylphenol	241000
2,4-dichlorophenol	<79
4-chloro-3-methylphenol	<62
2,4,6-trichlorophenol	<97
2,4-dinitrophenol	<393
4-nitrophenol	<485
2-methyl-4,6-dinitrophenol	<153
pentachlorophenol	<304

Approved By: Richard S. Rodgers

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7487	DATE ANALYZED	4/8/83
RMC I.D.	448	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<170	4-chlorophenyl phenyl ether	<57
bis(2-chloroethyl)ether	<49	n-nitrosodiphenylamine	<46
1,3-dichlorobenzene	<51	1,2-diphenylhydrazine	<74
1,4-dichlorobenzene	<51	4-bromophenyl phenyl ether	<92
1,2-dichlorobenzene	<49	hexachlorobenzene	<77
bis(2-chloroisopropyl)ether	<130	phenanthrene	<18
hexachloroethane	<67	anthracene	<18
n-nitrosodi-n-propylamine	<57	di-n-butyl phthalate	<13
nitrobenzene	<59	fluoranthene	<18
isophorone	<21	benzidine	<821
bis(2-chloroethoxy)methane	<34	pyrene	<23
1,2,4-trichlorobenzene	<49	butyl benzyl phthalate	<26
naphthalene	<16	benz(a)anthracene	<79
hexachlorobutadiene	<95	3,3'-dichlorobenzidine	<304
hexachlorocyclopentadiene	<92	chrysene	<79
2-chloronaphthalene	<23	bis(2-ethylhexyl)phthalate	<26
acenaphthylene	<16	di-n-octyl phthalate	<13
dimethyl phthalate	<23	benzo(b)fluoranthene	<61
2,6-dinitrotoluene	<82	benzo(k)fluoranthene	<36
acenaphthene	<26	benzo(a)pyrene	<49
2,4-dinitrotoluene	<72	indeno(1,2,3-c,d)pyrene	<105
fluorene	<23	dibenz(a,h)anthracene	<202
diethyl phthalate	<21	benz(g,h,i.)perylene	<457
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<255

Approved By: Richard S. Rodgers

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

National Bureau of Standards Library Search of
Major Non-Priority Pollutant Peaks from the
Chromatogram of Catalytic Sample #7487 (40 times dilution)

Peak Scan Number	Most Probable Compound Match	Total Abundance at Scan Number
312	2-methylphenol	175593
341	3-methylphenol	283557
363	2 or 4-ethylphenol	22551
373	2,5-dimethylphenol	54663
393	3,5 or 2,3-dimethylphenol	106694
406	3,4-dimethylphenol	54960
424	3-(1-methyethyl)phenol	11031
448	2-ethyl-4-methylphenol	40583
492	2,4-dimethylbenzaldehyde	48393
509	3,4-dimethylbenzaldehyde	56316

Approved By: Richard S. Rodgers
Richard S. Rodgers, Manager
Environmental Chemistry Laboratory

Canberra/RMC
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7487	DATE ANALYZED	3/30/83
RMC I.D.	448	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.08
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.2
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	<0.15	benzene	<0.05
acrolein	<80	dibromochloromethane	<0.10
acrylonitrile	<8	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.09	2-chloroethylvinyl ether	<1.6
1,1-dichloroethane	<0.10	bromoform	<0.2
trans-1,2-dichloroethene	<0.09	tetrachloroethene	<0.07
chloroform	0.44	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.03
1,1,1-trichloroethane	<0.05	chlorobenzene	<0.04
carbon tetrachloride	<0.04	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Kodym
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

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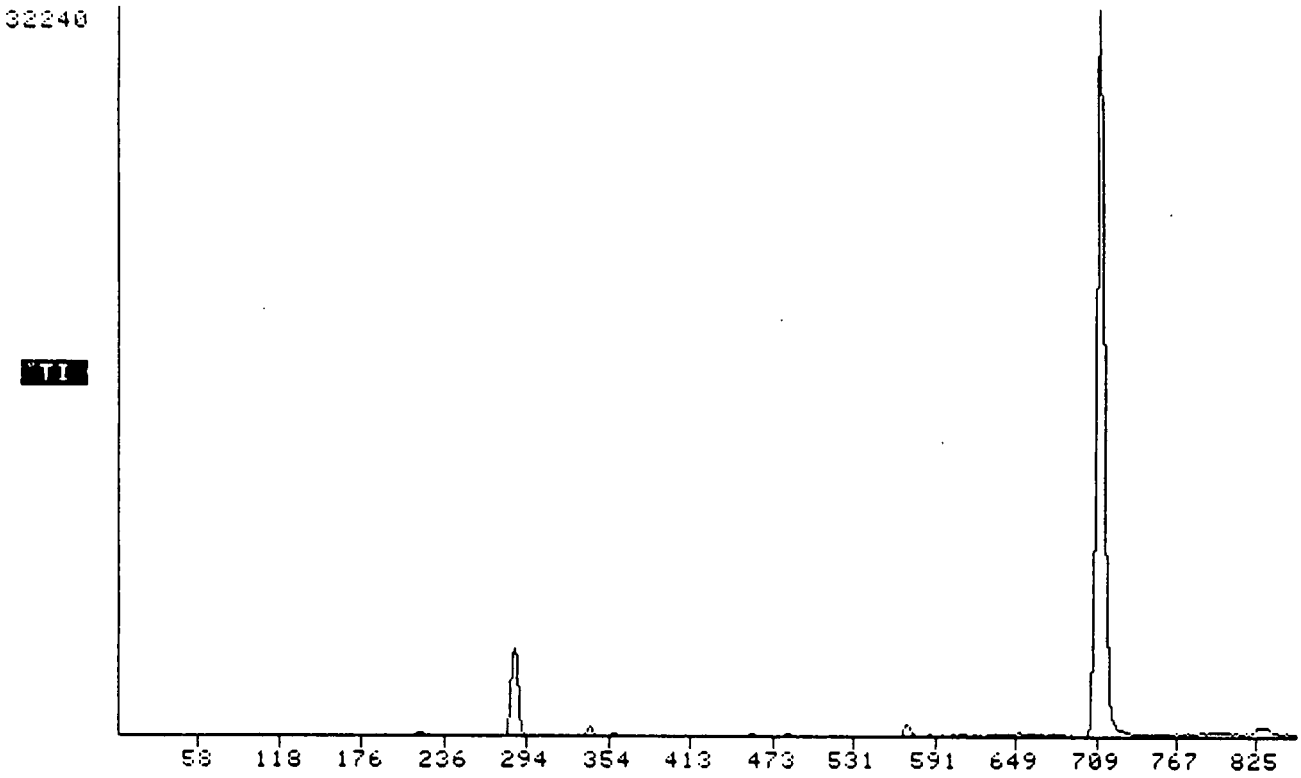

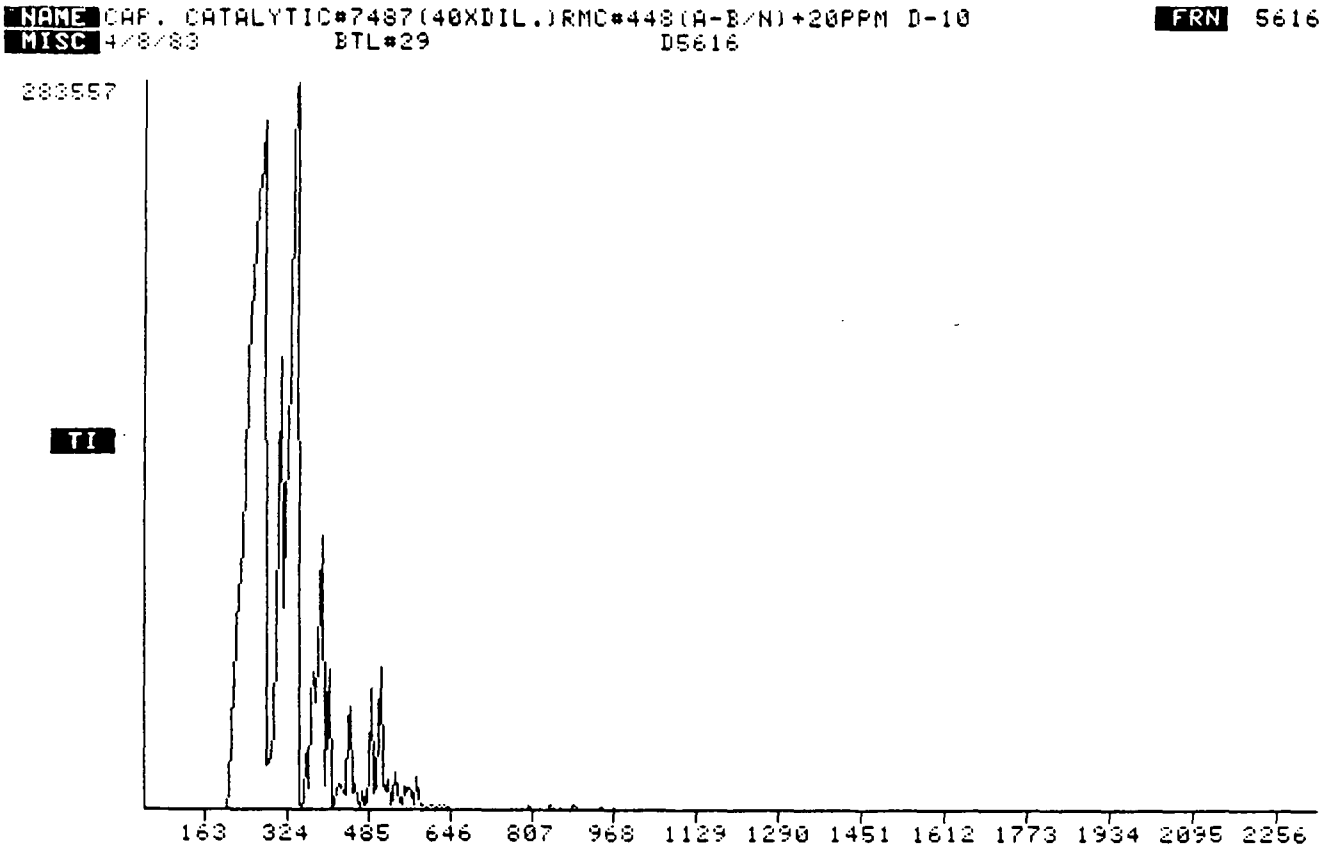
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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7488	DATE ANALYZED	4/8/83
RMC I.D.	449	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.5
2,4-dinitrophenol	<10.2
4-nitrophenol	<12.7
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: Richard S. Kobyra

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7488	DATE ANALYZED	4/8/83
RMC I.D.	449	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<1.9
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.4	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	17.4
nitrobenzene	<1.5	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.4
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<1.0
acenaphthene	<1.2	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<11.9
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<3.0

Approved By: Richard S. Kobza

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7488	DATE ANALYZED	3/30/83
RMC I.D.	119	ANALYZED BY	KFG

VOLATILES

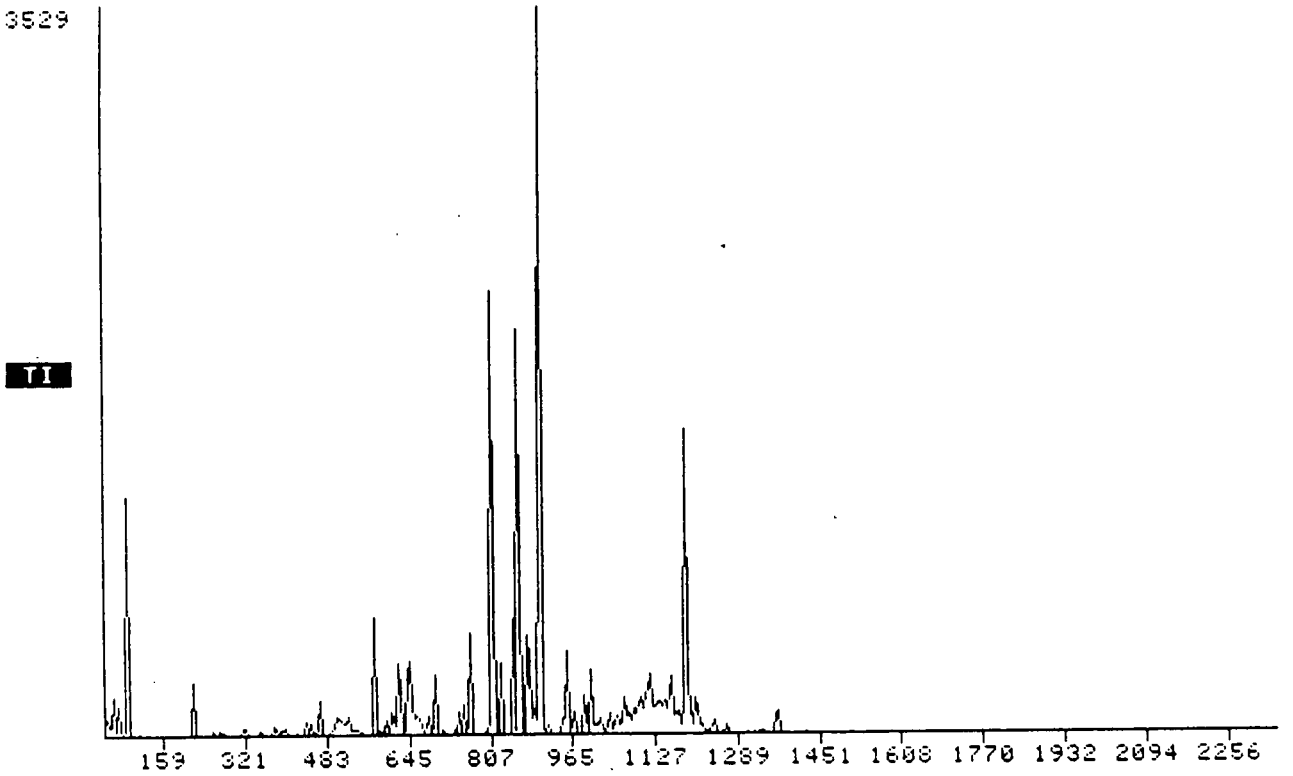
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.07
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.18
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	3.9	benzene	<0.04
acrolein	<70	dibromochloromethane	<0.09
acrylonitrile	<7	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.08	2-chloroethylvinyl ether	<1.5
1,1-dichloroethane	<0.09	bromoform	<0.18
trans-1,2-dichloroethene	<0.08	tetrachloroethene	<0.06
chloroform	<0.04	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.03
1,1,1-trichloroethane	<0.05	chlorobenzene	<0.04
carbon tetrachloride	<0.04	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Lodyga
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7488 RMC#449+20PPM D-10 FRN 5597
MISC 4/8/83 BTL#10 DS597



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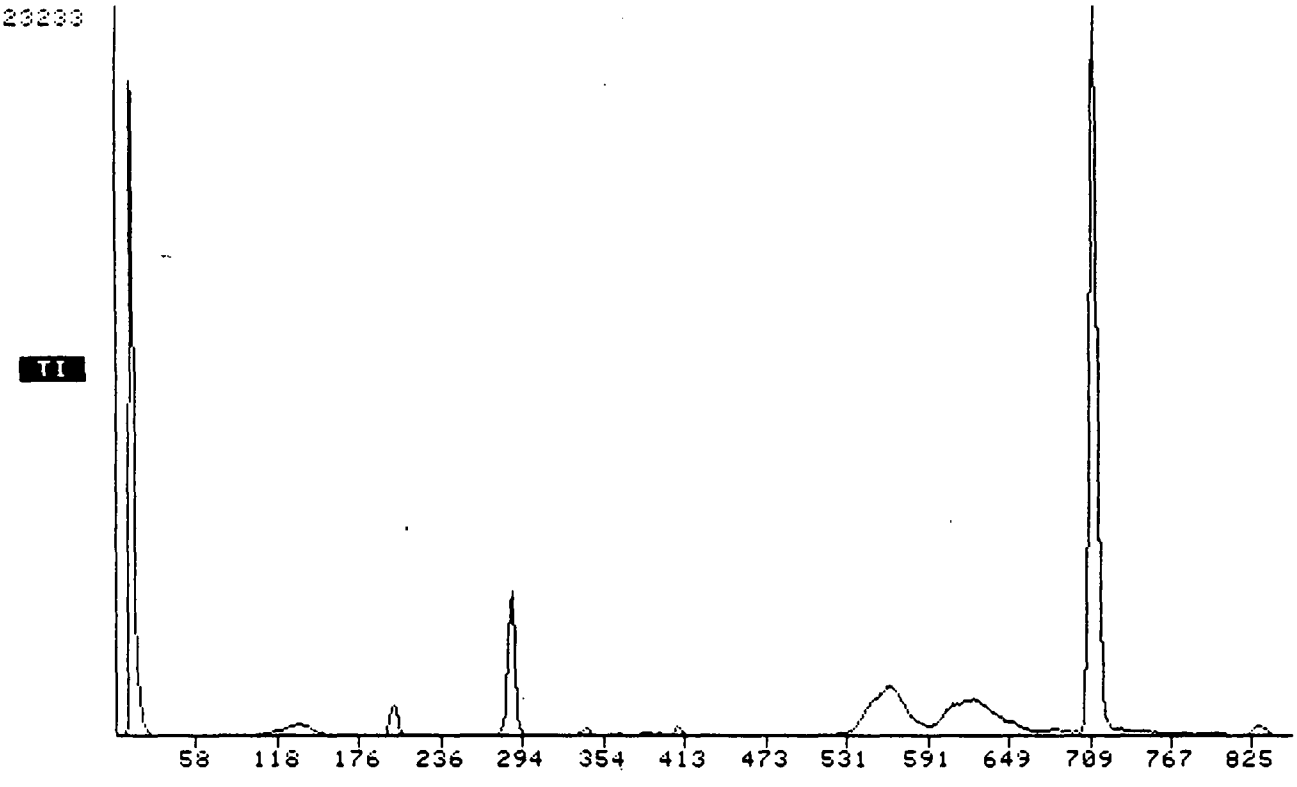
MISC 3/30/88



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7489	DATE ANALYZED	4/8/83
RMC I.D.	450	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.5
2,4-dinitrophenol	<10.2
4-nitrophenol	<12.6
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<7.9

Approved By: Richard S. Lodyga

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7489	DATE ANALYZED	4/8/83
RMC I.D.	450	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<1.9
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.4	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	16.5
nitrobenzene	<1.5	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.3
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<7.9
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	26.5
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<0.9
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.2
diethyl phthalate	<0.5	benz(g,h,i.)perylene	<11.9
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.1

Approved By: Richard S. Kalyn

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7489	DATE ANALYZED	3/30/83
RMC I.D.	450	ANALYZED BY	KFG

VOLATILES

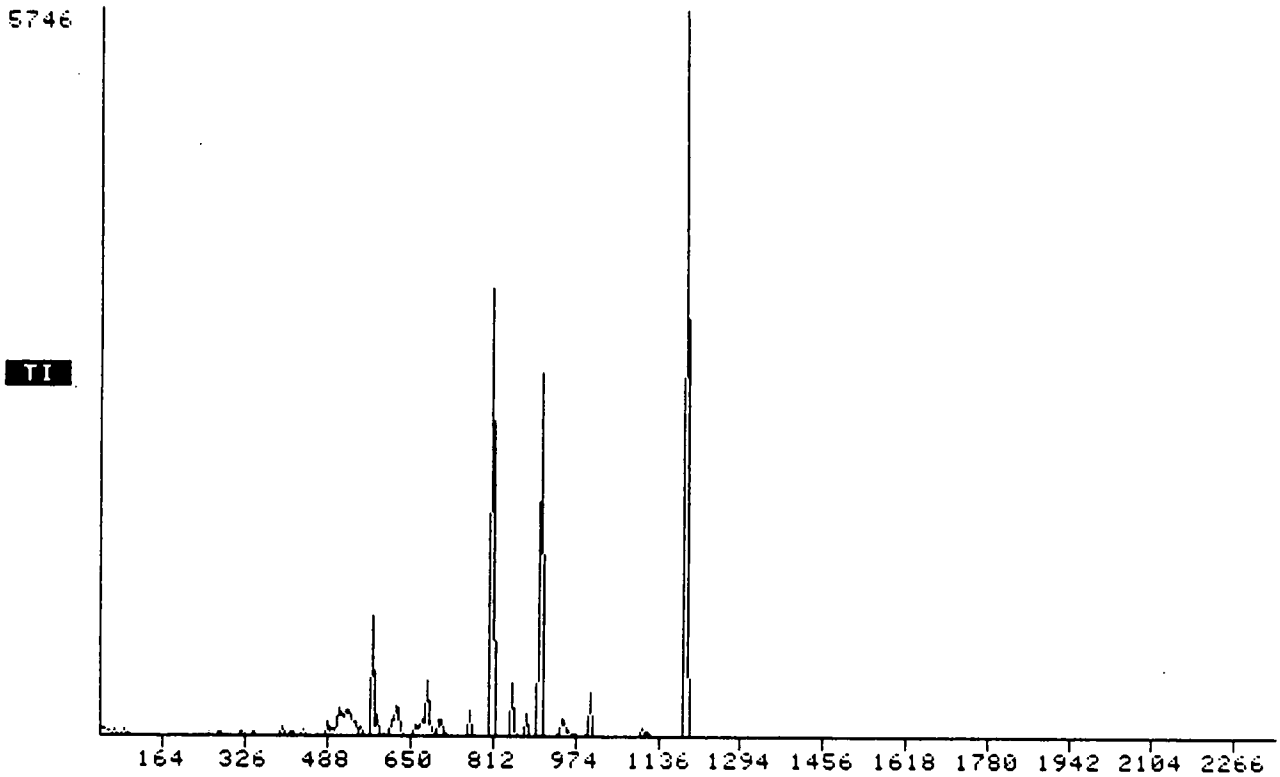
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.08
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.2
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	2.0	benzene	<0.05
acrolein	<80	dibromochloromethane	<0.10
acrylonitrile	<8	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.09	2-chloroethylvinyl ether	<1.6
1,1-dichloroethane	<0.10	bromoform	<0.2
trans-1,2-dichloroethene	<0.09	tetrachloroethene	<0.07
chloroform	1.8	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.03
1,1,1-trichloroethane	<0.05	chlorobenzene	<0.04
carbon tetrachloride	<0.04	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

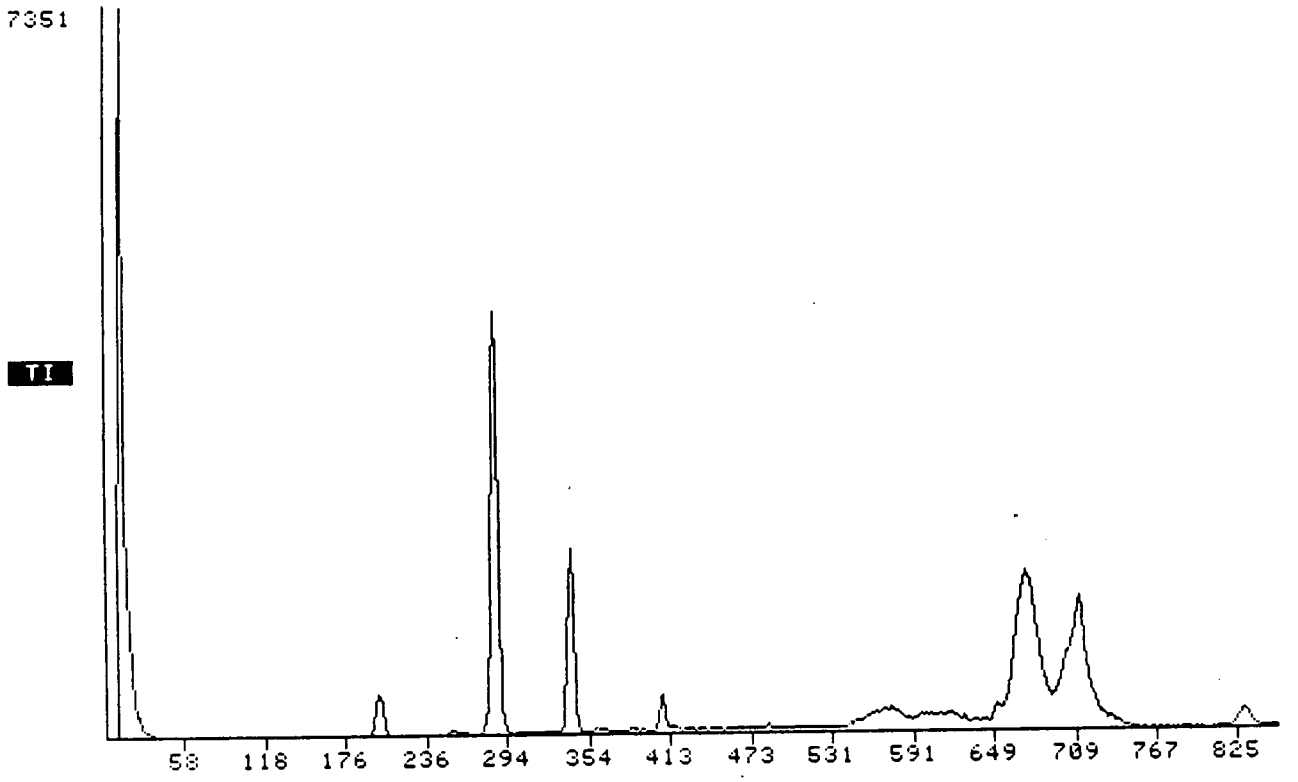
Richard S. Hodgson
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7489 RMC#450(A-B/N)+20PPM D-10 FRN 5598
MISC 4/8/83 BTL#11 D5598



NAME VOL. CATALYTIC#7489 RMC#450+10PPB I.S. EM1800 FRN 5533
MISC 3/30/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7490	DATE ANALYZED	4/8/83
RMC I.D.	451	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.3
4-nitrophenol	<12.7
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: Richard L. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7490	DATE ANALYZED	4/8/83
RMC I.D.	451	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	3.6
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.6
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.6	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.5	benz(g.h.i.)perylene	<12.0
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.5

Approved By: Richard S Rodgers

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7490	DATE ANALYZED	3/30/83
RMC I.D.	451	ANALYZED BY	KFG

VOLATILES

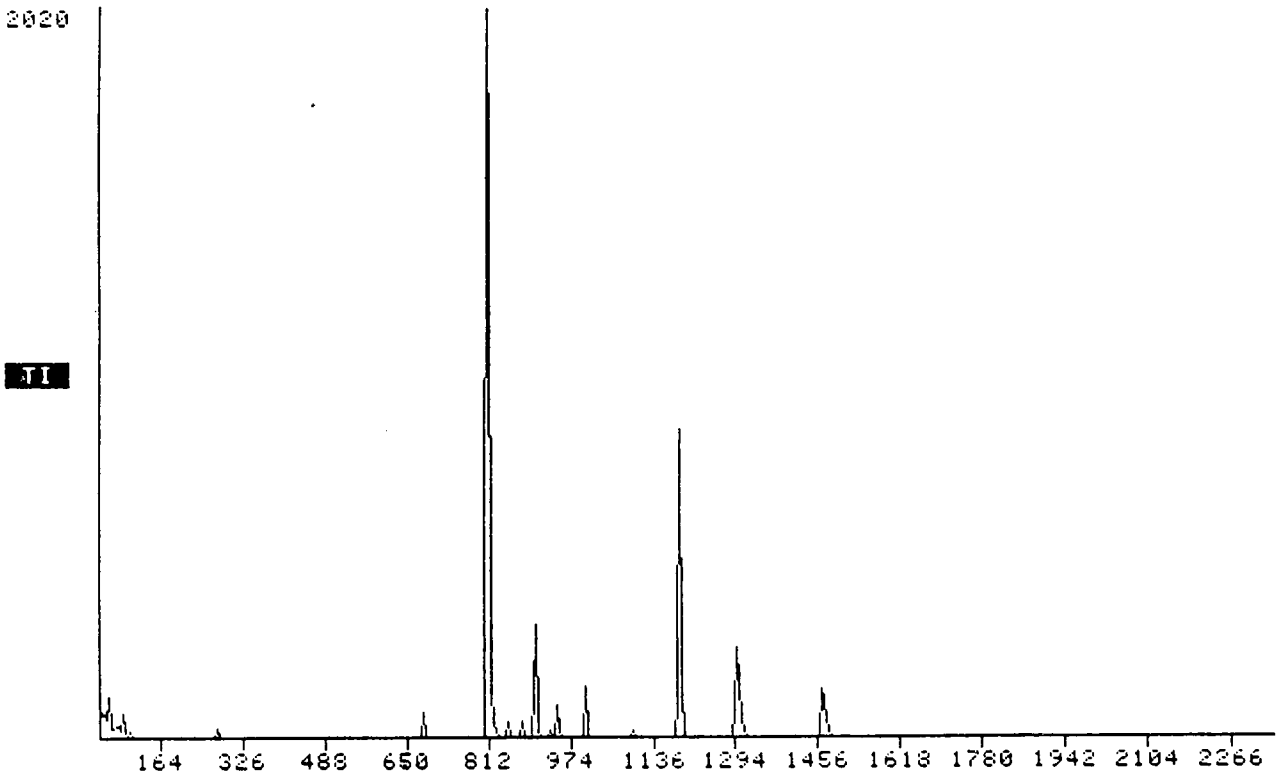
	µg/l		µg/l
chloromethane	<20	bromodichloromethane	<2.1
bromomethane	<5	1,2-dichloropropane	<5.7
vinyl chloride	<10	1,3-dichloropropene[1]	<5.0
chloroethane	<10	trichloroethene	<1.6
methylene chloride	<3.6	benzene	<1.3
acrolein	<2000	dibromochloromethane	<2.5
acrylonitrile	<194	1,1,2-trichloroethane	<5.7
1,1-dichloroethene	<2.3	2-chloroethylvinyl ether	<39
1,1-dichloroethane	<2.6	bromoform	<5.1
trans-1,2-dichloroethene	<2.3	tetrachloroethene	<1.8
chloroform	<1.1	1,1,2,2-tetrachloroethane	<9.4
1,2-dichloroethane	<6.7	toluene	<0.9
1,1,1-trichloroethane	<1.4	chlorobenzene	<1.1
carbon tetrachloride	<1.1	ethylbenzene	<0.8

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

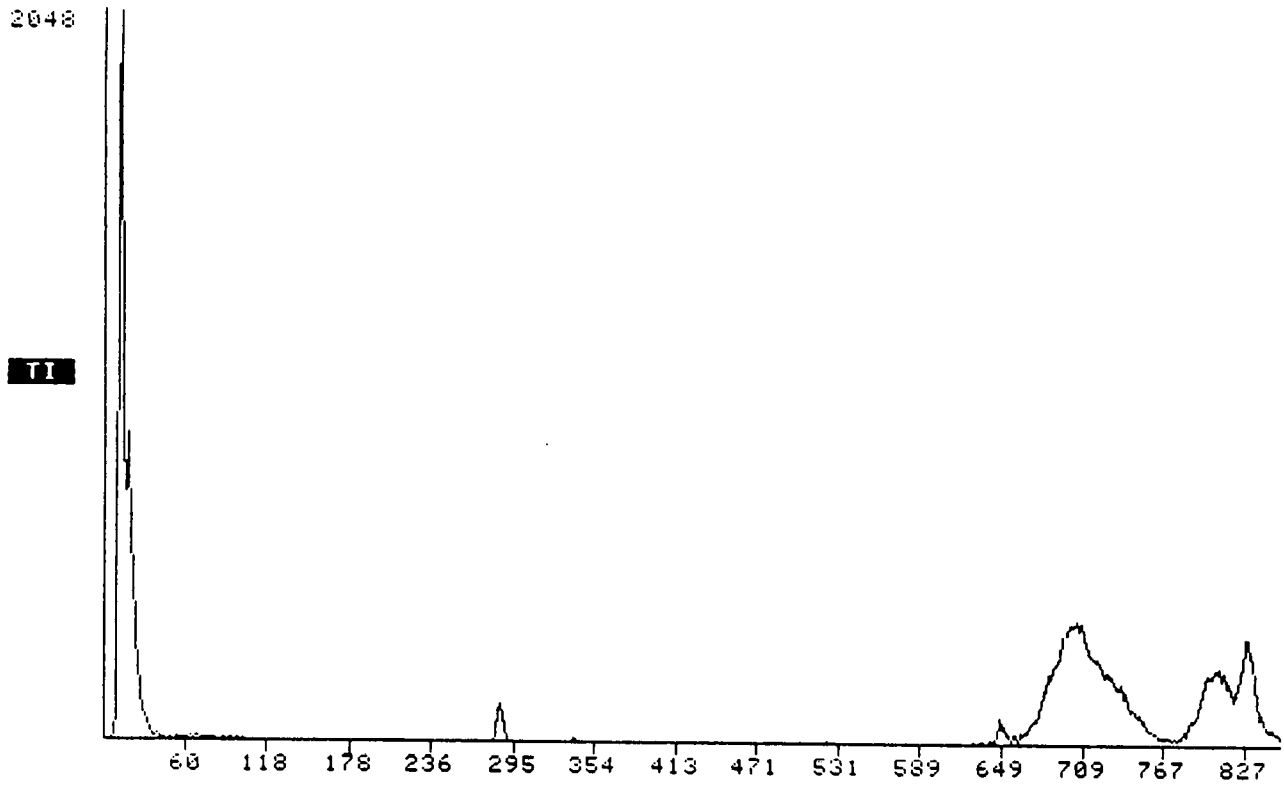
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

NAME CAP. CATALYTIC#7490 RMC#451(A-B/N)+20PPM D-10 FRN 5599
MISC 4/8/83 BTL#12 D5599



NAME VOL. CATLYTIC#7490 RMC#451+10PPB I.S. EM1800 FRN 5534
°MISC 3/30/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7491	DATE ANALYZED	4/8/83
RMC I.D.	452	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.4
4-nitrophenol	<12.8
2-methyl-4,6-dinitrophenol	<4.1
pentachlorophenol	<8.1

Approved By: Richard D. Kodgis

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7491	DATE ANALYZED	4/8/83
RMC I.D.	452	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.5	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	3.7
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.7
bis(2-chloroethoxy)methane	<1.0	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.8
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.6	3,3'-dichlorobenzidine	<8.1
hexachlorocyclopentadiene	<2.5	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	<1.0
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.2	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.2
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<12.1
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<4.0

Approved By: Richard L. Hedges

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7491	DATE ANALYZED	3/30/83
RMC I.D.	452	ANALYZED BY	KFG

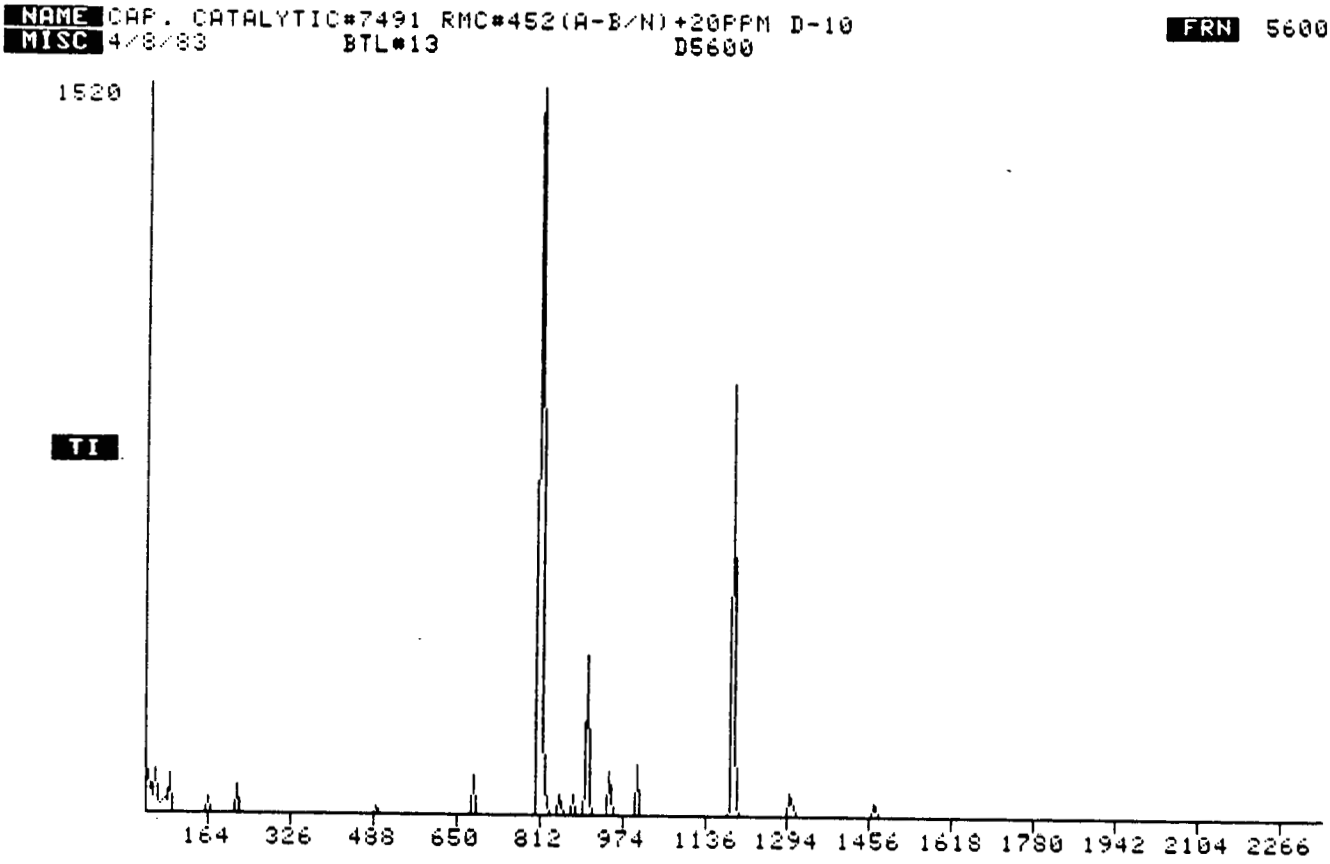
VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.08
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.3
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	6.9	benzene	<0.05
acrolein	<80	dibromochloromethane	<0.10
acrylonitrile	<8	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.09	2-chloroethylvinyl ether	<1.7
1,1-dichloroethane	<0.10	bromoform	<0.3
trans-1,2-dichloroethene	<0.09	tetrachloroethene	<0.07
chloroform	0.6	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.04
1,1,1-trichloroethane	<0.05	chlorobenzene	<0.04
carbon tetrachloride	<0.04	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464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MISC 4/8/83 BTL#13 D5600
FRN 5600
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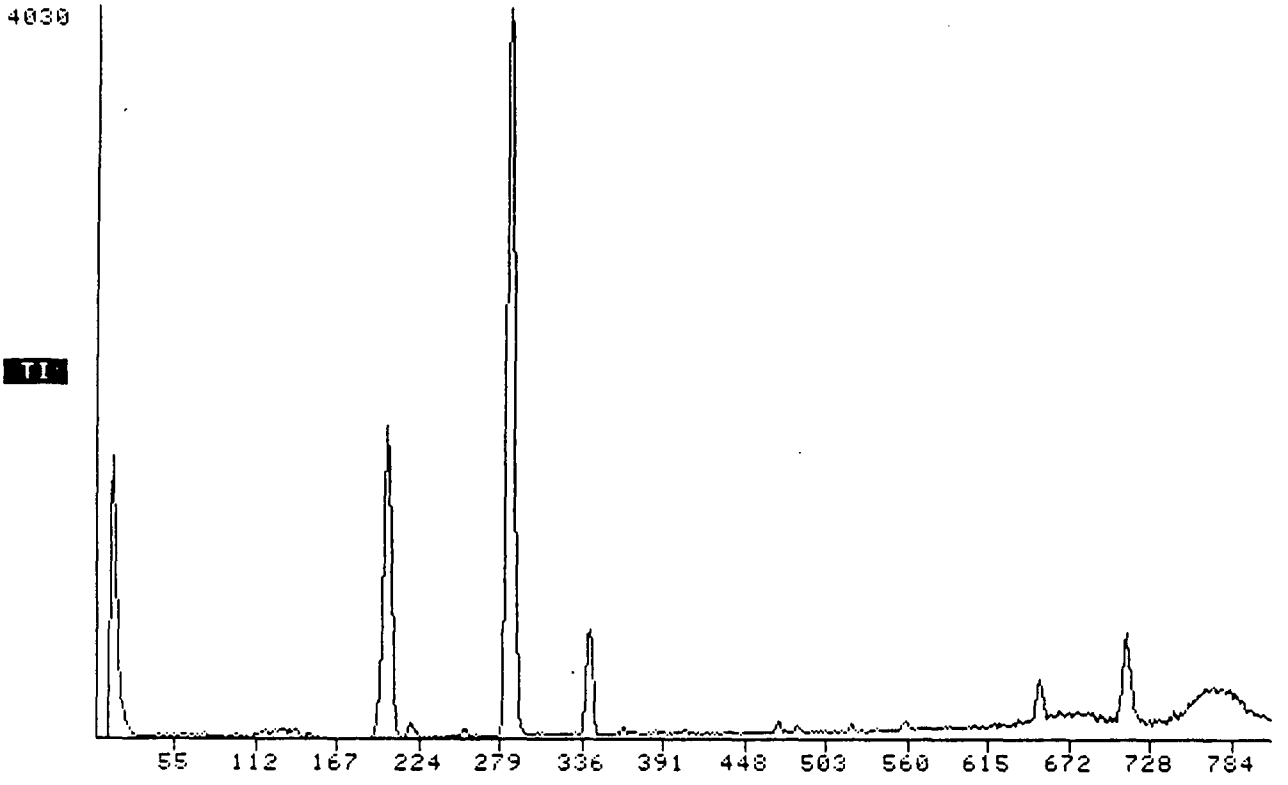
NAME VOL.CATALYTIC#7491+10PPB I.S. EM1800 FRN 5535
MISC 3/30/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7492	DATE ANALYZED	4/18/83
RMC I.D.	453	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.6
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.3
4-nitrophenol	<12.7
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: Richard S. Pedyna

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7492	DATE ANALYZED	4/8/83
RMC I.D.	453	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.4	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.0
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	15.4
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.5
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	1.5
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.7	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g,h,i.)perylene	<12.0
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<3.9

Approved By: Richard D. Rodgers

RMC Environmental Services Division
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7492	DATE ANALYZED	3/30/83
RMC I.D.	453	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.09
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.3
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	7.7	benzene	<0.05
acrolein	<90	dibromochloromethane	<0.11
acrylonitrile	<9	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.10	2-chloroethylvinyl ether	<1.7
1,1-dichloroethane	<0.11	bromoform	<0.3
trans-1,2-dichloroethene	<0.10	tetrachloroethene	<0.08
chloroform	0.8	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.04
1,1,1-trichloroethane	<0.06	chlorobenzene	<0.05
carbon tetrachloride	<0.05	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved. Values reported indicate the sum of both compounds.

Richard D. Kodgers
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
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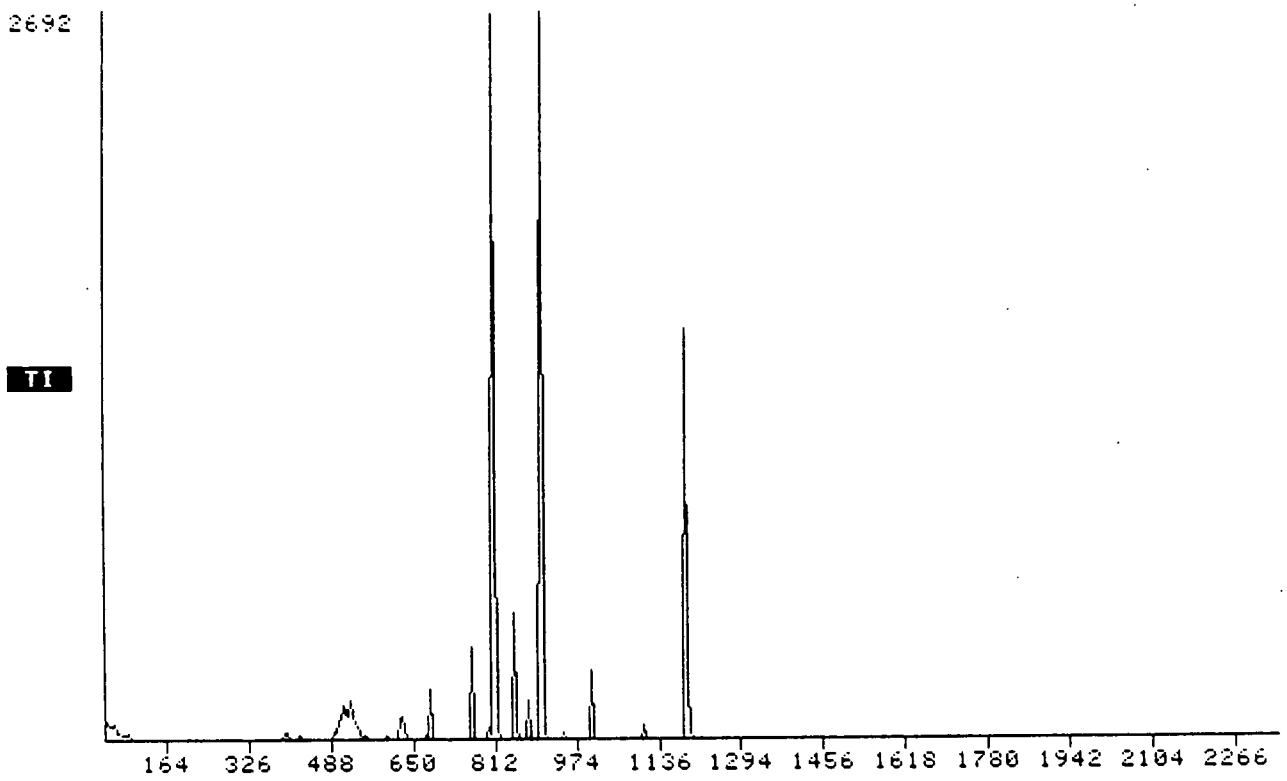
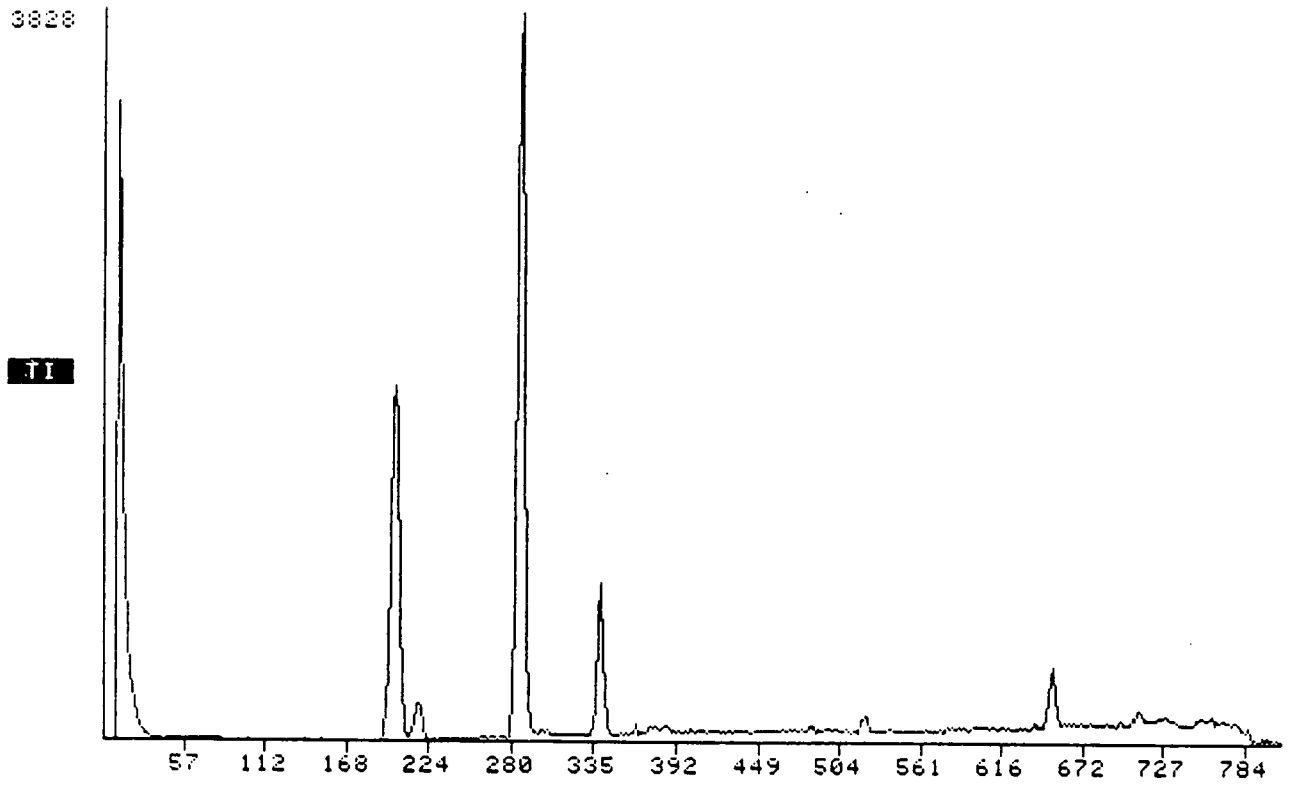
NAME CAP. CATALYTIC#7492 RMC#453(A/B/N)+20PPM D-10 FRN 5601
MISC 4/8/83 BTL#14 D5601



NAME VOL. CATALYTIC#7492 RMC#453+10PPB I.S. EM1800 FRN 5536
MISC 3/30/83



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7493	DATE ANALYZED	4/8/83
RMC I.D.	454	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	11.7
2-chlorophenol	<1.6
2-nitrophenol	<2.4
2,4-dimethylphenol	<1.6
2,4-dichlorophenol	<2.2
4-chloro-3-methylphenol	<1.7
2,4,6-trichlorophenol	<2.7
2,4-dinitrophenol	<10.7
4-nitrophenol	<13.2
2-methyl-4,6-dinitrophenol	<4.2
pentachlorophenol	<8.3

Approved By: Richard S. Hodgson

RMC Environmental Services Division
Environmental Services Division
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7493	DATE ANALYZED	4/8/83
RMC I.D.	454	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.6	4-chlorophenyl phenyl ether	<1.6
bis(2-chloroethyl)ether	<1.4	n-nitrosodiphenylamine	<1.3
1,3-dichlorobenzene	<1.5	1,2-diphenylhydrazine	<2.0
1,4-dichlorobenzene	<1.5	4-bromophenyl phenyl ether	<2.5
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.6	phenanthrene	<0.5
hexachloroethane	<1.9	anthracene	<0.6
n-nitrosodi-n-propylamine	<1.6	di-n-butyl phthalate	8.7
nitrobenzene	<1.6	fluoranthene	<0.5
isophorone	<0.6	benzidine	<22.5
bis(2-chloroethoxy)methane	<1.0	pyrene	<0.6
1,2,4-trichlorobenzene	<1.4	butyl benzyl phthalate	<0.8
naphthalene	<0.5	benz(a)anthracene	<2.2
hexachlorobutadiene	<2.7	3,3'-dichlorobenzidine	<8.3
hexachlorocyclopentadiene	<2.5	chrysene	<2.2
2-chloronaphthalene	<0.7	bis(2-ethylhexyl)phthalate	7.5
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.7	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.3	benzo(k)fluoranthene	<1.0
acenaphthene	<0.7	benzo(a)pyrene	<1.4
2,4-dinitrotoluene	<2.0	indeno(1,2,3-c,d)pyrene	<2.9
fluorene	<0.7	dibenz(a,h)anthracene	<5.5
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<12.5
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<2.3

Approved By: Richard D. Rodgers

RMC Environmental Services Division
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National Bureau of Standards Library Search of
Major Non-Priority Pollutant Peaks from the
Chromatogram of Catalytic Sample #7493

Peak Scan Number	Most Probable Compound Match	Total Abundance of Scan Number
542	p-(2-methylallyl)phenol)	1755

Approved By: Richard S. Hodges

Canberra/RMC
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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7493	DATE ANALYZED	3/30/83
RMC I.D.	454	ANALYZED BY	KFG

VOLATILES

	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.09
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.3
chloroethane	<1.0	trichloroethene	<0.07
methylene chloride	11.4	benzene	<0.05
acrolein	<90	dibromochloromethane	<0.11
acrylonitrile	<9	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.10	2-chloroethylvinyl ether	<1.8
1,1-dichloroethane	<0.11	bromoform	<0.3
trans-1,2-dichloroethene	<0.10	tetrachloroethene	<0.08
chloroform	<0.05	1,1,2,2-tetrachloroethane	<0.5
1,2-dichloroethane	<0.3	toluene	<0.04
1,1,1-trichloroethane	<0.06	chlorobenzene	<0.05
carbon tetrachloride	<0.05	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Lodzen
Approved By

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Fricks Lock Road, R.D. 1
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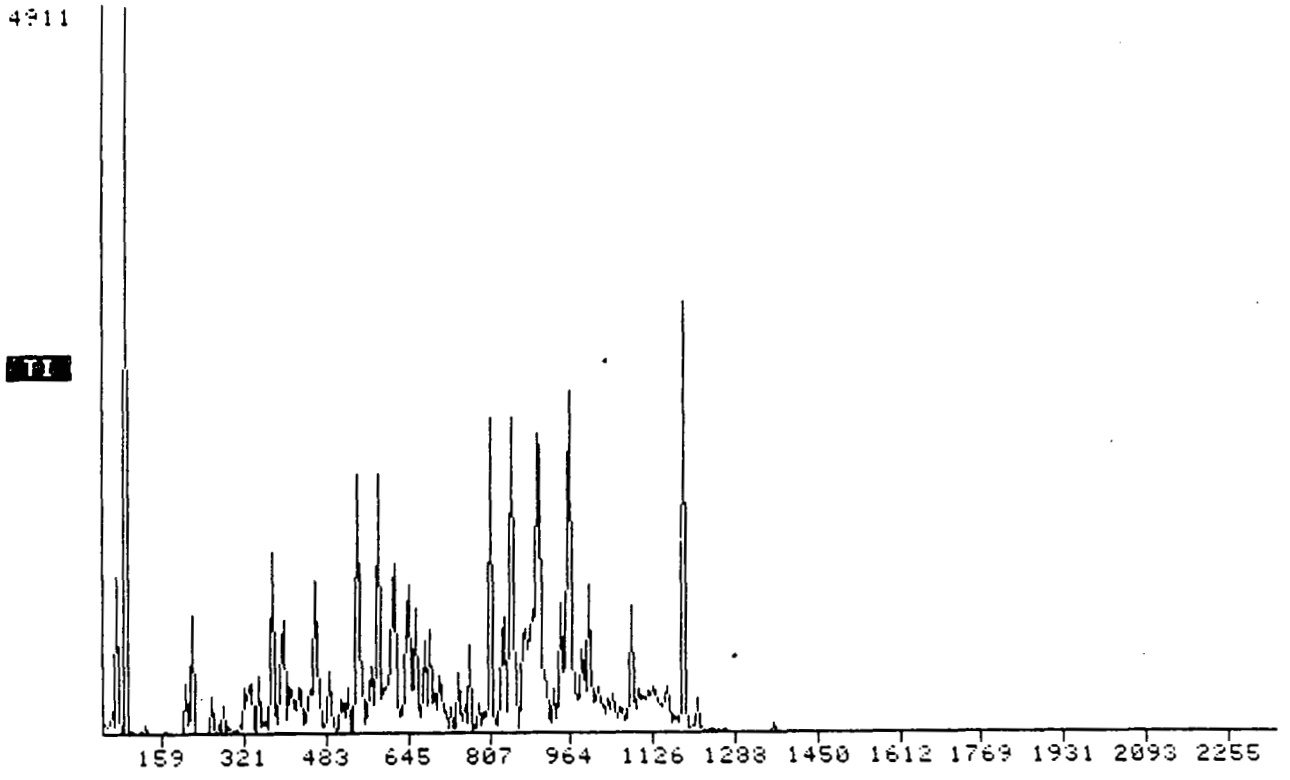
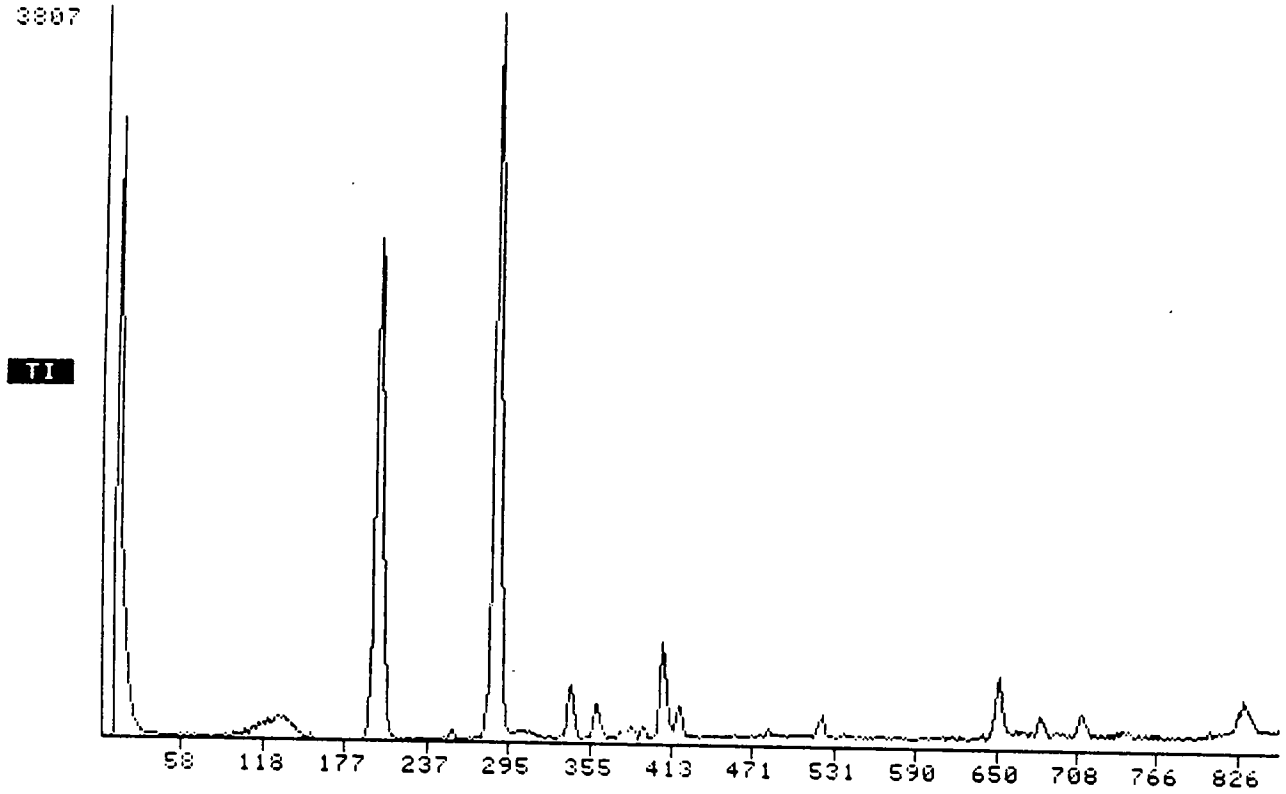
NAME CAP. CATALYTIC#7493 RMC#454(A-B/N)+20PPM D-10 FRN 5602
MISC 4/8/83 BTL#15 D5602



NAME VOL. CATALYTIC#7493 RMC#454+10PPB I.S. EM1800
MISC 3/30/83

FRN 5537



SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7494	DATE ANALYZED	4/8/83
RMC I.D.	455	ANALYZED BY	KFG

ACID COMPOUNDS

	µg/l
phenol	<1.5
2-chlorophenol	<1.6
2-nitrophenol	<2.3
2,4-dimethylphenol	<1.5
2,4-dichlorophenol	<2.1
4-chloro-3-methylphenol	<1.6
2,4,6-trichlorophenol	<2.6
2,4-dinitrophenol	<10.3
4-nitrophenol	<12.7
2-methyl-4,6-dinitrophenol	<4.0
pentachlorophenol	<8.0

Approved By: Richard S. Hodges

RMC Environmental Services Division
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SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7494	DATE ANALYZED	4/18/83
RMC I.D.	455	ANALYZED BY	KFG

BASE/NEUTRAL COMPOUNDS

	µg/l		µg/l
n-nitrosodimethylamine	<4.5	4-chlorophenyl phenyl ether	<1.5
bis(2-chloroethyl)ether	<1.3	n-nitrosodiphenylamine	<1.2
1,3-dichlorobenzene	<1.4	1,2-diphenylhydrazine	<1.9
1,4-dichlorobenzene	<1.4	4-bromophenyl phenyl ether	<2.4
1,2-dichlorobenzene	<1.3	hexachlorobenzene	<2.1
bis(2-chloroisopropyl)ether	<3.5	phenanthrene	<0.5
hexachloroethane	<1.8	anthracene	<0.5
n-nitrosodi-n-propylamine	<1.5	di-n-butyl phthalate	2.9
nitrobenzene	<1.5	fluoranthene	<0.5
isophorone	<0.6	benzidine	<21.6
bis(2-chloroethoxy)methane	<0.9	pyrene	<0.6
1,2,4-trichlorobenzene	<1.3	butyl benzyl phthalate	<0.7
naphthalene	<0.5	benz(a)anthracene	<2.1
hexachlorobutadiene	<2.5	3,3'-dichlorobenzidine	<8.0
hexachlorocyclopentadiene	<2.4	chrysene	<2.1
2-chloronaphthalene	<0.6	bis(2-ethylhexyl)phthalate	1.4
acenaphthylene	<0.5	di-n-octyl phthalate	<0.4
dimethyl phthalate	<0.6	benzo(b)fluoranthene	<1.7
2,6-dinitrotoluene	<2.1	benzo(k)fluoranthene	<0.9
acenaphthene	<0.7	benzo(a)pyrene	<1.3
2,4-dinitrotoluene	<1.9	indeno(1,2,3-c,d)pyrene	<2.8
fluorene	<0.6	dibenz(a,h)anthracene	<5.3
diethyl phthalate	<0.6	benz(g,h.i.)perylene	<11.9
		2,3,7,8-tetrachlorodibenzo-p-dioxin	<5.3

Approved By: Richard S. Kobyra

RMC Environmental Services Division
Environmental Chemistry Laboratory
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Pottstown, PA 19464

SUMMARY OF ORGANIC PRIORITY POLLUTANT ANALYSIS

CLIENT	Catalytic	DATE RECEIVED	3/18/83
CLIENT I.D.	7494	DATE ANALYZED	3/30/83
RMC I.D.	455	ANALYZED BY	KFG

VOLATILES

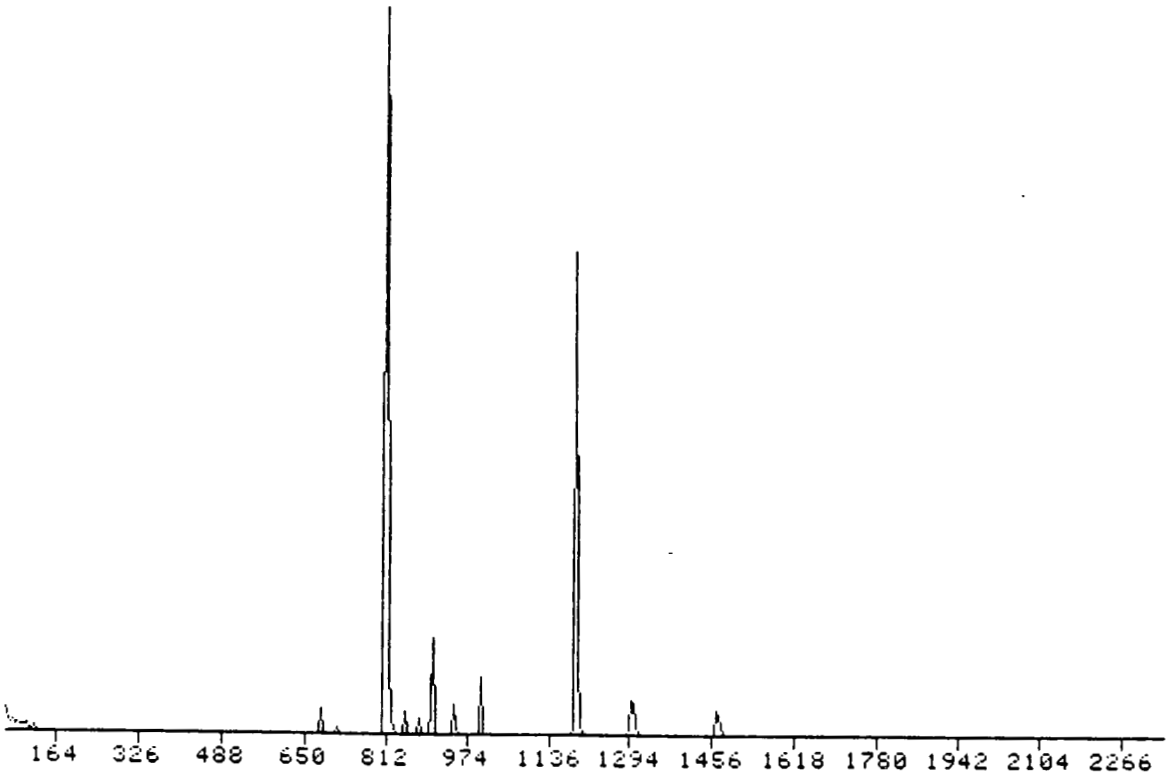
	µg/l		µg/l
chloromethane	<2.0	bromodichloromethane	<0.09
bromomethane	<0.5	1,2-dichloropropane	<0.3
vinyl chloride	<1.0	1,3-dichloropropene[1]	<0.3
chloroethane	<1.0	trichloroethene	<0.06
methylene chloride	9.1	benzene	<0.05
acrolein	<90	dibromochloromethane	<0.11
acrylonitrile	<8	1,1,2-trichloroethane	<0.3
1,1-dichloroethene	<0.10	2-chloroethylvinyl ether	<1.7
1,1-dichloroethane	<0.11	bromoform	<0.3
trans-1,2-dichloroethene	<0.10	tetrachloroethene	<0.08
chloroform	0.6	1,1,2,2-tetrachloroethane	<0.4
1,2-dichloroethane	<0.3	toluene	<0.04
1,1,1-trichloroethane	<0.06	chlorobenzene	<0.05
carbon tetrachloride	<0.05	ethylbenzene	<0.03

[1] 1,3-cis-dichloropropene and 1,3-trans-dichloropropene could not be resolved, values reported indicate the sum of both compounds.

Richard S. Radzan
Approved By

RMC Environmental Services
Environmental Chemistry Laboratory
Fricks Lock Road, R.D. 1
Pottstown, PA 19464

CATALYTIC#7494 RMC#455(A-B/N)+20PPM D-10 FRN 5603
3 BTL#16 D5603



NAME VOL. CATALYTIC#7494 RMC#455+10PPB I.S. EM1800 FRN 5538
MISC 3/30/88