RFP--4939

RF/ER - 94-0028.UN

POTASSIUM FERRATE TREATMENT OF RFETS' CONTAMINATED GROUNDWATER

Rocky Flats Environmental Technology Site

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

U.S Department of Energy
Rocky Flats Field Office
Golden, Colorado

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

January, 1995

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

SECTION		PAGE
1.0	INTRODUCTION	1-1
1.1	Site Description	1-4
1.1.1	Site Name and Description	1-4
1.1.2	History of Operations	1-5
1.2	Groundwater Description	1-5
1.3	Treatment Technology Description	1-6
1.4	Previous Studies of Ferrate Water Treatment of RFETS	1-10
2.0	CONCLUSIONS AND RECOMMENDATIONS	2-1
2.1	Conclusions	2-1
2.2	Recommendations	2-7
3.0	TREATABILITY STUDY APPROACH	3-1
3.1	Test Objectives and Rationale	3-1
3.2	Experimental Design	3-2
3.3	Experimental Equipment, Materials and Procedures	3-6
3.3.1	Experimental Equipment	3-6
3.3.2	Experimental Materials	3-6
3.3.3	Experimental Procedures	3-7
3.4	Sampling and Analysis	3-9
3.4.1	Waste from this Study	3-10
3.4.2	Experimental Treatment Process	3-10
3.5	Data Management	3-11
3.6	Deviation from the Work Plan	3-11
4.0	RESULTS AND DISCUSSION	4-1
4.1	Phase I Results and Discussion	4-1
4.1.1	Conclusions from Phase I Tests	4-9
4.2	Phase II results and Discussion	4-10
4.2.1	Determining the Test Conditions to be Used in Phase III Tests	4-16
4.2.2	Discussion of Phase II Results with Corrected Radionuclide Data	4-20
4.2.3	Conclusions from Phase II Tests	4-31
4.3	Phase III Results and Discussion	4-32
4.3.1	Preliminary Engineering Data	4-33
4.3.2	Phase III Potassium Ferrate Treatment Demonstration Results	4-35

4.3.3	Discussion of the Statistical Implications of Phase III Results	4-38
4.3.4	Conclusion from Phase III Tests	4-39
5.0	QUALITY ASSURANCE / QUALITY CONTROL (QA/QC)	5-1
5.1	Groundwater Sampling	5-1
5.2	Chemical Analysis	5-1
5.3	Computer Modeling	5-1
5.4	Instrumentation	5-3
5.5	Laboratory Techniques	5-3

FIGURES

4.1-1	Summary of Results of Phase I Tests Using ECHIP Program	4-4
4.1-2	Response Surface of Americium	4-6
4.1-3	Summary of the Responses from Modified Phase I Test Program	4-9
4.2.1-1	Combined Response Surface Using Uncorrected Radionuclide Data	4-18
4.2.2-1	Summary of Results of Phase II Tests Using ECHIP Program	4-20
4.2.2-2	Pareto Effect Graph of Americium	4-22
4.2.2-3	Response Surface of Americium	4-23
4.2.2-4	Pareto Effects Graph of Uranium	4-24
4.2.2-5	Pareto Effects Graph of Aluminum	4-25
4.2.2-6	Aluminum Response to Ferrate Treatment	4-26
4.2.2-7	Combined Response Surface of Corrected Phase II Results	4-27
4.3.1-1	General Flowsheet for Ferrate Treatment of RFETS Groundwater	4-36

TABLES

1.0-1	CWQCC Discharge Limits	1-2
1.0-2	Analytical Methods and Detection Limits Used in This Study	1-3
1.2-1	Approximate Volume of Groundwater from Various Monitoring Wells	1-6
1.2-2	Analysis of Untreated Water at Beginning of Each Phase of the Study	1-7
2.1-1	Results of potassium Ferrate Water Treatment and Comparison to the CWQCC Discharge Limits and the Analytical Detection Limits	2-2
2.1-2	Initial Groundwater and Phase III Treated Water Chemical Analysis Percent Removal	2-5
2.1-3	Effect of pH and Ferrate Addition Upon the Response of Americium	2-6
2.1-4	Effect of pH and Ferrate Addition Upon the Response of Uranium	2-6
2.1-5	Effect of pH and Ferrate Addition Upon the Response of Barium	2-7

2.1-6	Effect of Alum and Polymer Change on the Response of Some of the COCs at the Same pH and Ferrate Addition	2-8
3.2-1	Test Matrix Used for the First Phase of this Study	3-4
3.2-2	Phase II Test Matrix	3-5
4.1-1	Analytical Results for Phase I Ferrate Treatment Tests	4-2
4.1-2	Coefficients for Response of Americium	4-5
4.1-3	Coefficients for Response of Uranium	4-7
4.2-1	Phase II Test Matrix	4-13
4.2-2	Modified Phase II Test Matrix	4-14
4.2-3	Analytical Results for the Modified Phase II Ferrate Treatment Tests	4-15
4.2.1-1	Predicted Contaminant Concentrations at the Optimum Conditions Using Uncorrected Radionuclide Data	4-19
4.2.2-1	Predicted Contaminant Concentrations at the Optimum Treatment Conditions	4-28
4.2.2-2	Predicted Results at Phases III Treatment Conditions Using the Corrected Data Response Surface Model	4-30
4.3.2-1	Results of the Phase III Ferrate Treatment Tests at the Optimum Conditions	4-37
5.5-1	Material Balance Calculations	5-6

References

Appendices

Appendix A	Analytical Reports of Treated Water from Phase I Tests	A-1
Appendix B	Analytical Report of Treated Water From Phase II Tests	B-1
Appendix C	Analytical Report of Test Products From Phase III Tests	C-1
Appendix D	ECHIP Output of Phase I Results	D-1
Appendix E	ECHIP Output of Phase I Modified Test Plan	E-1
Appendix F	ECHIP Output of Phase II Modified Test Plan	F-1
Appendix G	Acronym List	G-1

1.0 INTRODUCTION

The potassium ferrate treatment study of Rocky Flats Environmental Technology Site (RFETS) groundwater was performed under the Sitewide Treatability Studies Program (STSP). This study was undertaken to determine the effectiveness of potassium ferrate in a water treatment system to remove the contaminants of concern (COCs) from groundwater at the RFETS. Potassium ferrate is a simple salt where the iron is in the plus six valence state. It is the iron at the plus six valence state (Fe^{+6}) that makes it an unique water treatment chemical, especially in waters where the pH is greater than seven. In basic solutions where the solubility of the oxides/hydroxides of many of the COCs is low, solids are formed as the pH is raised. By using ferrate these solids are agglomerated so they can be effectively removed by sedimentation in conventional water treatment equipment.

The objective of this study was to determine the quality of water after treatment with potassium ferrate and to determine if the Colorado Water Quality Control Commission (CWQCC) discharge limits for the COCs listed in Table 1.0-1 could be met (1). Radionuclides in the groundwater were of special concern.

Laboratory work was performed by personnel from the Environmental Technology and Environmental Engineering Technology group of Rocky Flats Plant under the supervision and direction of ACTA Resources, Inc. All potassium ferrate test work was performed in Laboratory 264, Building 881 in accordance with the guide lines of the treatability work plan (2).

Chemical analysis of the untreated and treated water samples generated during this study were done by Accu-Labs Research, Inc. using EPA methods listed in Table 1.0-2.

Table 1.0-1 CWQCC Discharge Limits

Analytes	Discharge Limits
Radionuclides, pCi/l	
Gross alpha (a)	7-11
Gross beta (b)	5-19
Am 241	0.05
Pu 239,240	0.05
U total	5-10
Target Metals, mg/l	
Aluminum	0.087
Antimony	0.024
Barium	1.0
Beryllium	0.004
Cadmium	0.0015
Chromium	0.05
Cobalt	0.05
Iron	0.3
Lead	0.028
Manganese	0.56
Mercury	0.00001
Nickel	0.125
Selenium	0.01
Silver	0.00059
Vanadium	0.1
Zinc	0.35

Table 1.0-2 Analytical Methods and Detection Limits Used in This Study

Analytes	Analytical Method	Detection Limit	Units
Radionuclides			
Gross alpha/beta	EPA 900.0	3-4	pCi/l
Am 241	ALR 3804224	0.00	pCi/l
Pu 238,239,240	ALR 3804223	0.01	pCi/l
U, total	EPA 908.1	0.0001	mg/l
Target Metals			
Aluminum	EPA 200.7	0.05	mg/l
Antimony	EPA 204.7	0.005	mg/l
Arsenic	EPA 206.2	0.005	mg/l
Barium	EPA 200.7	0.05	mg/l
Beryllium	EPA 200.7	0.005	mg/l
Cadmium	EPA 213.2	0.0005	mg/l
Chromium	EPA 200.7	0.005	mg/l
Cobalt	EPA 200.7	0.005	mg/l
Copper	EPA 200.7	0.005	mg/l
Iron	EPA 200.7	0.01	mg/l
Lead	EPA 239.2	0.005	mg/l
Manganese	EPA 200.7	0.005	mg/l
Mercury	EPA 245.1	0.0001	mg/l
Molybdenum	EPA 200.7	0.01	mg/l
Nickel	EPA 200.7	0.01	mg/l
Selenium	EPA 270.2	0.005	mg/l
Silver	EPA 272.2	0.0002	mg/l
Thallium	EPA 200.7	0.1	mg/l
Vanadium	EPA 200.7	0.005	mg/l
Zinc	EPA 200.7	0.005	mg/l

Analytical results for uranium were reported as milligrams per liter (mg/l) even though the CWQCC discharge limits are in picoCuries per liter (pCi/l). To convert from mg/l to pCi/l the conversion factor is:

$$pCi/l = 0.03 \text{ (mg/l U, total)}.$$

Design of the test matrix and the analysis of the resulting data was done using a computer program called ECHIP (ECHIP, Inc. 724 Yorklyn Road, Hockessin, DE 19707-8703). This statistical based program was used for several reasons. First, the examination and interpretation of the large number of measured responses, 19 elements, 3 of which are radionuclides, required a computer program to optimize the process conditions to obtain the maximum removal of all the COCs. Second, the low concentration of the contaminants of concern created significant error associated with the analysis and it was desired to minimize the impact of this when the data was evaluated. Third, in Phase I there were four primary variables; pH, ferrate, alum and polymer concentrations. It was necessary to examine and determine the individual and interactive effects on each of the COCs.

1.1 SITE DESCRIPTION

1.1.1 Site Name And Description

RFETS, a 6550 acre industrial reservation is located in northern Jefferson County, Colorado. The RFETS is situated on a recent Alluvium which overlays the Arapahoe sandstone formation, the two major geological stratigraphic units. The Alluvium consists of weathered claystone (Kacl) and the Arapahoe formation (Kass), being the bedrock in the area, consists of weathered and unweathered sandstone. Based on a hydrogeological survey the Alluvium is more permeable to groundwater than the Arapahoe unit (3, 4).

Monitoring wells within the RFETS reservation are all drilled through the Alluvian and penetrated the Arapahoe formation 10 to 20 feet. The contaminated groundwater used in this study were drawn from these monitoring wells.

1.1.2 History Of Operations

From the mid-1950s to the present, RFETS has been a government-owned [Department of Energy (DOE)] contractor-operated facility which manufactured weapon components primarily from plutonium, uranium, beryllium and stainless steels. RFETS also reprocessed certain plutonium residues for the recovery of weapons grade plutonium. Metals reprocessing, using a variety of chemicals and solvents, generated wastes which were discharged to holding facilities. During the 1970s five Solar Evaporation Ponds (SEPs) were constructed (i.e. 207A, 207B North, 207 Center, 207 South, also 207 c). These ponds received and stored liquid wastes from various buildings on the RFETS.

The operation of the RFETS caused some inadvertent contamination of the groundwater on the site through a path yet to be determined.

1.2 GROUND WATER DESCRIPTION

Water for this study, which had been collected prior to the start of the program, came from four monitoring wells on the RFETS. The water had been archived in one gallon polyethylene bottles which were enclosed in plastic bags. In order to have an adequate sample volume for the entire three phases of the study, multiple gallon samples from each well were selected and mixed in a 30 gallon polyethylene tank. The samples were selected to produce a lage enough composite

sample that would have concentrations of the COCs as close as possible to those set forth in the work plan. The approximate volumes from each well are shown in Table 1.2-1.

Table 1.2-1 Approximate Volume of Ground Water from various Monitoring Wells

Monitoring Well Number	Approximate Volume Used Gallons
3086	4.000
09091	7.000
B206789	2.000
7287	6.500

The composite sample was analyzed during each phase of the study to make sure there were no changes in the concentration of the COCs due to such factors as organic growth in the storage container. Analysis of the samples, prior to treatment, are presented in Table Number 1.2-2 with the average concentration and statistical data.

1.3 TREATMENT TECHNOLOGY DESCRIPTION

Removal of metallic or other contaminants from water by normal water treatment techniques requires that the contaminants form a solid phase of sufficient particle size so that they settle out of the water. To accomplish this in water treatment systems, reagents are added to the water and/or the pH is adjusted to precipitate the contaminants. Various treatment chemicals can also be added to assist the agglomeration process to achieve the desired removal results. Additional treatment chemicals can be added to increase the solids concentration of the solution which is sometimes necessary to sweep the suspended solids from solution. In water treatment process that depend upon sedimentation, it is usually necessary to have some minimum solid content for it to be effective. In some processes, filtration can be used in place of settling for water

Table 1.2-2 Analysis of Untreated Water at Beginning of Each Phase of the Study

Element	Units	1st Phase	2nd Phase	3rd Phase	Average	S.D.
Silver	mg/l	0.029	0.028	0.030	0.029	0.001
Aluminum	mg/l	18.	20.	20.	19.33	1.155
Barium	mg/l	0.23	0.23	0.28	0.247	0.029
Beryllium	mg/l	<0.005	<0.005	<0.005	<0.005	**
Cadmium	mg/l	<0.005	<0.005	<0.005	<0.005	**
Cobalt	mg/l	0.007	0.006	~~<0.01~~	0.0065	0.0007
Chromium	mg/l	0.020	0.025	0.026	0.0237	0.0032
Copper	mg/l	0.029	0.023	0.030	0.0273	0.0038
Iron	mg/l	19.	19.	22.	20.0	1.73
Manganese	mg/l	0.24	0.24	0.29	0.257	0.0289
Molybdenum	mg/l	<0.01	<0.01	~~0.01~~	<0.01	**
Nickel	mg/l	~~0.02~~	<0.05	<0.05	<0.05	**
Antimony	mg/l	<0.05	<0.05	<0.05	<0.05	**
Selenium	mg/l	0.044	0.040	~~0.021~~	0.042	0.0028
Thallium	mg/l	~~<0.1~~	<0.5	<0.5	<0.5	**
Vanadium	mg/l	0.042	0.043	0.045	0.0433	0.0015
Zinc	mg/l	0.086	0.081	0.093	0.0867	0.0060
Arsenic	mg/l	~~0.016~~	0.010	0.010	0.010	0.0000
Mercury	mg/l	<0.0001	<0.0001	<0.0001	<0.0001	**
Lead	mg/l	0.012	0.013	0.012	0.0123	0.0006
Radionuclides						
Am 241	pCi/l	0.86	1.1	0.81	0.92	0.155
Pu 239/240	pCi/l	7.5	6.7	9.1	7.8	1.22
Uranium	mg/l	0.044	0.036	0.040	0.040	0.004

** insufficient data to calculate SD (standard deviation)

~~0.0XX~~ these data not used in the calculation of the SD

polishing. However, filtration is an expensive unit operation and was not investigated as part of this study.

Because of its' unique chemistry potassium ferrate has been studied for its use in water treatment by many investigators (5,6,7). The iron in potassium ferrate is in the plus 6 valence state. Historically, iron based chemicals used in water treatment have been in the plus two or plus three valence state. It appears, that this difference in valence state is the reason that ferrate produces different results than normal iron treatment chemicals used in water treatment. It appears that ferrate is effective in coagulating the fine hydroxide/oxides precipitated in basic waters, especially radionuclides. Several reasons for this enhanced removal have been suggested. First, the ferrate slowly decomposes in basic solutions, allowing greater interaction with the suspended solids. This phenomena is different when compared to the almost immediate formation of iron (III) hydroxide when iron (III) sulfate is added to basic solution. Second, the decomposition of the potassium ferrate produces positively charged iron oxide/hydroxide that seem to be attracted to the other solids which are negatively charged in basic water. This interaction is more effective than with other iron water treatment chemicals because those chemicals do not yield significant amounts of positively charged products when added to basic solutions. Third, there is the potential for the formation of insoluble heavy metal ferrate compounds that are also removed from solution by settling. Whatever the actual mechanism, it is believed the use of potassium ferrate, in addition with other common water treatment chemicals, it may be possible to clean the RFETS groundwater to lower concentrations than conventional water treatment methods. Implementation of this simple treatment process might meet the CWQCC water discharge limits for the COCs.

The water treatment process that was studied is similar to a conventional water treatment process, except for two additional steps. The two additional steps are the introduction and degradation of the potassium ferrate chemical. The general process steps and the desired effects are as follow:

1. Adjust pH: This initial step is needed to produce insoluble metal hydroxides (solids) which will be removed from the water in the subsequent steps. As the pH of the contaminated solution rises, the COCs become more insoluble.

2. Add potassium ferrate: This step requires time to allow ferrate to proceed through several decomposition steps which coagulate the metal hydroxide solids, forming larger particles. Decomposition of ferrate enhances the agglomeration of the suspended solids which promotes more efficient solids removal during the settling step.

3. Reduce the remaining ferrate: Ferrate decomposes at a slow rate in solutions with a pH greater than 10. Therefore, it is necessary to eliminate the excess with a chemical reducing agent. This is necessary because any ferrate remaining in the solution prevents the removal of some of the COCs. In this study, the reductant used was sodium thiosulfate. The reaction product in this case will be potassium sulfate, an unregulated water impurity.

4. Add alum: Alum (aluminum sulfate) when added to the wastewater forms aluminum hydroxide floc which is very voluminous. This voluminous floc, formed by the addition of a small amount of alum, disperses throughout the solution, increasing the possibility that all of the suspended particles will be bridged with the aluminum hydroxide, thereby creating larger particles.

5. Add an organic polymer: Since aluminum hydroxide does not settle well because it is light, due to the waters of hydration, an organic polymer is added to make the flocs heavier so settling occurs faster.

During the entire laboratory test the pH was monitored and adjusted to the desired value with either potassium hydroxide or sulfuric acid. In plant operations, pH adjustment will not be a problem since only one control point will be monitored, that is the effluents. The addition of caustic will be only at the beginning of the process based upon the effluent pH.

1.4 PREVIOUS STUDIES OF FERRATE TREATMENT AT RFETS

One previous study of potassium ferrate treatment of wastewater has been conducted on the RFETS site (8). In this study, surrogates of radionuclide contaminants were added to water to simulate the wastewater that would be produced when the plutonium processing plant would be in operation. Treatment of this wastewater with TRU/Clear™ (potassium ferrate based treatment product) decreased the gross alpha radioactivity from 3.0×10^6 to 6000 pCi/l or a reduction of 99.8 percent. The results were below the desired water radioactivity goal of 12,500 pCi/l. In addition, the weight of waste-solids produced was six to seven times lower than that produced using the reagent iron (III) sulfate. This previous study, using TRU/Clear™ as an additive demonstrated that the plant would meet the established discharge limits and do so with a significant reduction of the amount of radioactive sludge produced.

2.0 CONCLUSIONS AND RECOMMENDATIONS

Potassium ferrate treatment of RFETS' contaminated groundwater was conducted over several months in the fall of 1994 using a mutiphased program. In this program there were four variables to be examined for their effects upon 19 COCs in the contaminated groundwater. Therefore, experimental design techniques were used to obtain enough information to reach definitive and unambiguous conclusions. Because of the way the experiments were designed it was possible to mathematically analyze the data generated to produce response surfaces that could be used as a model to predict results under different treatment conditions. The Phase I screening tests produced data that enabled the model to predict results of Phase II testing and was used to establish the test design in this phase of the work. Phase III was a demonstration of the technology at the optimum treatment conditions. A software package called ECHIP, which is based upon a large body of literature, was used to aid in the experimental design, statistically analyze the results and develop the mathematical models.

2.1 CONCLUSIONS

The first and major conclusion is that potassium ferrate treatment will reduce the concentrations of the COCs to very low levels. Table 2.1-1 contains the Phase III treated water analysis (average of four tests), the analytical detection limits and the CWQCC discharge limits. Table 2.1-1 shows that 11 of the COCs, including the radionuclides, were reduced to concentration which meet or exceeds the CWQCC discharge limits and there is a 99 % assurance that these results can always be achieved. The analytical detection limit was above the CWQCC discharge limits for seven of the COCs. Though the concentration of these COCs were below the analytical detection limits in the treated water, it is uncertain if they meet the discharge limits

Table 2.1-1 Results of Potassium Ferrate Water Treatment and Comparison to the CWQCC Discharge Limits and the Analytical Detection Limits

Element	Chemical Analysis of Treated Water from Phase III Tests	Analytical Detection Limits	CWQCC Discharge Limits	Treated Water Meets the CWQCC Limits
Radionuclides	pCi/l	pCi/l	pCi/l	
Americium 241	0.00	0.00	0.05	Yes
Plutonium 239/240	0.0325	0.00	0.05	Yes
Uranium, total	0.053	0.003	5-10	Yes
Other COCs		ICP Method		
	mg/l	mg/l	mg/l	
Silver	<0.005	0.005	0.00059	?
Aluminum	<0.1	0.1	0.087	?
Barium	<0.05	0.05	0.024	?
Beryllium	<0.005	0.005	0.004	?
Cadmium	<0.005	0.005	0.0015	?
Cobalt	<0.01	0.01	0.05	Yes
Chromium	<0.005	0.005	0.05	Yes
Copper	<0.005	0.005	No limit available	-
Iron	0.02	0.005	0.3	Yes
Manganese	<0.005	0.005	0.56	Yes
Molybdenum	<0.01	0.01	No limit available	-
Nickel	<0.05	0.05	0.125	Yes
Thallium	<0.5	0.5	No limit available	-
Vanadium	<0.005	0.005	0.1	Yes
Zinc	<0.005	0.005	0.35	Yes
		GFAA Method		
Arsenic	<0.005	0.005	No limit available	-
Antimony	<0.05	0.05	0.024	?
Mercury	<0.0001	0.0001	0.00001	?
Lead	<0.005	0.005	0.028	Yes
Selenium	0.0562	0.005	0.005	No

because these discharge limits are below the detection limits. However, the results of Phase III tests suggest that these elements meet the discharge limits based upon statistical analysis of the other elements. Selenium is the only element, which for certain, failed to meet the discharge limits using this technology.

The overall conclusion is that water treatment with potassium ferrate is a very effective technology, especially for the removal of the radionuclides. In fact, the statistical analysis of the Phase III results show that there is a 99 % probability that the CWQCC discharge limits for the radionuclides will be met when this technology is applied to the RFETS groundwater. The statistical analysis of the other Phase III results indicate, that those element that have met the CWQCC discharge limits in this phase of work, have a 95 % or better probability of meeting the CWQCC discharge limits if this technology is used at RFETS. This high level of confidence in the results from this study shows that the process is a very positive method for the removal of many inorganic elements from contaminated waters.

An equally important conclusion is that the technology is tolerant of minor process deviations. For example, predicted optimum treatment condition from preliminary analytical results of Phase II treated water was at a pH of 10.35 and addition of 10.5 mg/l 45 % potassium ferrate. These conditions were used to conduct Phase III tests, even though these conditions were not the optimum when the final Phase II results were evaluated, but still the Phase III test results were exceptional. Also, at the conclusion of the tests in Phase III the measured pH of the treated water was 9.8, but still produced better results than were expected from the preliminary data. The optimum conditions from the analysis of the final and corrected results of the Phase II were pH 10.6 and 19.05 mg/l of 45 % potassium ferrate. As can be seen, even though there were major differences between Phase III test conditions and the predicted optimum, the results were exceptional, demonstrating the process is tolerant of process variations. This is very important

when it comes to designing and operating a full scale plant in that excessive instrumentation will not be required and minor upsets can be tolerated.

Table 2.1-2 displays the analytical results of the contaminated groundwater (average of three samples) and the treated water from Phase III (average of four tests). From these data the percent removal was calculated by:

$$\text{Percent removal} = \frac{\text{Concentration of Groundwater - Concentration of Treated Water}}{\text{Concentration of Groundwater}} \times 100$$

Where there were definite values for both solutions the percent removals are high (for example, radionuclides removal were in excess of 95 %). For the elements where there is not a definite concentration in the treated water the recoveries are a function of the starting concentration. Therefore, not much importance should be given to their magnitude. However, based upon the results of the radionuclides it seems that all the COCs removal should exceed 90%.

The results of the Phase III test were all within the 95% confidence limit range of the values predicted from the Phase II response model. In fact all of the COCs concentration in the Phase III treated water were below the exact value predicted. These data indicate that the results of Phase III are better than predicted. This is possibly due to the under estimation of interaction effects in Phase II because the tests were all conducted at conditions quite different than the optimum. It can be concluded that the model conservatively predicted the response of the COCs in the potassium ferrate water treatment process.

Additionally, it has been concluded that elements respond differently to ferrate treatment. For example, americium's removal was caused almost exclusively by ferrate as shown by the data in

Table 2.1-2 Initial Groundwater and Phase III Treated Water Chemical Analysis and Percent Removal

Elements	Initial Groundwater	Phase III Treated Water	Percent Removal
Radionuclides	pCi/l	pCi/l	
Americium 241	0.92	0.00	100.0
Plutonium 230/240	7.8	0.0325	99.6
Uranium, total	1.33	0.053	96
Other COCs			
	mg/l	mg/l	
Silver	0.029	<0.005	>82.8
Aluminum	19.33	<0.1	>99.5
Barium	0.247	<0.05	>79.8
Beryllium	<0.005	<0.005	
Cadmium	<0.005	<0.005	
Cobalt	0.0065	<0.01	>53.8
Chromium	0.0237	<0.005	>78.9
Copper	0.0273	<0.005	>81.7
Iron	20.0	0.02	99.9
Manganese	0.257	<0.005	>98.1
Molybdenum	<0.01	<0.01	
Nickel	<0.05	<0.05	
Thallium	<0.5	<0.5	
Vanadium	0.0433	<0.005	>88.4
Zinc	0.0867	<0.005	>94.2
Arsenic	0.010	<0.005	>50.0
Mercury	<0.0001	<0.0001	
Lead	0.0123	<0.005	>59.3
Selenium	0.042	0.0562	None

Table 2.1-3. While uranium's removal was caused primarily by increasing pH with little effect seen by ferrate addition. Uranium's response data is given in Table 2.1-4. Finally, some COCs showed a mixed response where both pH and ferrate addition effect the removal. Barium does demonstrate mixed response as shown by the data in Table 2.1-5 and is the simplest of the systems. Most of the other COCs show a more complex response to pH and ferrate addition as can be seen in the two dimensional response graphs in the Appendices D, E and F.

Table 2.1-3 Effect of pH and Ferrate Addition Upon the Response of Americium

Treatment pH	9.5	10	11.5
	Americium Concentration in Treated Water (pCi/l)		
Ferrate Addition (mg/l)			
1	0.090	0.080	0.045
5	0.037	0.042	0.029
40	0.016	0.023	0.018

Table 2.1-4 Effect of pH and Ferrate Addition Upon the Response of Uranium

Treatment pH	9.5	10.0	11.5
	Uranium Concentration in Treated Water (mg/l)		
Ferrate Addition (mg/l)			
1	0.0215	0.0158	0.0050
5	0.0205	0.0147	0.0032
40	0.0192	0.0134	0.0019

It was concluded from Phase I work that the increasing amounts of alum and polymer added did not improve the removal of the COCs. However, a minimum amount was required to flocculate the suspended solids in the groundwater. Table 2.1-6 show this effect by comparing one test at

the lowest addition of these two reagents and another test at the highest, both having the same pH and ferrate addition.

Table 2.1-5 Effect of pH and Ferrate Addition Upon the Response of Barium

Treatment pH	9.5	10.0	11.5
	Barium Concentration in Treated Water (mg/l)		
Ferrate Addition (mg/l)			
1	0.027	0.005	0.000
5	0.020	0.001	0.000
40	0.012	0.000	0.000

One further conclusion can be made from this study. That is that between 96 to 99 percent of the solids recovered from the treatment tests were generated by contaminants from the untreated water. The balance of one to four percent of the dried solids were a result of the reagents added.

From the preliminary engineering data obtained in Phase III of this study it can be concluded that the equipment required for implementation of a full scale plant will be of modest size requiring minimal design, instrumentation and procurement. There will be no need to design new or special equipment. This treatability study of RFETS groundwater has demonstrated that potassium ferrate water treatment technology produced water for discharge of excellent quality.

2.2 RECOMMENDATIONS

The process chemistry indicates that treated water can be produced meeting the CWQCC discharge limits. However, for several of the COCs it cannot be said for sure that their concentrations in the treated water were below the CWQCC discharge limits because the

analytical method detection limits were not low enough. It is recommended that new or different analytical methods be investigated and some experiments, such as those in Phase III, be repeated to establish definitively that the concentrations of those COCs in the treated water were below the CWQCC discharge limits.

Table 2.1-6 Effect of Alum and Polymer Change on the Response of some of the COCs at the same pH and Ferrate Addition

Variables		Phase I Test 2 (Ave test 2A and 2B) pH 11.5 15.7, mg/l ferrate	Phase I Test 3 (Ave Test 3A and 3B) pH 11.5 15.7, mg/l ferrate
	Alum, mg/l	10	0.5
	Polymer, mg/l	50	5
Elements		pCi/l	pCi/l
Americium 241		-0.035	-0.020
Plutonium 239/240		0.205	0.185
		mg/l	mg/l
Uranium		0.0022	0.0038
Iron		0.77	0.79
Selenium		0.0535	0.0525
Silver		0.005	0.0025

Selenium does not respond to the ferrate treatment process because it exists as the selenate anion which does not form an insoluble solid. However, this anion can be reduced to selenium metal and be removed by the ferrate process. It is recommended that a laboratory program be undertaken to examine this potential procedure and integrate it into the overall process allowing a single plant to treat the groundwater.

As was discussed in this report thiosulfate is a complexing agent for silver and may prevent its' complete removal. There are many reductants that can be used to decompose the ferrate rather than thiosulfate. Therefore, if silver does not meet the CWQCC discharge limits it is recommended that a laboratory program be undertaken to find a reductant and determine if it conflicts with the removal of the other COCs.

Once these brief laboratory studies are completed and the results meet the treatment goals it is recommended that a limited engineering study be undertaken. This engineering study will develop cost estimates for the design, construction and operation of water treatment plant or plants utilizing the ferrate technology demonstrated in this laboratory study.

Upon the completion of the engineering study it is recommended that a pilot water treatment plant be built and operated to treat contaminated groundwater. This pilot plant will initially be used to decontaminate the RFETS groundwater and provide full size scale up of operating protocols, maintenance requirements and overall costs. It would also be possible to use this pilot plant to investigate ferrate treatment of other liquid waste streams on the RFETS.

3.0 TREATABILITY STUDY APPROACH

3.1 TEST OBJECTIVES AND RATIONALE

It has been claimed by some investigators that using ferrate in conjunction with a conventional treatment process will improve the removal of inorganic metals and radionuclides from wastewater. At the same time, ferrate treatment seems to produce less solid waste to be disposed. Water treatment plants are relatively easy to design, build and operate and the operational costs are relatively low when compared to other treatment methods. For these reasons ferrate treatment appeared to be an appropriate technology to examine in order to remediate the RFETS groundwater problem. As with all technologies, a preliminary feasibility study of the process was needed to determine if the goals of the desired cleanup standards could be met. The overall goal of this study was to determine if ferrate technology could remove the COCs from groundwater at RFETS to levels that would allow the treated water to be discharged into surface waters. More specifically, the goal was to meet the CWQCC discharge limits given in Table 1.0-1 with emphasis on the radionuclides.

To determine the lowest concentrations of the COCs utilizing potassium ferrate treatment a multiphase program was used. At the suggestion of a representative of the Colorado Department of Public Health and Environment (CDPHE), the statistically based experimental design computer software ECHIP was utilized. This software was used to setup and evaluate the results of the first two phases of this study. Use of this program enabled the investigators to clearly elucidate the effect of changes of the variables upon the concentration of the COCs in the treated water to meet the objective of each phase of the study. The specific objectives of the three phases are as follows:

Phase I objectives: To determine the relative effect of the following variables on COCs concentration in potassium ferrate treated water:

a) potassium ferrate concentration,

b) pH of the water during treatment,

c) the need for and the effects of alum addition and

d) the need for and the effects of organic polymer addition.

Phase II objectives: To use the information obtained in Phase I and establish process conditions that:

a) minimize reagent consumption and

b) maintain acceptable removal of the COCs from the treated water.

Phase III objectives: To use the information gathered in the previous two phases of testing to:

a) confirm that the concentrations of the COCs, predicted from the Phase II calculated response surfaces, can be duplicated by test at optimum process conditions and

b) gather preliminary engineering data.

3.2 EXPERIMENTAL DESIGN

Design of the experiments for this study was controlled by a computer program, ECHIP, that is based on a large body of literature on statistical experiment design. Discussion in detail of the program is not appropriate for this report, but some discussion is needed to understand the reasoning for these particular experimental designs.

In the first phase of the study it was desired to study the effect of four variables on the removal of the COCs from the RFETS ground water. To gather sufficient data to mathematically analyze the data and determine any interaction would require over 50 tests if an interactive model were used. This seemed excessive in view of the fact there was no information to guide the selection of the range of the variables to be examined. Therefore, a linear screening test design was used where the number of tests required to obtain sufficient data was at a minimum of fourteen tests. This design estimates only the first order effects of the variables plus the constant in a linear equation . There is some danger in using this design in that interactive effects may be significant and not found. The equation used in the analysis of the data by the program was:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

In this equation y is the measured response, the analytical concentration of the COCs in the treated water. There are five calculated constants (a_o, a_1, a_2, a_3 and a_4). The test variables are: x_1 - the equilibrium pH at the end of the test, x_2 - the amount of 45 % potassium ferrate added in mg/l, x_3 - the amount of alum used in the test in mg/l and x_4 - the amount of polymer used in the test in mg/l. Utilizing all the test results, the computer calculated the constants and compared the calculated equation with the actual values to determine the degree of fit. The computer program also has the ability to create two and three dimensional plots of the each of the responses measured. The test matrix of the variables used for Phase I is given in Table 3.2-1. Tests were run in the order presented in Table 3.2-1 to eliminate any systematic errors that might occur during testing. These systematic errors are variations that occur during testing, such as changes in temperature, changes in the test solution concentration or any other differences in test techniques that differ from test to test but were inadvertent and not controlled that might effect the outcome of a single test.

When any of the variables showed little or no response they can be eliminated from further consideration. Phase I data showed that within the range tested, alum and polymer had little or no effect upon the measured responses. Therefore, only two variables needed to be considered in

Table 3.2-1 Test matrix used for the First Phase of this Study

Test Number	pH	Ferrate (mg/l)	Alum (mg/l)	Polymer (mg/L)
11	10.0	47.15	30	2.75
3	11.5	15.7	50	5
8	8.5	15.7	50	5
4	8.0	78.6	10	0.5
2	11.5	15.7	10	0.5
5	11.5	78.6	10	5
7	11.5	78.6	50	0.5
6	8.5	15.7	50	0.5
3	11.5	15.7	50	5
10	8.5	15.7	10	0.5
2	11.5	15.7	10	0.5
1	8.5	78.6	50	5
9	11.5	78.6	50	5
1	8.5	78.6	50	5

Phase II of this study. As a result, limited number of tests produced sufficient data to satisfy any of the three interactive models available in the ECHIP program. The selection of which model to be used to present the results was based upon the best fit of the data. The second phase of this study used a test design to estimate interaction effects and provide sufficient data to satisfy any of the three interactive models provided in the ECHIP software. Interaction effects are important to measure, in that it might be possible to use more of a cost effective reagent and less of an expensive reagent still achieveing the same results. In other words, an economic optimum can be

found. The only variables investigated during Phase II were ferrate addition and pH. The amount of alum and polymer used in all of the second phase tests were held constant and set at 20 mg/l and 10 mg/l, respectively. The test matrix of the variables for Phase II is given in Table 3.2-2. To eliminate systematic testing errors the tests were run in the order are given in Table 3.2-2.

Table 3.2-2 Phase II Test Matrix

Test Number	pH	log(mg/l ferrate)	mg/l ferrate added
3	7.8	2.2	158.5
4	8.81	1.57	37.2
3	7.8	2.2	158.5
12	9.65	2.2	158.5
11	9.63	1.09	12.3
9	11.5	0.00	1.0
1	11.5	2.2	158.5
2	11.5	1.1	12.6
8	9.65	2.2	158.5
1	11.5	2.2	158.5
10	10.45	0.6	4.0
1	11.5	2.2	158.5
2	11.5	1.1	12.6
2	11.5	1.1	12.6

Phase III consisted of running several tests at optimum conditions determined in Phase II to: 1) confirm the predicted results at the optimum treatment reagent additions and 2) gather some preliminary engineering data. Since these confirmation tests were all done at the same treatment condition, a designed test series for Phase III was not necessary.

3.3 EXPERIMENTAL EQUIPMENT, MATERIALS AND PROCEDURES

3.3.1 Experimental Equipment

In addition to the usual standard laboratory glassware and plastic bottles, a Phipps and Bird stirring unit with two liter B-KER^{2} ™ beakers were used. This stirrer is a standard unit for conducting water treatment experiments. It allows control of the energy input into the reactor to aid in scale-up. The pH meter used was an Orion 230.

3.3.2 Experimental Materials

With two exceptions, all chemicals were analytical grade or better. The organic polymer used was a product of Cytec (a division of American Cyanamid Co.) called Magnifloc 985N, a nonionic polyacrylamide. Potassium ferrate used was 45% pure with the balance of the product being a mixture of potassium chloride and potassium hydroxide with a minor amount of magnesium salts. This product was produced by Analytical Development Co., Colorado Springs, Colorado.

The test reagents and their concentrations as used are:

KOH (potassium hydroxide)	2N
$Na_2 S_2 O_3$ (sodium thiosulfate)	5% solution
K_2FeO_4 (potassium ferrate)	dry powder (45%)
Alum (aluminum sulfate, Al_2SO_4)	40 g/l solution
Polymer (Cytec 984 N, made fresh daily)	2 g/l solution

3.3.3 Experimental Procedures

Groundwater from several monitoring wells was blended in a 30 gallon tank in the laboratory several days in advance of testing. See Tables 1.2-1 and 1.2-2 for the source and composition of the water samples used in these tests. The laboratory was at a constant temperature so the water sample had thermally equilibrated. The tank was covered with a plastic membrane to minimize evaporation, then covered with the hard tank cover.

To ensure that any given aliquot used in a test would be representative of the bulk of the blended groundwater, it was necessary to mix the bulk sample. This was accomplished using a large stirring rod and agitated by hand until all the solids were uniformly suspended. Two liter samples were taken for each test by dipping a plastic beaker into the tank. The dip samples were measured in a 1000 ml graduated cylinder and transferred to the test apparatus. The effectiveness of this mixing and sampling procedure can be seen by the agreement of the analytical results of the three aliquots taken in each phase of this study, several weeks apart, Table 1.2-2.

Usually, four tests were run at a time since the Phipps and Bird was a four position stirrer. The beakers, B-Ker^2 ™, were filled with two liters of the ground water to be treated. The B-Ker^2 ™ polycarbanate beakers used were 4.5 inches by 4.5 inches square and approximately eight inches deep. The stirrer blade used was three inches by one inch by one quarter inch and its speed is controlled to within 2% of the test rpm.

The test solutions were stirred at 300 rpm. The pH was measured and adjusted to the desired test condition, using potassium hydroxide in all cases. During the pH adjustment, the electrode was immersed in the water for constant measurement as the solution was being stirred.

When the pH had been adjusted to the appropriate level, the entire amount of the dry potassium ferrate was added to the reactor. The dry ferrate was weighed on an electronic balance located in the testing laboratory and had an accuracy of 0.0001 gram. This solution was stirred for a set time in Phase I, 15 minutes. During Phase II the time of mixing was varied depending on the amount of ferrate added.

The basic solutions of potassium ferrate were relatively stable, therefore a small amount of sodium thiosulfate, a reducing agent, was added during the mixing stage to cause the ferrate to decompose. In Phase I the amount of sodium thiosulfate added was based on the following chemical equation:

$$17H_2O + 3Na_2S_2O_3 + 8K_2FeO_4 \rightarrow 8Fe(OH)_3 + 6K_2SO_4 + 4KOH + 6NaOH$$

This equation gave the stoichiometric relationship of:

mg sodium thiosulfate = 3.34 (mg potassium ferrate)

for pure potassium ferrate. Therefore, since 45 % potassium ferrate was used in this study the amount of thiosulfate required to reduce all of the ferrate added would be 1.5 mg of thiosulfate for every mg of potassium ferrate added to the reactor. The equation may not accurately represent the actual products of the reaction. This was of no consequence since the thiosulfate / ferrate ratio was not affected by assuming other products of reaction. For example, if the iron product is assumed to be either FeO(OH) or Fe_2O_3 , the relationship between thiosulfate and ferrate is the same.

It was believed that most of the ferrate would be consumed in the water treatment process and that only a small amount of the ferrate added would have to be reduced by the thiosulfate. Therefore, in Phase I only ten percent of the stoichiometric requirement was added. This proved to be insufficient in several test as could be seen by the presence of the purple color after completion of the test. Therefore, in Phase II the amount of sodium thiosulfate used was that

required to eliminate the purple color of the ferrate. The actual amount used was recorded and became a variable to be examined with the other test results.

In Phase I the thiosulfate solution was added quickly while mixing was continued for 15 minutes at 300 rpm . During the tests in Phase II, if any color remained after the completion of the initial mixing time more thiosulfate was added and mixed for 15 minutes. This sequence was repeated until the color had completely disappeared. Once the reaction of thiosulfate with the ferrate was complete, the pH was adjusted to the desired test condition.

After the appropriate pH was established, the mixing speed was slowed to about 60 rpm (+/- 5%). Alum was prepared as a dilute solution with a concentration of 40 grams per liter. The required amount of alum was then added to the reactor. The aluminum hydroxide floc formed instantly and the pH shifted. The pH was adjusted again while mixing continued.

The prescribed amount of organic polymer as a dilute solution of 2.0 g/l was added to the reactor. Stirring was continued for 15 minutes at the slow speed of 30 rpm. The polymer solution was made up well in advance of its use to insure the polymer was completely dissolved.

After this final mixing period, the stirring was stopped. The covered beaker was set aside and allowed to settle overnight. An large aliquot of the treated water was taken the next day for chemical and radionuclide analysis.

3.4 SAMPLING AND ANALYSIS

Sampling of groundwater from the monitoring well was conducted by a subcontractor to the

Environmental Restoration Program Division (ERPD) of EG&G, using operating procedure for groundwater sampling (OPS-GW-06, March 1992). Approximately 10 gallons of water were collected from each well in one gallon plastic bottles over a five day period. The samples were stored for some time prior to the star of this study. Some of these groundwater samples were used in this study with no pretreatment, to prepare a bulk composite sample. An aliquot of this bulk sample was submitted for analyses at the beginning of each phase of this treatability study.

Samples from the treated water were collected the day following completion of each test. The liquid above the settled solids was decanted into clean plastic bottles, sealed and sent for analysis. Accu-Labs Research Inc. of Golden, Colorado analyzed the test samples for metals, radionuclides and several other parameters such as TSS, pH and hardness. The EPA approved analytical methods are shown in Table 1.0-2.

3.4.1 Waste Stream

Waste from this study was about 70 liters of treated water plus the sludge produced during the treatment. Approximately 80 grams of dry solids were generated and contained most of the contaminants and radionuclides from the 70 liters of water used in these tests.

3.4.2 Experimental Treatment Process

Techniques used during the experimental phases of this study were done to simulate the process described in Section 1.3.1. Since standard test techniques were utilized, the results can be used to estimate full scale water treatment plant costs. However, this study was directed toward the process chemistry rather than to optimize the mechanical parameters. Additional test work will be required to minimize the equipment costs of a full scale plant.

3.5 DATA MANAGEMENT

All pertinent information collected from this study was recorded by EG&G personnel in bound notebooks. Accu-Labs Research, Inc. reported the analytical results in a typed report (Appendix A, B, and C) and archived the data. These data were entered into a computer for use with the ECHIP software for evaluation and analysis by ACTA Resources, Inc. personnel. Much of the information generated with this program is presented in Appendices D, E and F.

3.6 DEVIATION FROM THE WORK PLAN

Deviations from the work plan were minimal. The main reason for being able to conform to the work plan closely was that the work plan allowed the second and third phases of the study to be developed after the completion and analysis of the results from the preceding work. The data analysis of one phase of work generated a definite direction for the subsequent treatability tests.

There were two minor deviations. First, the work plan specified that the water would not be stored more than six weeks. The storage time was exceeded due to the time required for analytical determinations, which prolonged the study. However, the replicate chemical analysis of the bulk water samples at each phase of the study indicate that this deviation is not significant, (Table 1.2-2). Second, several of the analytical method detection limits specified in the work plan were not met. The elements affected were aluminum, barium, molybdenum, nickel and silver. This was significant for three elements because the analytical detection limits were above the CWQCC discharge limits. These three elements were aluminum, cadmium and silver.

4.0 RESULTS AND DISCUSSION

A detailed discussion of each phase of this study follows. The conclusions reached in each phase of work are presented at the end of the discussion of each of the phases. The overall conclusion and recommendations from this study are in Section 2.0. Results of each phase of the study were used to determine experimental procedures and test conditions in the subsequent phase. A large amount of information was generated by the computer program, which is displayed in the Appendices D, E and F rather than in the body of the report.

4.1 PHASE I RESULTS AND DISCUSSION

Fourteen tests were performed in Phase I following the procedures outlined in Section 3.3.3. This phase of the study was designed to examine the magnitude of the effects of four variables on the removal of 19 COCs in the RFETS groundwater. To interpret and understand the results of Phase I work the ECHIP computer software was used to analyze the data. The matrix of the test variables (Table 3.2-1) and the analytical results of the treated water were input into the program. The pH values of the supernatant liquid (treated water) as measured and reported by Accu-Labs were used rather than the values measured at the time of testing. It was believed, because of the time between completion of the tests and mixing while handling the samples, that the measurements made by Accu-Labs were the true pH values (Appendix A, B and C).

Analytical data were entered into the ECHIP program as shown in Table 4.1-1. Of the 19 COCs, only those listed in the table had three or more values above the analytical detection limits. To define a response surface, in the linear model used to analyze the results, at least three measured responses from analytical results were needed. When using the feed solution (shown as test 17)

as one point, the omitted elements still had fewer than three data points. As a consequence of this, only the elements listed in Table 4.1-1 were examined in Phase I. Selenium was analyzed by Accu-Labs by inductive coupled plasma (ICP) and graphite furnace-AA (GFAA) methods. In all cases in this report the GFAA results were used in the analysis of the data. Values of the analytical results reported below the analytical detection limits were entered into Table 4.1-1 as zeros for those COCs analyzed. The radionuclide values were entered even when negative, that is less than zero. This may overestimate the effects, but Phase I was a screening series of tests, so the conclusions will not be affected. The radiochemical determinations for americium (Am) 241

Table 4.1-1 Analytical Results for Phase I Ferrate Treatment Tests

	Am	Pu	U	Al	Ba	Cr	Fe	Se	Ag	V
Test	pCi/l	pCi/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	-0.03	0.18	0.038	0.7	0.06	0.000	0.03	0.051	0.000	0.000
1	-0.06	0.17	0.037	0.7	0.06	0.000	0.03	0.047	0.000	0.000
4	0.01	0.21	0.039	0.2	0.08	0.000	0.04	0.047	0.005	0.000
6	-0.03	0.16	0.036	0.7	0.07	0.000	0.02	0.052	0.000	0.000
8	-0.02	-0.02	0.037	0.2	0.09	0.000	0.02	0.049	0.000	0.000
10	0.02	0.02	0.036	0.2	0.08	0.000	0.02	0.056	0.000	0.000
11	0.00	0.00	.0035	0.3	0.00	0.000	0.13	0.055	0.007	0.000
17	0.86	7.50	0.044	18.	0.23	0.020	19.00	0.044	0.029	0.042
2	-0.06	0.17	.0024	0.0	0.00	0.000	0.78	0.055	0.005	0.000
2	-0.01	0.24	.0020	0.0	0.00	0.000	0.76	0.052	0.005	0.000
3	0.01	0.14	.0042	2.2	0.00	0.000	0.68	0.053	0.000	0.006
3	-0.05	0.23	.0035	1.7	0.00	0.000	0.90	0.052	0.005	0.005
5	-0.05	0.12	.0025	0.2	0.00	0.000	2.30	0.054	0.000	0.000
7	0.05	0.12	.0028	2.2	0.00	0.005	2.70	0.052	0.009	0.005
9	0.09	0.19	.0034	2.0	0.00	0.006	2.30	0.050	0.006	0.000

and plutonium (Pu) 239/240 were reported in picoCuries per liter (pCi/l, total). Uranium (U) and all other elements' analytical results are reported in milligrams per liter (mg/l).

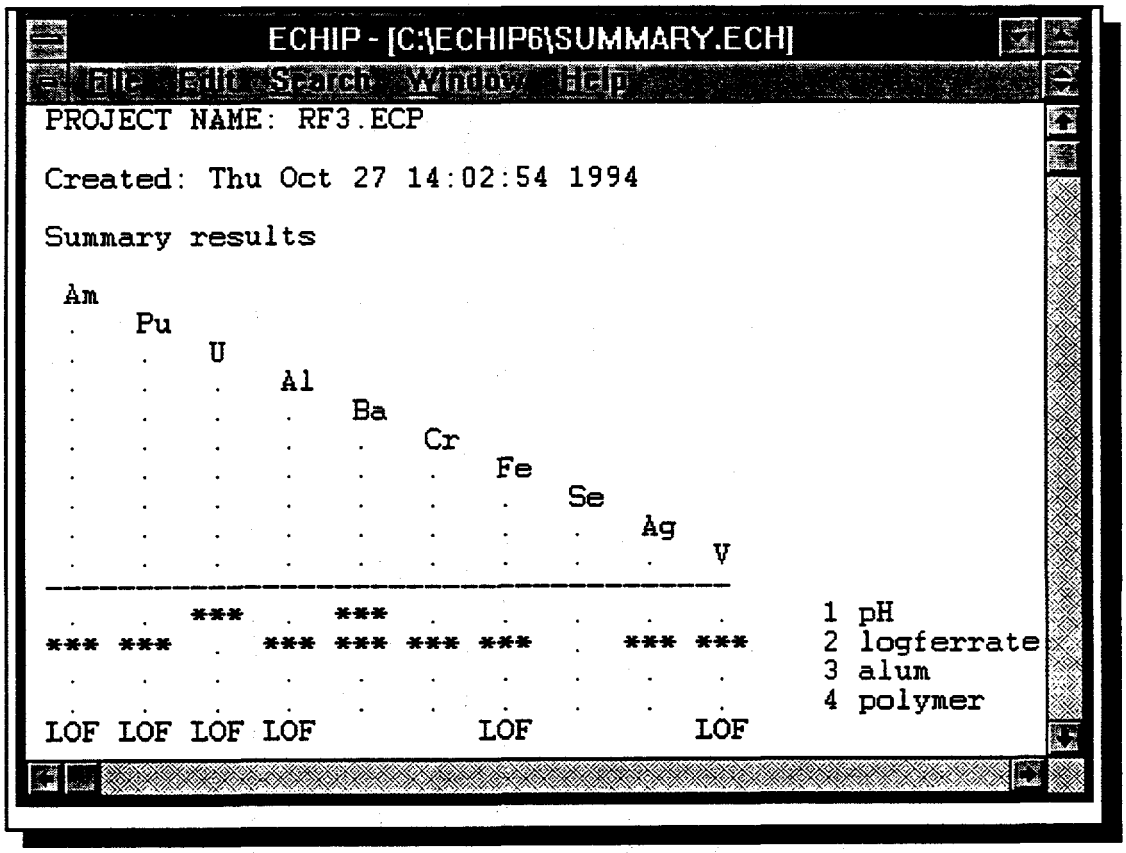
The ECHIP program, utilizing the information in Tables 3.2-1 and 4.1-1 analyzed the results. The program creates numerous sets of output data (Appendix D). The program calculated the coefficients of the linear equation and estimated the fit of the data to the model.

The test matrix designed by ECHIP required duplicates of Tests 1, 2 and 3 be done to estimate the testing error and the standard deviation (SD). Therefore, these duplicate treatment tests and chemical analyses were run separately as individual tests. The calculated SD from duplicate tests is shown in Tables 4.1-2 and 4.1-3, called Replicate SD. Also shown is the difference between the calculated values of the model and the actual test values, called Residual SD. If these two SD values are close there is a fit of the calculated model to the data. If not, a "Lack of Fit" (LOF) message is displayed, which occurred for six of the ten elements where there was sufficient data in this phase of the study.

Figure 4.1-1 is the first output from the ECHIP program showing the effect of individual variables upon the elements listed. The number of stars, in the row to the left of the variable name, indicates the relative effect of that variable. The more stars, the greater the effect a change in that variable has upon the element's concentration in the treated water. In Figure 4.1-1 there are no stars in the polymer and alum rows indicating, that over the range of the amount of reagents used in this phase of the study, there was little or no effect upon the element's concentration in the treated water caused by these two reagents. By examining the numerical values of the coefficients of alum and polymer in Table 4.1-2 and 4.1-3 for these two variables, it can be seen that they are very small, < 0.002. Therefore, the effects are insignificant and can be eliminated as a variable in subsequent phases. The number of stars indicated that ferrate had a

major impact upon eight of the ten constituents. Again, from the number of stars, pH and ferrate are both significant for the removal of barium while pH is the only important variable affecting uranium removal.

Figure 4.1-1 Summary of Results of Phase I Tests Using ECHIP Program



To discuss Tables 4.1-2 and 4.1-3, which shows the coefficients of response, the equation used for this analysis must be recalled; it is:

$$y = a_o + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

Coefficients a_0 through a_4 are shown in Tables 4.1-2 and 4.1-3 for each of the variables: x_1 = pH, x_2= logferrate, x_3 = alum and x_4 = polymer, in units of mg/l. The value of y is the concentration of the COCs in solution. A sign was assigned to the coefficients; as the concentration of the reagent (variable) increases the sign of the coefficient is positive (+) if the concentration of the particular element increases or negative (-) if it decreases. Other than the

Table 4.1-2 Coefficients for Response of Americium

«××××××××××××» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.332844				0 CONSTANT
-0.00477232	0.0165708	0.7792-	0.943	1 pH
-0.177047	0.0250332	0.0000	0.847	2 logferrate
0.000793209	0.00147026	0.6013-	0.841	3 alum
-0.00197069	0.0130205	0.8827-	0.866	4 polymer

N trials = 15
N terms = 5

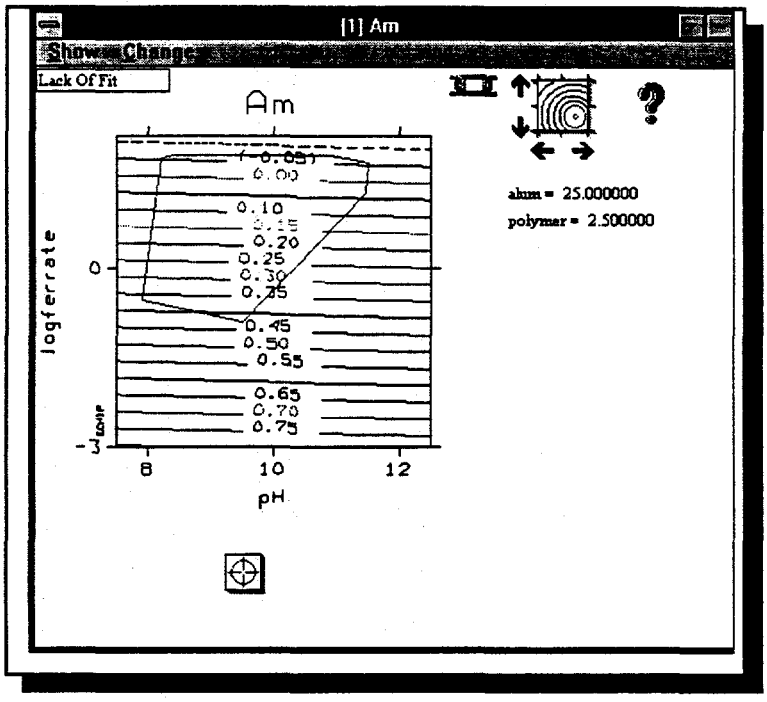
Residual SD = 0.096570, Lack-Of-Fit P=0.0373 *
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.034157
Replicate DF = 3

R Squared = 0.872, P=0.0002 ***
Adj R Squared = 0.821

constant term (a_0) in the case of Am 241, the largest coefficient (a_2) was for logferrate and minus. This means that the addition of ferrate will cause a decrease in the concentration of americium. The coefficients for the other reagents are two to three orders of magnitude smaller.

Figure 4.1-2 Response Surface of Americium



Therefore, these reagents will have little or no effect on the concentration of americium in the treated water. Figure 4.1-2 displays the system in graphical form which shows a reduction of the americium concentration as more ferrate was added, but as pH increases little or no effect was observed.

From published information on the aqueous chemistry of americium, it would be expected that as the pH rises, americium would form a hydroxide and as a solid phase should have been removed

more effectively. This anticipated result was not observed and raised the question as to the applicability of the test procedures or whether the addition of ferrate in basic solutions caused increased americium solubility. Examination of the other elements' responses shows this same discrepancy, especially iron (Appendix D). The only exceptions to this observation were barium and uranium. In Table 4.1-3 the coefficients for uranium's response to the variables

Table 4.1-3 Coefficients for Response of Uranium

«××××××××××××» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0179644				0 CONSTANT
-0.0105585	0.000952577	0.0000	0.943	1 pH
-0.000472097	0.00143904	0.7496	-0.847	2 logferrate
1.23131e-005	8.45186e-005	0.8871	-0.841	3 alum
-5.29126e-005	0.000748485	0.9450	-0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.005551, Lack-Of-Fit P=0.0007 ***
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000524
Replicate DF = 3

R Squared = 0.934, P=0.0000 ***
Adj R Squared = 0.907

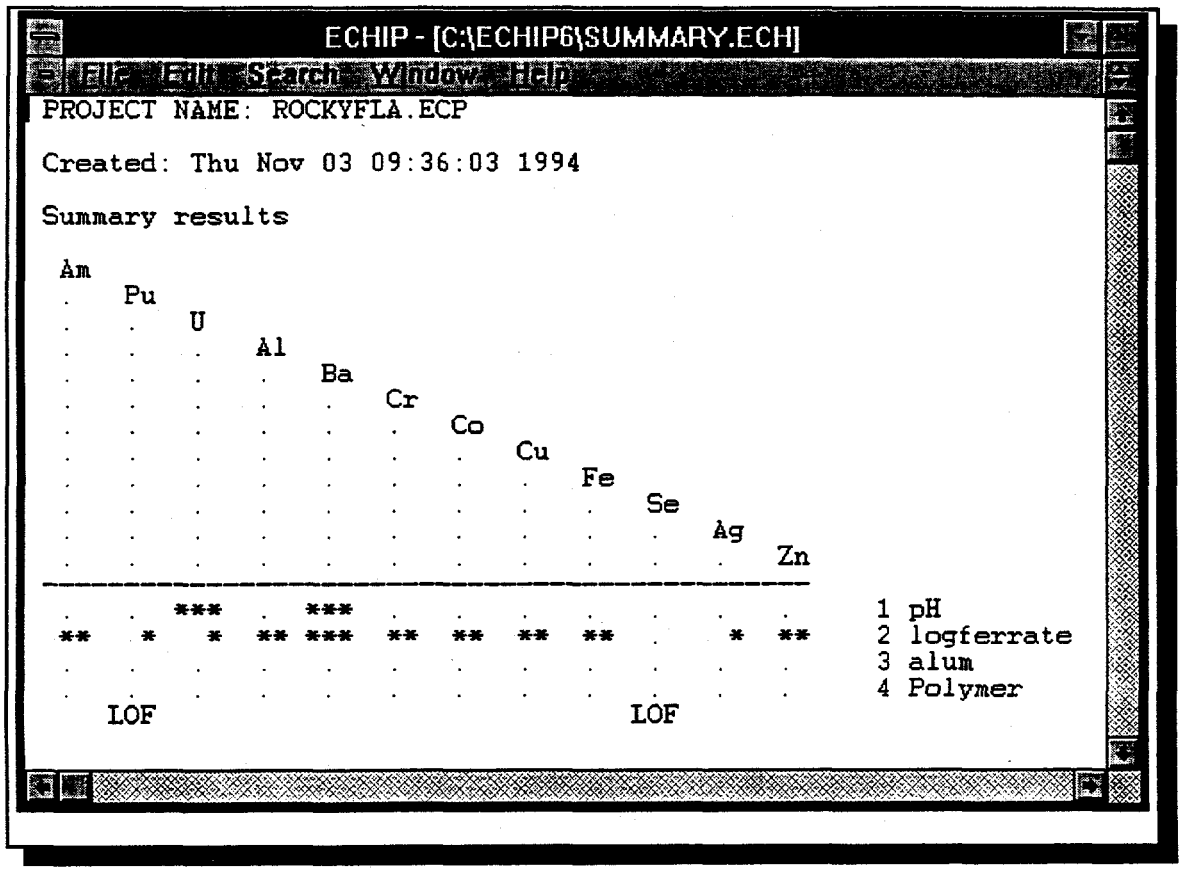
shows that the coefficient for pH is three orders of magnitude larger than any of the others; therefore, it is the only variable that had any measurable effect upon the removal of uranium. This effect of pH was what would be expected from aqueous chemistry of uranium.

In reviewing all the response data in Appendix D, it is seen that Al, Cr and Fe, which also precipitate as the pH of the solution rises, should have been removed more effectively at higher pH but were not. Since these results were completely unexpected other factors were examined to explain this phenomenon. Observations made during testing indicated that the ferrate ion was not completely reduced at the end of the tests. This was obvious, since the purple color of the ferrate ion was still present in the solution. The next day, when the solution was decanted for analysis, those tests which had the purple color were then cloudy and yellow. This seemed to indicate that some iron compounds had not settled out of the solution. The chemical analysis of the treated water confirmed this assumption. From these results it was concluded that the incomplete reduction of ferrate accounted for the lack of effect of increasing pH upon the removal of the COCs in the treated water.

Other observations made are: 1) the response of barium was closer to what was expected in that there was a response to both ferrate and pH and 2) selenium was not effected by this technology. In order to obtain more significant information from this phase of the study a modified test matrix was used to analyze the results. This modified matrix used data for only those tests where no color was seen at the end of the test (Test Nos.1,1,4,6,8,10 and 11) and the analytical data of the sample of the bulk solution, labeled as Test No. 17, in an analytical results matrix (Appendix E). Summary of the responses from the calculations using the modified matrix of both the test variables and analytical results are given in Figure 4.1-3 The results fit the data better than the full test matrix in that only plutonium and selenium have the LOF message.

Analysis of the modified Phase I test results over the limited pH range (pH 7.4 to 9.7), showed combined response to both pH and ferrate by most of the COCs concentration in the treated water. These were the expected responses.

Figure 4.1-3 Summary of the Responses from the Modified Phase I Test Program



4.1.1 Conclusions from Phase I Tests

The following conclusions result from analysis of Phase I data:

1) Ferrate does lower the concentration of several of the COCs from the RFETS

contaminated groundwater, at least Am, Pu, Al, Fe and possibly Cr, at pH at less than 9.7;

2) Removal of contaminants is more effective if all of the ferrate is eliminated by chemical reduction during treatment;

3) Chemical reduction of ferrate is more difficult at pH values greater than 9.7, requiring longer mixing times in the reactor;

4) Several elements show mixed response, where both pH and ferrate concentration effect the final concentration after treatment. These include Ba, Ag and U with U having negative response to ferrate addition and silver showing an increase in concentration as the pH rises and

5) Changing the concentration of both alum and polymer has a very slight affect upon the removal of any of the contaminants of concern; however, the observations suggest that a minimum amount is required.

4.2 PHASE II RESULTS AND DISCUSSION

According to the work plan, the design of the Phase II tests was to be based upon the results of Phase I and lead to the overall objective of the study. Results and conclusions of Phase I pointed out that: 1) the range of pH investigated must be expanded, 2) more time for the degradation of the ferrate must be allowed and 3) before the tests were completed all of the ferrate must be eliminated by chemical reduction, that is all of the purple color must be gone. Since the COCs had different responses to the treatment, an optimum treatment condition was

sought that would maximize the removal of all the COCs with a single treatment and still produce treated water meeting the CWQCC discharge limits (Table 1.0-1). For example, the radionuclides of americium and plutonium were eliminated by the addition of ferrate and uranium was removed by increasing the pH.

Secondary treatment was not considered as part of the process to be investigated in this study.

Phase I results showed that the COCs removal was not improved with the addition of more than 10.0 mg/l alum or 0.50 mg/l polymer. As a result, these two reagents were not considered variables in Phase II and their additions were constant in all the tests.

Phase I results also indicated that there was interaction between ferrate addition and pH upon the removal of several COCs. In Phase II ferrate addition and pH were tested over a broader range to determine, if in fact, a common point did exist in the system to remove most, if not all, of the COCs in the groundwater. The dosing of ferrate studied in the Phase II tests ranged from 0 to approximately 160 mg/l. The pH range examined was from the value of the groundwater as received up to 11.5.

To find a common point where all the COCs were removed to acceptable limits, Phase II examined the COCs' responses as a function of ferrate and pH and the interactions of these two variables. The results of Phase II tests had to be evaluated with a model that was capable of estimating interactions. Even though there were only two variables, a large number of tests were required to gather sufficient data to estimate the interaction terms in any model chosen. In addition, replicate tests were needed to estimate the statistical variations from test to test.

Using the ECHIP software, it was determined that 18 was the minimum number of tests needed to satisfy the interaction estimating models. Five replicate tests were recommended by the program. To save time and analytical costs it was decided that only three replicate tests would be needed. Several Phase I tests could be used in the calculations as replicate tests. The Phase II study then consisted of 15 additional tests which satisfied the criteria of any of the models available in the ECHIP software. Table 4.2-1 shows the matrix of the variables to be used for Phase II testing generated by ECHIP.

As was the case in Phase I, the tests were conducted in the order presented in the test matrix to eliminate any systematic errors that might be introduced by the experimenter. Alum and polymer were constant at 10 mg/l and 5.0 mg/l respectively in each test in the second phase of this study. Thiosulfate was added in several stages of addition and mixing (15 minutes) to completely eliminate all of the purple color of the ferrate ion. Other than these changes the tests were done as described in Section 3.3.3.

The treated water was decanted the day after completing the test into plastic bottles, sealed, labeled and sent to Accu-Labs for analysis of both the inorganic and radionuclide contaminants. Appendix B contains three analytical reports of the treated water from Accu-Labs. These reports consist of the inorganic analysis report dated 10/04/94, a preliminary radionuclide report dated 10/04/94 and the final and corrected radionuclide report dated 10/25/94.

Upon receiving the analytical results, the data was input into the Response Table of the ECHIP program for analysis. As before, the pH values reported by Accu-Labs were used for the data analysis.

In order to obtain sufficient data to satisfy the interactive models of the ECHIP software seven Phase I tests were used with the Phase II matrix (Table 4.2-1) to produce the modified Phase II test matrix (Table 4.2-2) prior to computer analysis. Different amounts of alum and polymer were used in these Phase I tests but because these two variables had little or no effect upon the removal of the COCs they were acceptable for use in this computer analysis of Phase II results. Chemical analysis of the feed solution (Test 17) from both Phase I and II were also included in the matrix. This modified test matrix was used to the analyze the performance of ferrate treatment technology to eliminate COCs from RFETS groundwater.

Table 4.2-1 Phase II Test Matrix

Trial Number	pH	log Ferrate	Ferrate, mg/l	Comments
3	7.80	2.200	158.5	As received
4	8.81	1.576	37.7	
12	9.65	2.2	158.5	
11	9.63	1.069	11.7	
9	11.5	0.000	1.0	
1	11.50	2.200	158.5	
2	11.50	1.100	12.6	
8	9.65	2.200	158.5	
1	11.50	2.200	158.5	
10	10.45	0.602	4.0	
2	11.50	1.100	12.6	
13	10.00	1.100	12.6	
14	11.5	-3.000	0.0	0 mg/l Ferrate
16	10.00	2.200	158.5	
17	8.0	-3.000	0.0	Feed Sol'n

Table 4.2-2 Modified Phase II Test Matrix

Trial Number	pH	log(mg/l ferrate)	Comments
1	11.4	2.200	Phase II Test 1
1	11.4	2.200	Phase II Test 1
2	11.8	1.100	Phase II Test 2
2	11.8	1.100	Phase II Test 2
3	8.5	2.200	Phase II Test 3
4	8.6	1.576	Phase II Test 4
8	9.4	2.200	Phase II Test 0, on analytical report
9	11.6	0.000	Phase II Test 9
11	9.6	1.069	Phase II Test 11
12	9.8	2.200	Phase II Test 12
13	10.2	1.100	Phase II Test 13
12	10.0	2.200	Phase II Test 16
17	8.0	-3.000	Phase II Feed Solution, untreated
18	8.2	1.895	Phase I Test 1
18	8.3	1.895	Phase I Test 1
19	8.4	1.196	Phase I Test 6
19	8.3	1.196	Phase I Test 10
20	9.7	1.673	Phase I Test 11
10	10.1	0.602	Phase II Test 10
14	11.9	-3.000	Phase II Test 14
17	7.4	-3.000	Phase I Feed Solution
19	8.2	1.196	Phase I Test 8
18	8.2	1.895	Phase I Test 4

Table 4.2-3 Corrected Analytical Results for the Modified Phase II Ferrate Treatment Tests

Test	Am	Pu	U	Al	Ba	Cr	Co	Cu	Fe	Se	Ag	Zn
	pCi/l	pCi/l	mg/l									
8	0.03	0.26	0.020	0.2	0.0	0.008	0.0	0.0	0.05	0.058	0.008	0.0
1	0.01	0.12	0.0011	0.5	0.0	0.009	0.0	0.0	0.08	0.055	0.010	0.0
1	0.03	0.12	0.0012	0.4	0.0	0.006	0.0	0.0	0.13	0.056	0.007	0.0
2	0.02	0.17	0.0039	0.1	0.0	0.000	0.0	0.0	0.19	0.056	0.005	0.0
2	0.01	0.14	0.0015	0.0	0.0	0.000	0.0	0.0	0.26	0.059	0.007	0.006
3	0.04	1.1	0.034	0.0	0.07	0.011	0.0	0.0	0.0	0.049	0.009	0.0
4	0.02	0.36	0.030	0.0	0.08	0.008	0.0	0.0	0.0	0.059	0.011	0.0
9	0.04	0.10	0.0018	0.0	0.0	0.000	0.0	0.0	0.07	0.054	0.000	0.0
10	0.03	0.13	0.0069	0.0	0.0	0.000	0.0	0.0	0.02	0.065	0.000	0.0
11	0.00	0.19	0.027	0.0	0.0	0.000	0.0	0.006	0.02	0.061	0.005	0.0
12	0.02	0.20	0.025	0.0	0.0	0.000	0.0	0.0	0.02	0.059	0.007	0.0
13	0.08	1.8	0.022	0.0	0.0	0.000	0.0	0.0	0.02	0.059	0.008	0.0
12	0.03	0.12	0.0077	0.0	0.0	0.000	0.0	0.0	0.05	0.056	0.009	0.0
17	1.10	6.70	0.036	20.0	0.23	0.025	0.006	0.023	19.00	0.040	0.028	0.081
14	0.00	0.00	0.001	0.0	0.0	0.000	0.008	0.0	0.02	0.056	0.000	0.0
18	-0.03	0.18	.038	0.7	0.06	0.000	0.00	0.00	0.03	0.051	0.000	0.0
18	-0.06	.17	.037	0.7	0.06	0.00	0.03	0.02	0.03	0.047	0.000	0.0
19	-0.03	0.16	.036	0.7	0.07	0.00	0.00	0.00	0.02	0.052	0.000	0.0
19	0.02	0.02	0.036	0.2	0.08	0.00	0.00	0.00	0.02	0.056	0.000	0.0
20	0.00	0.00	0.0035	0.3	0.00	0.00	0.00	0.00	0.13	0.055	0.000	0.0
17	0.86	7.5	0.044	18	0.25	0.20	0.007	0.029	19	0.044	0.029	0.086
19	-0.02	-0.02	0.037	0.2	0.09	0.00	0.00	0.00	0.02	0.049	0.000	0.0
18	0.01	0.21	0.039	0.2	0.08	0.00	0.00	0.00	0.04	0.047	0.005	0.00

The analytical response table used for the analysis of the second phase work is displayed in Table 4.2-3. As in Phase I only those elements that had a sufficiently large number of responses above the analytical detection limits were input into the program. Analytical results reported below the detection limits were entered into this table as zeros. The radionuclide data were entered into the table as reported, even when that value was negative. Using zero values may over estimate the response but because of the large number of tests used the impact on the results and conclusions is not significant. This statement can be substantiated by the fact that the residual standard deviation for these tests is large when compared to the analytical detection limits. For example, the analytical detection limit is 0.05 mg/l for aluminum and the residual standard deviation calculated is 0.437. This means that whatever the true concentration of the metal element is in the treated water below the detection limit, the value would not effect the results of the computer analysis of the data.

Three mathematical models were tried to analyze the data. Of the three, the partial cubic model fit the best and will be used for the discussion of Phase II results. The partial cubic model is expressed by the following equation:

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_{12} x_1 x_2 + a_{11} x^2_1 + a_{22} x^2_2 + a_{112} x^2_1 x_2 + a_{122} x_1 x$$

In this equation y is the concentration of the COCs in solution and x_1 is the pH and x_2 is the log of the concentration of potassium ferrate in mg/l and the a_i are coefficients calculated by the ECHIP software.

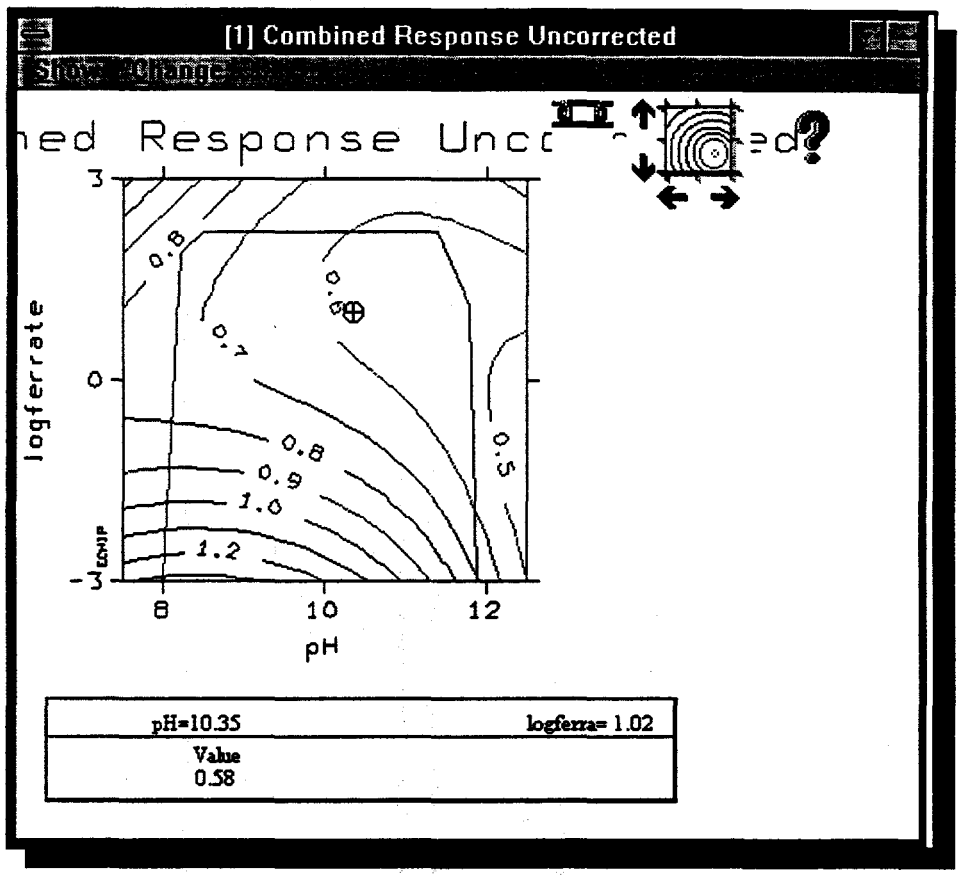
4.2.1 Determining the Test Conditions to be Used in Phase III Tests

To maintain the schedule of this study the preliminary radionuclide analytical results were used to

estimate the optimum treatment conditions to be used in Phase III. This required that a set of treatment conditions be found that would reduce the concentrations of all the COCs in solution to acceptable concentrations of the COCs. Again the ECHIP, program was used to accomplish this goal. The program allows for responses of all of the elements to be combined to calculate a combined response surface so that the optimum conditions can be determined. A graph of the response surface is produced that displayed a region that maximizes the removal of all the COCs. Within this region there was a optimum set of treatment conditions.

To combine the responses of the individual elements their response's were weighted, as part of the calculations, based upon the CWQCC discharge criteria. This weighting factor was simply one divided by the allowable discharge concentration normalized so the total would be one. Therefore, the optimum value in the combined response contour plot would have a value of one if all of the discharge limits were met exactly for each element. If the value of the combined response was very small then there would be some assurance that all the elements had met the discharge limits. Figure 4.2.1-1 shows the contour plot of the combined responses using the uncorrected radionuclide analysis. The optimum conditions selected from this figure are pH 10.35 and logferrate 1.02. This point was picked to minimize the consumption of reagents and still yield acceptable responses of all elements. At this point the calculated combined response is 0.58. It is not possible to say that all the contaminants met their individual limits but, on the average, the elements are below the CWQCC discharge limits. Since an average is not good enough, each individual limit must be met, the optimum condition was checked on each individual plot to get a predicted concentration at these conditions. The results are shown in Table 4.2.1-1. In Table 4.2.1-1 there are 13 elements for which the predicted results are below the CWQCC discharge limits. Four of the elements have CWQCC discharge limits that are below the analytical detection limits; therefore, it is not known if their discharge limits were met.

Figure 4.2.1-1 Combined Response Surface Using Uncorrected Radionuclide Data



Notice that the 95 % confidence limit range is rather broad. This means that the predicted value has a 95 % probability that it falls within this range and not at the predicted value. Therefore, Phase III tests were required to determine if the predicted values could be achieved at the optimum treatment conditions. The predicted values indicate that ferrate water treatment technology, when applied to the RFETS groundwater, will produce treated water meeting most of the CWQCC discharge limits with the exceptions of selenium and possibly silver.

Table 4.2.1-1 Predicted Contaminant Concentrations at the Optimum Condition Using Uncorrected Radionuclide Data

	Predicted Results				CWQCC Discharge Limits	Meets Discharge Limits
	At Optimum	95 % Confidence				
Elements		Low Level	High Level	Units		
Americium	0.032	-0.089	0.153	pCi/l	0.05	Yes
Plutonium	0.04	-0.48	0.56	pCi/l	0.05	Yes
Uranium	0.0107	-0.0048	0.0262	mg/l		Yes
U (Calc)	0.357	-0.160	0.873	pCi/l	5-10	Yes
Aluminum	-0.09	-1.13	0.940	mg/l	0.087	Yes
Barium	-0.008	-0.035	0.020	"	1	Yes
Chromium	0.0007	-0.0078	0.0091	"	0.05	Yes
Cobalt	-0.0008	-0.0169	0.0153	"	0.05	Yes
Copper	0.0007	-0.0109	0.0153	"	NA	---
Iron	-0.06	-0.32	0.21	"	0.3	Yes
Selenium	0.0613	0.0539	0.0686	"	0.01	No
Silver	0.0038	-0.0044	0.0121	"	0.0006	No
Zinc	-0.0004	-0.0043	0.0035	"	0.35	Yes
Element Reported Below ADL			Analytical Detection Limits (ADL) mg/l			
Beryllium			0.005		0.004	?
Cadmium			0.005		0.0015	?
Manganese			0.005		0.56	Yes
Nickel			0.02		0.125	Yes
Vanadium			0.005		0.1	Yes
Antimony			0.05		0.024	?
Arsenic			0.005		NA	---
Lead			0.005		0.028	Yes
Mercury			0.0001		0.00001	?

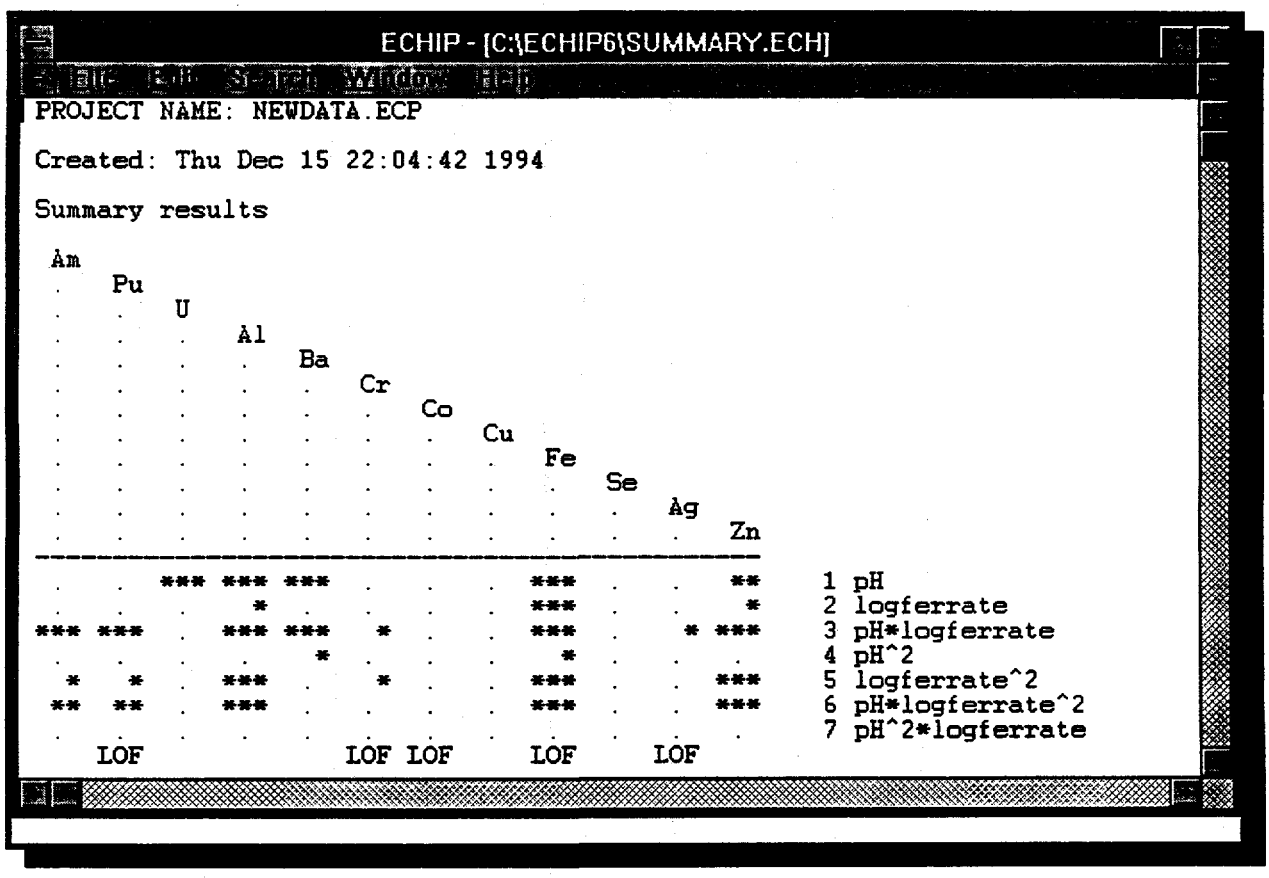
NA CWQCC discharge limit not available

Similar calculations were done with the corrected data. These results and other details of the computer analysis using the corrected analytical data are discussed in some detail, rather than discussing the results with the uncorrected data.

4.2.2 Discussion of Phase II Results With Corrected Radionuclide Data

The ECHIP program generates substantial amounts of information which is not germane to the study but may be of interest to those who want to examine such factors as the robust nature of the

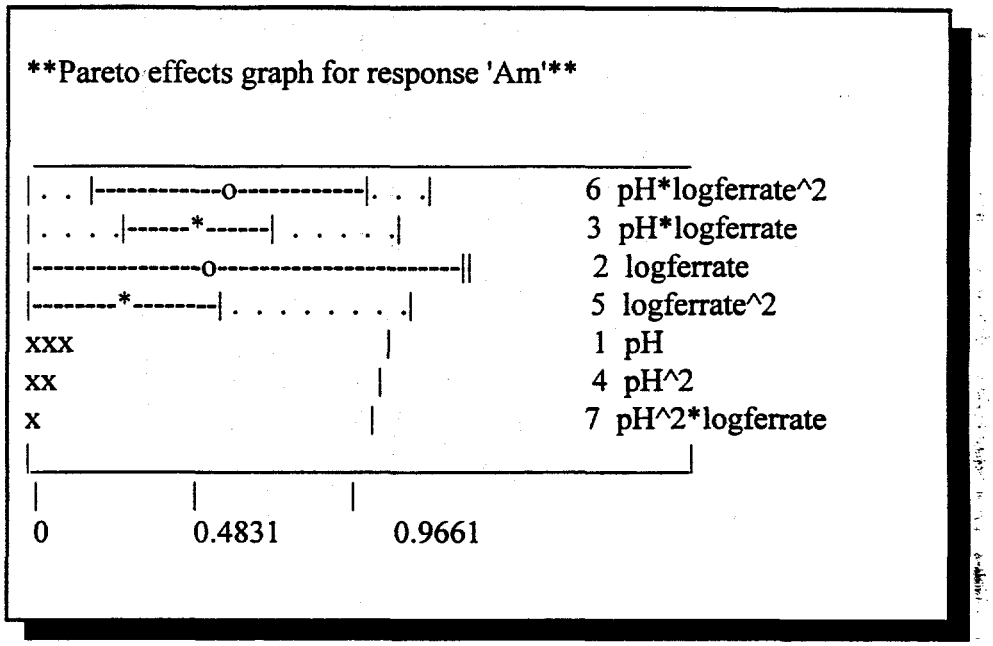
Figure 4.2.2-1 Summary of Results of Phase II Tests Using ECHIP Program



results or other statistical information; therefore, the complete output for the partial cubic model is presented in Appendix F. Figure 4.2.2-1 is the first of the computer outputs showing the effects of the variables, pH and ferrate, upon the elements. In this table the number of stars under each element and in the row of a particular factor indicate the relative effect. This figure does not give the absolute magnitude or sign of the effect. Figure 4.2.2-1 shows a lack of fit, using this model, for only five of the contaminants Pu, Cr, Co Fe, and Ag. Lack of Fit message is displayed when there was a significant difference between the residual SD and the replicate SD. Many of the analytical results were at or below the analytical detection limits and the replicate SD is a small number, so this lack of fit for at least Cr, Co and Ag was not serious. There was no explanation for the lack of fit for iron, but it could be attributed to the addition of iron to the experiment, causing a different response and thus requiring a different model to analyze the results. Also, the lack of fit for silver (Ag) was probably caused by its interaction with thiosulfate, a known complexing agent for silver.

To determine the magnitude and sign of the coefficients of the variables, the "Pareto Graphs" are very useful. Several of these are presented here to point out the effect of the test variables upon the removal of the COCs. Interaction of ferrate with pH creates a more effective response for an element's removal than either by itself. In Figure 4.2.2-2 the Pareto Graph is presented for americium. Notice that the effects are in descending order of the absolute effects. The effects are scaled to the units of the response, in this case pCi/l. The line represents the 95% confidence limit and was very broad. This is due to experimental error, both testing and analytical, and it is not possible to separate the two in this study. The " * " in the line is for a positive coefficient and the " o " is for a negative response. Those factors with " x " only, no line, has a small effect so it can be eliminated from consideration.

Figure 4.2.2-2 Pareto Effects Graph of Americium

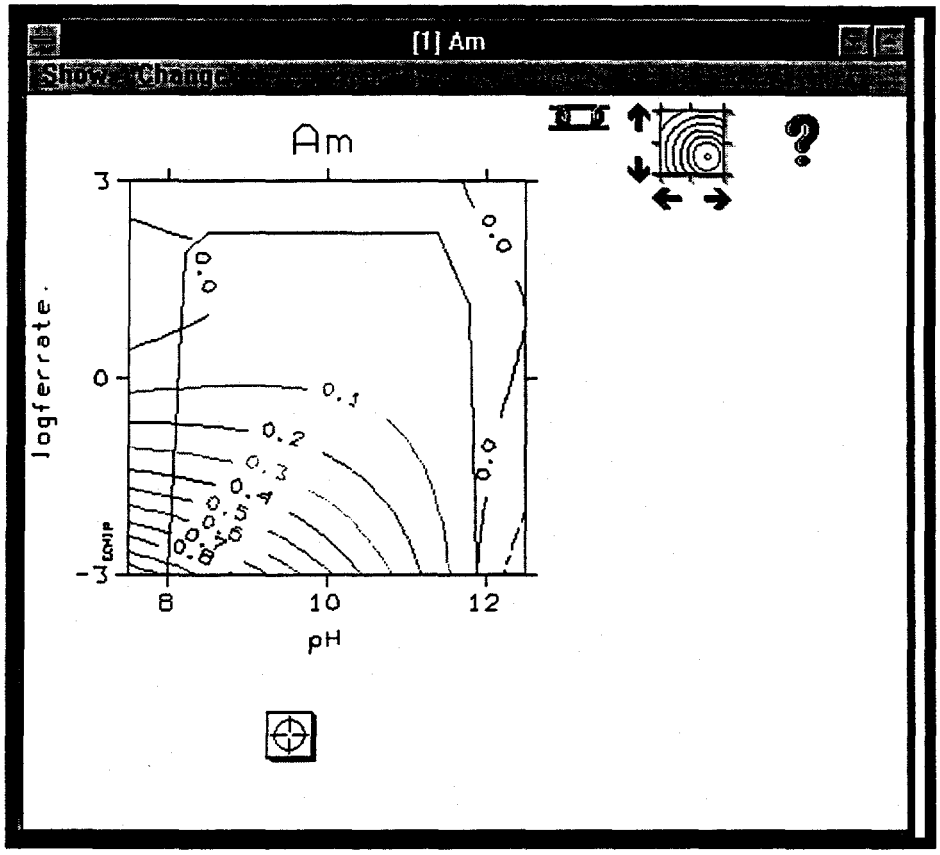


For americium, it is obvious that ferrate addition is needed to reduce its' concentration in solution because the effect of logferrate and pH*logferrate^2 are negative. As these two values increase, the concentration of americium decreases. Notice that pH and pH^2 have little or no effect upon americium, which confirms what was observed in Phase I.

Figure 4.2.2-3 presents the two dimensional graph of the response surface for americium. This figure shows the response surface calculated from the equation generated by the computer analysis of the test data. The contours in this figure are approximately one standard deviation apart. The series of lines that cross the contours is essentially the experimental region.

Review of the information in Appendix F shows that the responses are similar for groups of elements. Uranium and barium have similar response surfaces and are more dependent upon pH than are the other elements. Americium and plutonium have similar removal responses, which

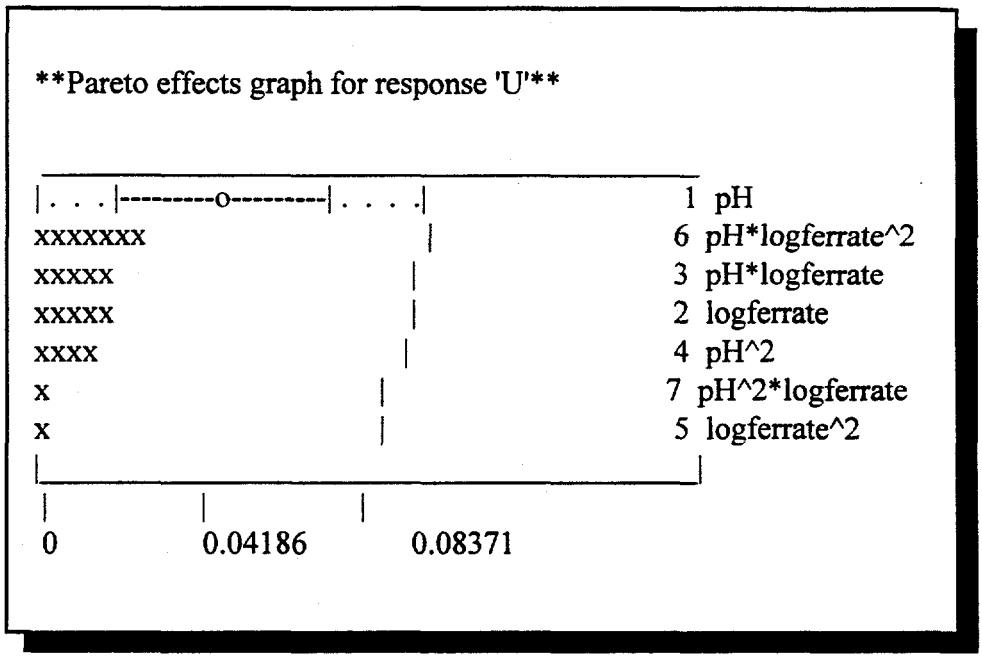
Figure 4.2.2-3 Response Surface of Americium



are dependent on ferrate in combination with pH. Cr, Co, Cu and Ag are similar having a rather complex response. Selenium shows a response very different from any of the other contaminants in that there is no decrease in its' concentration in the test region. In fact a maximum occurs in the center of the field of investigation. It is possible that this is due to the fact that there are more data points in this region. Fe, Al and Zn are similar in their response to the interaction of ferrate and pH.

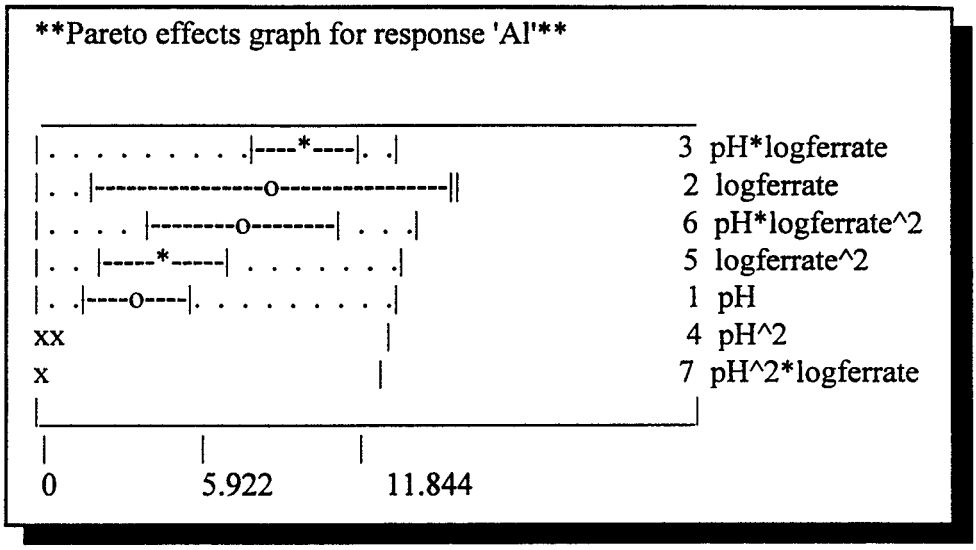
The Pareto Graph for uranium is shown in Figure 4.2.2-4. It can be seen that pH was the only major factor that removed it from solution. All of the other factors were of no importance. Barium is similar but with some interaction of the two variables pH and ferrate.

Figure 4.2.2-4 Pareto Effects Graph of Uranium



The Pareto Graph of Al shows the strong effect of ferrate upon its' removal from solution, but with more interaction of the variables. Figure 4.2.2-5 shows that pH*log ferrate has a strong positive effect, that is the concentration of Al in solution will increase as the product of these two variables increases. However, the second term logferrate has a strong negative effect, therefore, it is obvious which variable to manipulate to increase the removal of Al from the treated water. From the Pareto Graph its difficult to picture what actually occurs. It is much easier to interpret this system using the two dimensional graph, Figure 4.2.2-6.

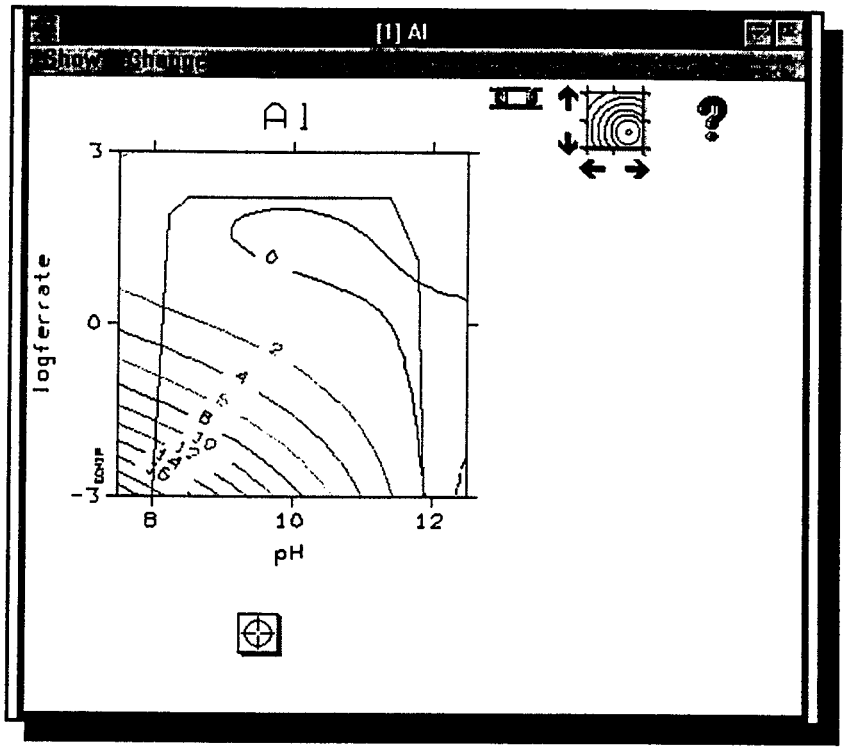
Figure 4.2.2-5 Pareto Effects Graph of Aluminum



Results of the computer analysis of Phase II data show that all the COCs except selenium are removed by the ferrate treatment process. By inspection of the response surfaces in Appendix F it appeared that concentrations below the CWQCC discharge limits were achieved in a common region of all the elements, except for selenium and possibly silver.

The final step of the analysis of Phase II results was to determine the optimum treatment conditions using the corrected radionuclide data. Again the objective of this optimum search was to determine if there is a single set of treatment conditions that would produce treated water in which all of the COCs are below the CWQCC discharge limits. This was done by combining the responses using the same weighting factor used when the uncorrected data was optimized. Figure 4.2.2-7 shows the combined response graph and the optimum point picked by searching the region where the combined response was less than 0.06. The optimum conditions selected from this figure are pH 10.2 and logferrate 1.36 (22.9 mg/l 45 % potassium ferrate). This point

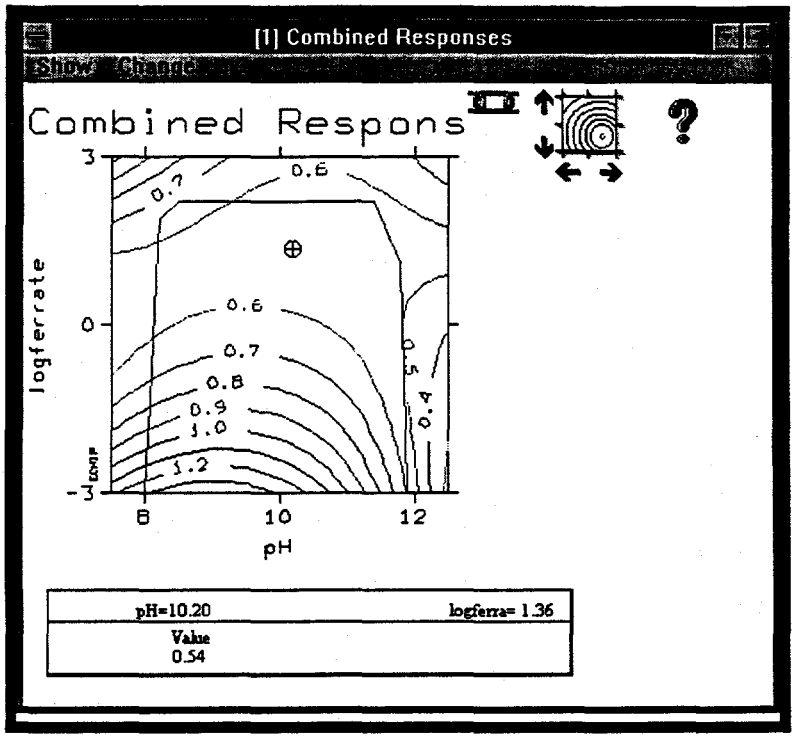
Figure 4.2.2-6 Aluminum Response to Ferrate Treatment



was picked to minimize reagent consumption of reagents and still yield acceptable responses of the majority of the elements. At this point the calculated combined response is 0.54. It is not possible to say that all the contaminants met their individual limits. Therefore, as before, the optimum condition was checked for each of the element on their response plots to determine the concentration of the COCs that can be expected from treatment with these conditions. The results are shown in Table 4.2.2-1.

In Table 4.2.2-1 there are 13 elements where the predicted results are below the CWQCC discharge limits. Four additional the elements have CWQCC discharge parameters below the

Figure 4.2.2-7 Combined Response Surface of Corrected Phase II Responses



analytical detection limits; therefore, it is not known if the discharge limits were met. The predicted concentrations of plutonium, selenium and silver water are above the CWQCC discharge limits. However, the 95 % confidence range is rather broad, meaning that the elements predicted value has a 95 % probability that it falls within a range meeting CWQCC discharge limits. Therefore, test are required to confirm these predicted values. The results do show, however, that ferrate water treatment technology when applied to the RFETS groundwater will produce treated water meeting most of the CWQCC discharge limits.

Table 4.2.2-1 Predicted Contaminant Concentration at the Optimum Treatment Conditions

	Predicted Results				CWQCC Discharge Limits	Meets Discharge Limits
	At Optimum	95 % Confidence				
Elements		Low Level	High Level	Units		
Americium	0.027	-0.090	0.143	pCi/l	0.05	Yes
Plutonium	0.36	-0.69	1.41	pCi/l	0.05	No
Uranium	0.0118	-0.0028	1.41	mg/l		Yes
U (Calc)	0.393	-0.0924	46.95	pCi/l	5-10	Yes
Aluminum	-0.14	-1.14	0.86	mg/l	0.087	Yes
Barium	-0.005	-0.033	0.023	"	1	Yes
Chromium	0.0001	-0.033	0.0092	"	0.05	Yes
Cobalt	-0.0015	-0.0171	0.014	"	0.05	Yes
Copper	-0.0001	-0.0114	0.0111	"	NA	---
Iron	-0.12	-0.37	0.14	"	0.3	Yes
Selenium	0.0605	0.0534	0.0676	"	0.01	No
Silver	0.0048	-0.0031	0.0127	"	0.0006	No
Zinc	-0.0007	-0.0044	0.0031	"	0.35	Yes
Element Reported Below ADL			**Analytical Detection Limits (ADL) mg/l**			
Beryllium			0.005		0.004	?
Cadmium			0.005		0.002	?
Manganese			0.005		0.56	Yes
Nickel			0.02		0.125	Yes
Vanadium			0.005		0.1	Yes
Antimony			0.05		0.024	?
Arsenic			0.005		NA	---
Lead			0.005		0.028	Yes
Mercury			0.0001		0.00001	?

The element selenium did not respond to this process since it exists as an anion in these solutions. Selenium as an anion cannot form an insoluble solid phase under these conditions; therefore, it cannot be expected to be removed by this water treatment method because the technique depends upon the formation of a solid phase containing the contaminant of concern. Selenium can be changed, by a simple pretreatment step, into a form that can be removed by the treatment process tested in this study.

Silver, the other element that was not removed satisfactorily, can be eliminated by a minor modification to the process. In this test program, thiosulfate was used to reduce excess ferrate and it was the thiosulfate which caused the silver to remain in solution. Silver forms a strong soluble complex of thiosulfate which would prevent the precipitation of a solid silver compound. This problem can be overcome by using a reductant that does not complex any of the COCs. Sulfurous acid, SO_2 dissolved in water, would be a suitable alternative.

Phase III tests were performed at slightly different conditions than the optimum picked from the corrected combined response surface. The predicted concentrations at the treatment conditions used were determined from the response surface with the corrected results and tabulated in Table 4.2.2-2. It can be seen by comparing the data in Table 4.2.2-1 and 4.2.2-2 that Phase III tests were not conducted at the optimum conditions in that every predicted COCs concentration at the Phase III test conditions are higher than those predicted at the optimum conditions.

Table 4.2.2-2 Predicted Results at Phase III Treatment Conditions Using the Corrected Data Response Surface Model

	Predicted Results				CWQCC Discharge Limits	Meets Discharge Limits
	At Optimum	95 % Confidence				
Elements		Low Level	High Level	Units		
Americium	0.029	-0.092	0.15	pCi/l	0.05	Yes
Plutonium	0.47	-0.62	1.56	pCi/l	0.05	No
Uranium	0.0164	0.0013	0.0315	mg/l		Yes
U (Calc)	0.546	0.0433	1.049	pCi/l	5-10	Yes
Aluminum	-0.01	-1.08	1.03	mg/l	0.087	Yes
Barium	0.006	-0.023	0.035	"	1	Yes
Chromium	0.0004	-0.008	0.0089	"	0.05	Yes
Cobalt	-0.007	-0.0169	0.0155	"	0.05	Yes
Copper	0.0009	-0.0108	0.0126	"	NA	---
Iron	-0.13	-0.039	0.13	"	0.3	Yes
Selenium	0.0609	0.0536	0.0683	"	0.01	No
Silver	0.0043	-0.0036	0.0122	"	0.0006	No
Zinc	-0.0005	-0.0044	0.0034	"	0.35	Yes
Element Reported Below ADL			**Analytical Detection Limits (ADL) mg/l**			
Beryllium			0.005		0.004	?
Cadmium			0.005		0.002	?
Manganese			0.005		0.56	Yes
Nickel			0.02		0.125	Yes
Vanadium			0.005		0.1	Yes
Antimony			0.05		0.024	?
Arsenic			0.005		NA	---
Lead			0.005		0.028	Yes
Mercury			0.0001		0.00001	?

4.2.3 Conclusions from Phase II Tests

A major conclusion from Phase II was that ferrate effectively removed or aided in the removal of the COCs from the RFETS groundwater except selenium. The ferrate treatment process produces treated water that meets or very closely approaches the CWQCC discharge limits. The technology is simple and easy to apply in conventional water treatment plants. Other conclusions from this phase of the work are:

1) There is a single combination of pH and ferrate addition that can be used to eliminate the COCs from the RFETS groundwater and meet all but three of the CWQCC discharge limits.

2) Ferrate alone removes some elements from solution such as americium and plutonium.

3) High pH alone was effective in removing uranium from the groundwater.

4) Many elements respond to both pH and ferrate and/or their interaction, such as chromium, cobalt, copper and others.

4.3 PHASE III RESULTS AND DISCUSSION

Results of Phase II were very encouraging. The ECHIP mathematically calculated response surfaces, from the Phase II modified test matrix, predicted that for 12 of the 19 COCs their concentrations in water treated with potassium ferrate will be below the CWQCC discharge limits. For four of the elements the analytical detection limits were greater than the CWQCC discharge limits, so it is not certain if ferrate treatment reduced their concentrations enough to meet the discharge requirements. Plutonium, selenium and silver failed to meet the discharge limits as predicted by the combined surface model. The possible reasons for the lack of response of these element were discussed in Section 4.2 of this report.

Phase III was conducted to confirm that ferrate treated water would be as clean as predicted in Phase II (Table 4.2.2-2). Some preliminary engineering data were also obtained in this phase of the study. The Phase II combined response surface (Combined Response Contour plot Figure 4.2.2-7) shows a rather large area where the combined response (removal of the COCs) is less than 0.6 and a much smaller area where the combined response is less than 0.5. Treatment at points in the < 0.5 zone would yield the best overall removal of the COCs. However, raising the pH to over 12 so as to be in the <0.5 response zone and then neutralizing the treated water back to pH 7, for discharge, would greatly increase the dissolved solids in the treated water and consume large amounts of reagents. Rather than select the technical optimum (combined response < 0.5) a more practical economic optimum was selected. The practical optimum will produce water with acceptable COCs concentrations and minimize the amount of reagents required, lowering the overall treatment costs. The zone < 0.6 to > 0.5 was examined to find a point that would minimize reagents and still yield acceptable results. The optimum point picked using the uncorrected analytical results was at a pH of 10.35 with potassium ferrate addition of 10.5 mg/l (log ferrate 1.02). The Phase III test plan was to simply perform several tests at the

optimum treatment conditions. In this phase four tests were performed in order to statistically analyze the results and detect any significant differences in the tests results.

The Phase III test conditions were:

1) pH 10.35
2) 10.5 mg/l 45 % potassium ferrate (log ferrate 1.02)
3) 20 mg/l alum
4) 5 mg/l polymer

These tests were run as described in Section 3.3.3, except thiosulfate was added in two steps, allowing 15 minutes of mixing after each addition. As in the previous tests, an aliquot of the treated water was decanted from the settled solids into clean plastic bottles, sealed and submitted to Accu-Labs for chemical analysis.

4.3.1 Preliminary Engineering Data

In addition, several measurements were made to gather preliminary engineering data. The settling rate of the solids was measured as well as the volume of the settled solids. These two measurements were made using an Imhoff settling cone. After decanting the majority of the treated water from the beakers, into analytical sample containers, there was not enough slurry to conduct a settling test on individual test runs. Therefore, slurries from two tests were combined and then the settling rate and the settled solids volume determined. These measurements were done twice. Settling rate was measured, after the slurry was poured into the cone, by timing the drop of the solid/clear water interface and reporting the results in inches per minute. The Imhoff cone is calibrated at the bottom, in milliliters, so the volume of settled solids was read directly from this scale. The volume was measured at timed intervals until the volume of solids became

constant. The settled solids from the two tests were combined and then filtered to make an assessment of their filterability. It was not possible to conduct a filtration test because of the small volume of the settled solids available. Finally, the solids from all eight liters of groundwater treated in Phase III were dried, weighed and submitted to Accu-Lab for chemical analysis. Table 4.3-1 presents the analytical results (Appendix C) of the treated water from the four test and the combined dried solid from the four tests.

The preliminary engineering data gathered during Phase III were:

1) The settling rate of the flocculated solids was 2.5 inches per minute (average of two tests).

2) The solution above the settled solids was cloudy, but it cleared at an approximate rate of 0.05 inches per minute.

3) Solids compacted completely in 8 to 10 minutes to 17.25 ml per liter of treated solution or 2.31 cubic feet per 1000 gallons of treated water. This settled slurry was 13 percent solids (average of two tests).

4) The settled solids filtered rapidly; much faster than expected of water treatment sludge. Based on experience the rate was such that excessive filter surface area will not be required in a treatment plant.

5) The weight of dry solids recovered was 1.25 gm/l of treated water or 10.45 pounds per 1000 gallons of treated water.

A one liter sample of treated water produced 1.25 gm of solids. Only 0.0355 gm of reagents were added per liter of treated water. Assuming all of the reagents added to the water in the tests were recovered in the solids, then 96.8 % of that weight was formed by clarification and precipitation of the contaminants in the groundwater. Potassium ferrate and alum both form metal hydroxides in the system which are lighter than the reagents. Therefore, solids formed from the reagents would weigh less. For example, alum ($Al_2 (SO_4)_3$) will form $Al(OH)_3$ which weighs only 22.8% of the alum. If the weight loss of both these reagents is considered, it can then be said that 99.0% of the weight of the recovered solids are from the ground water.

Using the laboratory test procedures and this preliminary engineering information, a generalized flowsheet and material balance can be generated. A condensed flowsheet is presented in Figure 4.3.1-1. The potassium hydroxide (KOH) addition was not measured, but the pH was monitored, so an estimate of the consumption can be made. It was estimated that about 0.65 lb of KOH will be required to treat 1000 gal of groundwater. The other reagent consumption's are based upon the amounts used in the tests. The filtered solid waste was assumed to be 50 % moisture for the material balance. Overall, treating 1000 gal of RFETS contaminated groundwater with the ferrate process will produce 20.9 lb of wet waste material.

4.3.2 Phase III Potassium Ferrate Demonstration Results

The analytical results of the treated water are presented in Table 4.3.2-1 along with the averages of the four tests and the analysis of the dried solids recovered from the four tests.

All of the radionuclides were removed well below the CWQCC discharge limits and well below the predicted concentrations from any of the models developed in Phase II. Iron's results were

Figure 4.3.1-1 General Flowsheet for Ferrate Treatment of RFETS Contaminated Groundwater

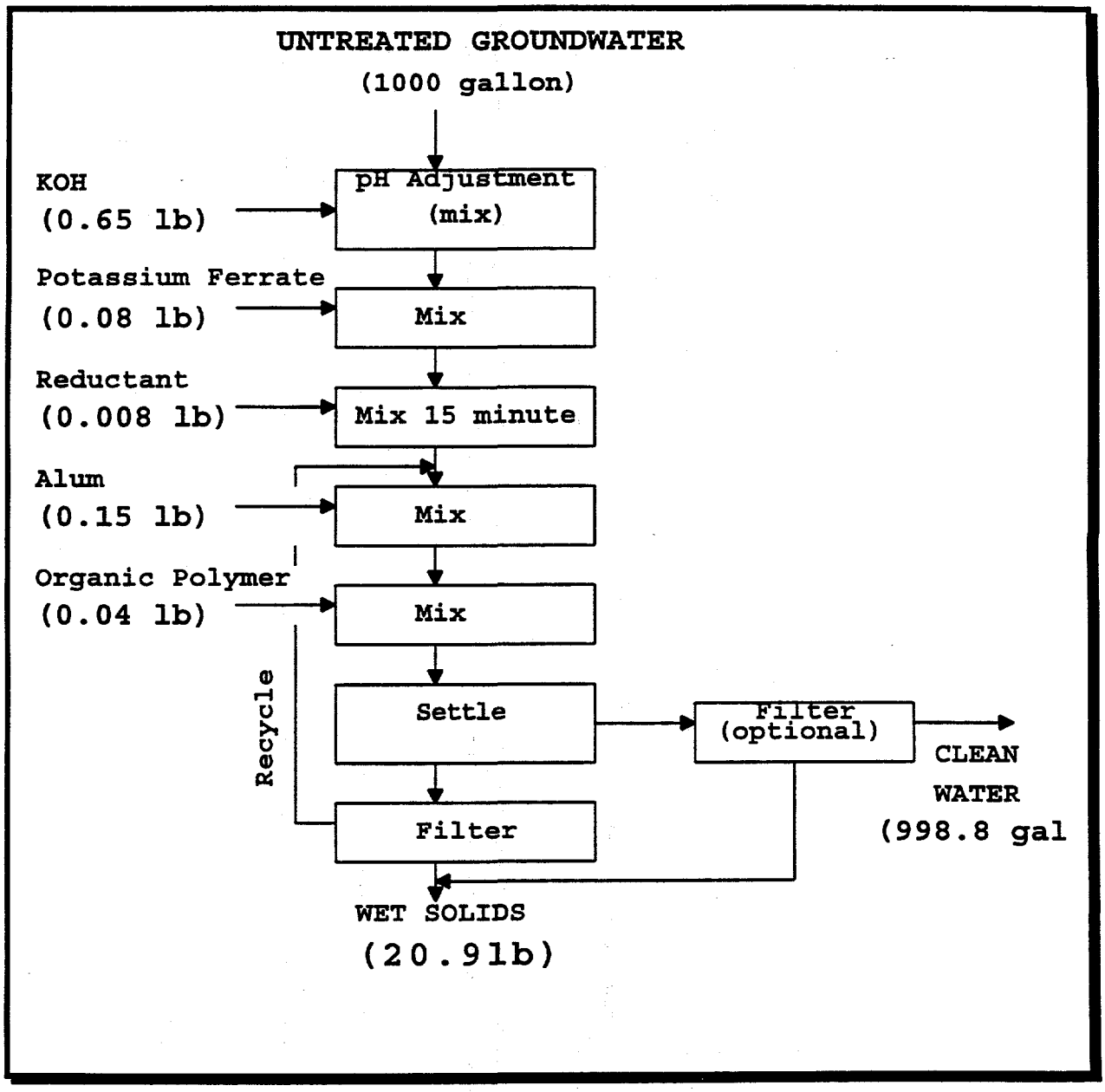


Table 4.3.2-1 Results of the Phase III Ferrate Treatment Tests at the Optimum Conditions

	Treated Water Analysis					Dried Solids Analysis
Element	**Test No. 1**	**Test No. 2**	**Test No. 3**	**Test No. 4**	**Average**	
Radionuclide	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/gm
Am 241	0.00	-0.02	0.00	0.00	0.00	1.7 +/- 0.72
Pu 239/240	0.02	0.04	0.04	0.03	0.0325	7.7 +/- 1.4
Uranium	0.0013 mg/l	0.0016 mg/l	0.0017 mg/l	0.0018 mg/l	0.0016 mg/l	31 ug/gm
U-calculated	0.043 pCi/l	0.053 pCi/l	0.057 pCi/l	0.060 pCi/l	0.053 pCi/l	
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/kg
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	21
Aluminum	<0.1	<0.1	<0.1	<0.1	<0.1	15,000
Barium	<0.05	<0.05	<0.05	<0.05	<0.05	150
Beryllium	<0.005	<0.005	<0.005	<0.005	<0.005	1.0
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	0.6
Cobalt	<0.01	<0.01	<0.01	<0.01	<0.01	6
Chromium	<0.005	<0.005	<0.005	<0.005	<0.005	17
Copper	<0.005	<0.005	<0.005	<0.005	<0.005	27
Iron	0.02	0.02	0.02	0.02	0.02	15,000
Manganese	<0.005	<0.005	<0.005	<0.005	<0.005	200
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	1
Nickel	<0.05	<0.05	<0.05	<0.05	<0.05	18
Antimony	<0.05	<0.05	<0.05	<0.05	<0.05	<5
Selenium	0.056	0.055	0.056	0.058	0.0562	<5
Thallium	<0.5	<0.5	<0.5	<0.5	<0.5	<50
Vanadium	<0.005	<0.005	<0.005	<0.005	<0.005	25
Zinc	<0.005	<0.005	<0.005	<0.005	<0.005	60
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	7.2
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.1
Lead	<0.005	<0.005	<0.005	<0.005	<0.005	11

* Uranium pCi/l calculated using the relationship 1 pCi/l = 0.03 mg/l

greater than predicted. All of the other element's the results were so low they were all below the analytical detection limits.

It appears from this data that all of the COCs concentration in treated water from this process will be below CWQCC discharge limits with the exception of selenium and possibly silver. For both of these elements a simple pretreatment of the water with a reductant, such as zinc, will ensure that they too will meet the CWQCC discharge limits.

4.3.3 Discussion of the Statistical Implications of Phase III Results

In the previous phases of this study the ECHIP software did the statistical analysis of the results. In this phase some discussion of the statistics are also necessary because there are some implications upon the conclusions from this work.

Calculations of the standard deviation of four elements where there is sufficient data show that the overall treatment error is very small. This includes both treatment testing error and analytical error. In fact, the results indicate that the overall error is much lower than the reported analytical error. If three times the standard deviation is added to the average results the total is below the CWQCC discharge limits. Interpreting this data indicates that at these treatment conditions there is a 99 % assurance that the treated water will meet the discharge limits. The treated water concentrations and three times the SD of the four COCs are presented below:

		3 X SD
Am	0.00 pCi/l	+/- 0.005 pCi/l
Pu	0.0325 pCi/l	+/- 0.029 pCi/l
U	0.053 pCi/l	+/- 0.022 pCi/l
Fe	0.02 mg/l	+/- 0.005 mg/l

This means that the treatment process will always meet the discharge limits for these elements and it can be assumed that the same accuracy applies to all the other elements that meet the discharge limits but are below the analytical detection limits in the Phase III results.

With the exception of selenium it seems reasonable that all of the COCs will be below the CWQCC discharge limits. This is based upon the fact that the actual Phase III results for the three radionuclides are at least one order of magnitude lower than the predicted concentrations using the ECHIP software. It is estimated that this same effect was experienced by the other COCs and their concentrations should have been well below CWQCC discharge limits. The reason that the results from Phase III are so much better than predicted from previous work is not clear; however one could postulate that the interaction effects at or near the optimum treatment condition are much more important than could be determined by testing over such a broad range of the test variables. This is especially true for uranium were it appeared that only pH effected its' removal. Results from these tests are much better than Phase II results would predict based upon pH removal only.

4.3.3 Conclusion from Phase III Tests

The results from the four tests were spectacular in that the removal of the COCs was much better than predicted for all of the elements, even silver. Also, the agreement of the analytical results (Table 4.3.2-1) between the four tests was excellent indicating the process is not very sensitive to minor variations and should be a relatively easy process to operate and control.

It also can be concluded from this phase of the work that the combined surface model developed in Phase II does predict the results of treatment conditions, but errors on the conservative side. In fact for the radionuclides the actual results are one order of magnitude less than predicted.

Iron, the only other element where the data was above the analytical detection limit was within the 95% confidence limits of the predicted results. It must be remembered that iron has a lack of fit to the mathematical model used to generate the combined response surface. If the difference between the predicted concentration and the actual is true, in that the actual is one order of magnitude lower, then even silver would meet the CWQCC discharge limits.

5.0 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

Throughout this study many of the steps were subjected to QA/QC controls, some formal and others as a result of the testing procedures. In this section the QA/QC procedures will be enumerated and discussed.

5.1 GROUNDWATER SAMPLING

The groundwater was taken from the monitoring walls within the RFETS over several days. Sampling was done in accordance to the EG&G operating procedure for groundwater sampling, OPS-GW-06, March 1992 by an EG&G subcontractor.

5.2 CHEMICAL ANALYSIS

All of the chemical analysis were performed by Accu-Labs Research, Inc., Golden, Colorado. The EPA approved methods are listed in Table 1.0-2 along with the detection limits for these methods. Accu-Labs is a certified environmental analytical laboratory following all the required QA/QC protocols.

5.3 COMPUTER MODELING

A software program called ECHIP was used in this study to evaluate the results of the experiments. These results were the analytical determinations of the COCs in the treated water from the experiments. The other input to the program were the experimental variables used in

each test. Therefore, the boundaries of the model used were conditions established by the investigators which were well defined and no extraneous factors could have been introduced. The spacing (grid) of the test variables was set at the limits of the range of the variable examined with one center point. The variables in the first phase of testing were pH, amount of ferrate, alum and organic polymer added to the reactor. In the second phase of the study there were only two variables, pH and ferrate addition. Measurement of the variable was done by instrumentation (pH meter) and weight or volume of dissolved reagents. All of these measurements were with in +/- 0.10 %.

The hardware needs for this program are those required for Windows™ . These requirements are:

80386 (or higher) processor
4 Mb of RAM (640K conventional + 3456 extended)
10.5 Mb free hard disk space
VGA video graphics.

The software ECHIP is based upon a large body of literature of experimental design and statistics. This program is licensed to users by ECHIP Inc. and is copyrighted. For use in this study, the program was not modified in any way from the published version 6.0.

The input information was only that generated in the laboratory or by the analytical laboratory. No assumptions were made in its application.

The output from the program are presented in Appendices D, E and F of this report and are clearly labeled.

Verification that the program was installed and operating correctly was done by solving several sample problems provided with the software. Since the models and other features within the software are not unique there was no other verification made.

5.4 INSTRUMENTATION

An Orion 230 pH meter was used to monitor the tests. This meter was calibrated each day and the standardization checked with a pH 10 buffer each time a measurement was made. If the pH meter reading was 0.05 pH units from 10 the meter was calibrated using the two point method, a common laboratory technique. The only other instrumentation used was the stirrer speed control. This was not calibrated or checked for accuracy. It was believed that since the unit used the electrical power frequency to calibrate itself no further calibrations were needed.

5.5 LABORATORY TECHNIQUES

Several procedures were followed when conducting this study to determine how well the program was performing and how consistent the results were from one phase of the program to the next since they were conducted several weeks apart.

First, an aliquot of the bulk groundwater sample was taken at the beginning of each phase of the study to determine if: 1) the mixing and sampling techniques of this bulk sample were adequate and 2) to insure that there was no change in the concentration of the COCs over the period of study (about three months) due to the growth of organisms or other factors. Table 1.2-2 shows the analysis of the bulk groundwater samples taken during each phase of the program. These data show that the mixing and sampling techniques used were consistent throughout the tests.

There were no changes in the concentration of the COCs over the several months when this study was conducted.

To assess the accuracy and precision of the analytical results and determine if the test methods used in this study were acceptable, a material balance was performed. In the last phase of the study the recovered solids and treated water were analyzed. Using these two analyses and the average analysis of the bulk solution it was possible to calculate a material balance for each of the COCs, shown in Table 5.5-1. These calculations show that the analytical data and experimental techniques were acceptable; especially, when considering the low concentrations of the contaminants where large deviations of analytical results are expected.

The material balance calculations in Table 5.5-1 were based upon the four two liter tests performed in Phase III. From these four tests 10.0 grams of dried solids and eight of liters of treated water were produced. The analysis of these products (Appendix C) and the average analysis of the bulk sample (Table 1.2-2) were used for the calculations. When the analytical results were below the detection limits, zeros were used in the calculation. The column labeled "Material Balance" is the recovered mg of the elements divided by the initial mg times 100. A value of 100 % would confirm accountability for the total weight of each COCs constituent in the Phase III tests. The table displays material balances for each COCs between 72% and 231% with an average accountability of 108% for the total COCs group. The only poor material balance was for americium which was 231%. When this value is removed, the average accountability is 100.4%, which is exceptional. Removal of the americium balance is justified by statistics because it is beyond three standard deviations (1 SD = 18.3%) of the average.

Table 5.5-1 Material Balance Calculations

Element	Groundwater		Treated Water		Dried Solids		Element Recover	Material Balance
	8 liters		8 liters		10.0 grams			
	mg/l	mg	mg/l	mg	mg/Kg	mg	mg	%
Silver	0.029	0.232	<0.005	0.000	21	0.21	0.21	90.5
Al	19.33	154.64	<0.1	0.000	15,000	150	150	97.0
Barium	0.247	1.967	<0.05	0.000	150	1.5	1.5	76.3
Be	<0.005	0.000	<0.005	0.000	1.0	0.01	0.01	NA
Cd	<0.005	0.000	<0.005	0.000	0.6	0.006	0.006	NA
Cobalt	0.0065	0.052	<0.01	0.000	6	0.06	0.06	115.4
Cr	0.0237	0.1896	<0.005	0.000	17	0.17	0.17	89.7
Copper	0.0273	0.2184	<0.005	0.000	27	0.27	0.27	127.5
Iron	20.0	160	0.02	0.16	15,000	150	150.16	93.8
Mn	0.257	2.056	<0.005	0.000	200	2.00	2.00	97.3
Mo	<0.01	0.000	<0.01	0.000	1	0.01	0.01	NA
Nickel	<0.05	0.000	<0.01	0.000	18	0.18	0.18	NA
Sb	<0.05	0.000	<0.05	0.000	<5	0.000	0.000	NA
Se	0.042	0.336	0.0562	0.4496	<5	0.000	0.4496	133.8
Th	<0.5	0.000	<0.1	0.000	<50	0.000	0.000	NA
V	0.0433	0.3464	<0.005	0.000	25	0.25	0.25	72.2
Zinc	0.0867	0.6936	<0.005	0.000	60	0.6	0.6	86.5
Arsenic	0.010	0.080	<0.005	0.000	7.2	0.072	0.072	90.0
Mercury	<0.0001	0.000	<0.0001	0.000	<0.1	0.000	0.000	NA
Lead	0.0123	0.0984	<0.005	0.000	11	0.11	0.11	111.8
Radionuclides								
Uranium	0.04	0.32	0.0016	0.013	31	0.31	0.323	100.9
	pCi/l	pCi	pCi/l	pCi	pCi/gm	pCi	pCi tot.	
Am	0.92	7.36	0.00	0.00	1.7	17	17.0	231.0
Pu	7.80	62.4	0.0325	0.26	7.7	77	77.26	123.8

REFERENCES

1) CDH/WQCC, Colorado Water Quality Standards 3.1.0 (5 CCR 1002-6) 1/15/74; amended 10/17/1991 (ARAR).

2) Work Plan for Potassium Ferrate Treatment of RFP Ground Water, Rocky Flats Plant, Environmental Restoration Program, July 1994, RFP/ERM-94-00010.

3) U. S. DOE 1991, "1990 Annual RCRA Grounwater Monitoring Report for Regulated Units at Rocky Flats Plant, Golden, Colorado," March 1991.

4) U. S. DOE, 1991, "1991 Annual RCRA Groundwater Monitoring Report for Regulated Units at Rocky Flats Plant, Golden, Colorado," March 1992.

5) Stoupine, D.Y., Ozernol, M. I., "Application of Commercially Available Sodium Ferrate for Treatment of Especially Hazardous Industrial Waste Waters," Environmental Conference, Moscow, September 1994.

6) Waite, T. D. "Feasibility of Wastewater Treatment with Ferrate," Journal of the Environmental Engineering Division, ASCE, vol. 105, NEE6, pp 1023-1034, 1979.

7) Potts, M. E., Churchwell, D. R., "Removal of Radionulides in Wastewaters Utilizing Potassium Ferrate (VI)," Water Environment Research, vol. 66, pp 107-109, March-April, 1994.

8) "Treatability Study for the TRU/Clear™ Precipitation Process at the Rocky Flats Plant," Rev. 1, EG & G Solicitation No. 221457BC, July, 1992.

APPENDIX A

ANALYTICAL REPORTS OF TREATED WATER FROM PHASE I TESTS

Accu-Labs® Research, Inc.

4663 Table Mountain Drive Golden, Colorado 80403-1650
(303) 277-9514 FAX (303) 277-9512

ANALYSIS REPORT

DATE: 08/31/94 PAGE 1

J.C. LAUL
EG&G ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE
P O BOX 464 BLDG 881
GOLDEN, CO 80402-0464

Lab Job Number: 2426-56170-15
Date Samples Received: 08/22/94
Customer PO Number: ASC233268JO3

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-56170-15-1	2426-56170-15-2	2426-56170-15-3	2426-56170-15-4
Sponsor Designation -	FEED SOLUTION	1A	1B	2A
Date Collected -				
Determinations in mg/L unless noted				
Silver - total	0.029	<0.005	<0.005	0.005
Aluminum - total	18	0.7	0.7	<0.1
Barium - total	0.23	0.06	0.06	<0.05
Beryllium - total	<0.005	<0.005	<0.005	<0.005
Calcium - total	130	57	60	1.2
Cadmium - total	<0.005	<0.005	<0.005	<0.005
Cobalt - total	0.007	<0.005	<0.005	<0.005
Chromium - total	0.020	<0.005	<0.005	<0.005
Copper - total	0.029	<0.005	<0.005	<0.005
Iron - total	19	0.03	0.03	0.78
Potassium - total	6.8	100	97	340
Lithium - total	0.15	0.14	0.15	0.14
Magnesium - total	30	25	26	0.12
Manganese - total	0.24	<0.005	<0.005	<0.005
Molybdenum - total	<0.01	<0.01	<0.01	<0.01
Sodium - total	150	150	150	140
Nickel - total	0.02	<0.02	0.02	<0.02
Antimony - total	<0.05	<0.05	<0.05	<0.05
Selenium - total	0.06	0.09	0.08	0.08
Thallium - total	<0.1	<0.1	<0.1	<0.1
Vanadium - total	0.042	<0.005	<0.005	<0.005
Zinc - total	0.086	<0.005	<0.005	<0.005
Alkalinity, Total (as CaCO3 to pH 4.5)	300	160	----	320
Carbonate (as CO3)	<5	<5	----	160
Bicarbonate (as HCO3)	360	200	----	5

Accu-Labs® Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 2
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56170-15-1	2426-56170-15-2	2426-56170-15-3	2426-56170-15-4
	Sponsor Designation -	FEED SOLUTION	1A	1B	2A
	Date Collected -				
Determinations in mg/L unless noted					
pH					
(pH Units)		7.4	8.2	8.3	11.5
Arsenic - total		0.016	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001
Lead - total		0.012	<0.005	<0.005	<0.005
Selenium - total		0.044	0.051	0.047	0.055
Nitrate (as N)		100	100	----	110
Total Dissolved Solids (@180 °C)		1,100	1,100	1,100	1,400
Chloride		36	49	----	39
Sulfate (as SO4)		91	130	----	100

Accu-Labs Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 3
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56170-15-5	2426-56170-15-6	2426-56170-15-7	2426-56170-15-8
	Sponsor Designation -	2B	3A	3B	4
	Date Collected -				
Determinations in ug/L unless noted					
Silver - total		0.005	<0.005	0.005	0.005
Aluminum - total		<0.1	2.2	1.7	0.2
Barium - total		<0.05	<0.05	<0.05	0.08
Beryllium - total		<0.005	<0.005	<0.005	<0.005
Calcium - total		1.2	1.1	1.0	85
Cadmium - total		<0.005	<0.005	<0.005	<0.005
Cobalt - total		<0.005	<0.005	<0.005	<0.005
Chromium - total		<0.005	<0.005	<0.005	<0.005
Copper - total		<0.005	<0.005	<0.005	<0.005
Iron - total		0.76	0.68	0.90	0.04
Potassium - total		330	370	350	66
Lithium - total		0.14	0.14	0.14	0.15
Magnesium - total		0.18	0.07	0.08	27
Manganese - total		<0.005	0.005	<0.005	<0.005
Molybdenum - total		<0.01	<0.01	<0.01	<0.01
Sodium - total		150	140	140	160
Nickel - total		<0.02	<0.02	<0.02	<0.02
Antimony - total		<0.05	<0.05	<0.05	<0.05
Selenium - total		0.08	0.08	0.07	0.06
Thallium - total		<0.1	<0.1	<0.1	<0.1
Vanadium - total		<0.005	0.006	0.005	<0.005
Zinc - total		<0.005	<0.005	<0.005	<0.005
Alkalinity, Total (as CaCO3 to pH 4.5)		----	300	----	----
Carbonate (as CO3)		----	160	----	----
Bicarbonate (as HCO3)		----	<5	----	----
pH					
(pH Units)		11.5	11.4	11.3	8.2

Accu-Labs® Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 4
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56170-15-5	2426-56170-15-6	2426-56170-15-7	2426-56170-15-8
	Sponsor Designation -	2B	3A	3B	4
	Date Collected -				
Determinations in mg/L unless noted					
Arsenic - total		<0.005	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001
Lead - total		<0.005	<0.005	<0.005	<0.005
Selenium - total		0.052	0.053	0.052	0.047
Nitrate (as N)		----	110	----	----
Total Dissolved Solids (@180 °C)		1,300	1,300	1,300	1,100
Chloride		----	39	----	----
Sulfate (as SO4)		----	120	----	----

Accu-Labs® Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 5
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-56170-15-9	2426-56170-15-10	2426-56170-15-11	2426-56170-15-12
Sponsor Designation -	5	6	7	8
Date Collected -				
Determinations in mg/L unless noted				
Silver - total	<0.005	<0.005	0.009	<0.005
Aluminum - total	0.2	0.7	2.2	0.2
Barium - total	<0.05	0.07	<0.05	0.09
Beryllium - total	<0.005	<0.005	<0.005	<0.005
Calcium - total	1.0	59	1.1	81
Cadmium - total	<0.005	<0.005	<0.005	<0.005
Cobalt - total	<0.005	<0.005	<0.005	<0.005
Chromium - total	<0.005	<0.005	0.005	<0.005
Copper - total	<0.005	<0.005	<0.005	<0.005
Iron - total	2.3	0.02	2.7	0.02
Potassium - total	390	92	390	52
Lithium - total	0.14	0.15	0.14	0.15
Magnesium - total	0.07	26	0.08	27
Manganese - total	<0.005	<0.005	<0.005	<0.005
Molybdenum - total	<0.01	<0.01	<0.01	<0.01
Sodium - total	150	160	140	160
Nickel - total	<0.02	<0.02	<0.02	<0.02
Antimony - total	<0.05	<0.05	<0.05	<0.05
Selenium - total	0.09	0.07	0.07	<0.05
Thallium - total	<0.1	<0.1	<0.1	<0.1
Vanadium - total	<0.005	<0.005	0.005	<0.005
Zinc - total	<0.005	<0.005	<0.005	<0.005
pH				
(pH Units)	11.5	8.4	11.5	8.2
Arsenic - total	<0.005	<0.005	<0.005	<0.005
Mercury - total	<0.0001	<0.0001	<0.0001	<0.0001

Accu-Labs Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 6
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-56170-15-9	2426-56170-15-10	2426-56170-15-11	2426-56170-15-12
Sponsor Designation -	5	6	7	8
Date Collected -				
Determinations in mg/L unless noted				
Lead - total	<0.005	<0.005	<0.005	<0.005
Selenium - total	0.054	0.052	0.052	0.049
Total Dissolved Solids (@180 °C)	1,400	1,100	1,400	1,100

Accu-Labs® Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 7
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56170-15-13	2426-56170-15-14	2426-56170-15-15
	Sponsor Designation -	9	10	11
	Date Collected -			
Determinations in mg/L unless noted				
Silver - total		0.006	<0.005	0.007
Aluminum - total		2.0	0.2	0.3
Barium - total		<0.05	0.08	<0.05
Beryllium - total		<0.005	<0.005	<0.005
Calcium - total		1.3	65	6.7
Cadmium - total		<0.005	<0.005	<0.005
Cobalt - total		<0.005	<0.005	<0.005
Chromium - total		0.006	<0.005	<0.005
Copper - total		<0.005	<0.005	<0.005
Iron - total		2.3	0.02	0.13
Potassium - total		360	73	210
Lithium - total		0.14	0.15	0.14
Magnesium - total		0.06	27	11
Manganese - total		<0.005	<0.005	<0.005
Molybdenum - total		<0.01	<0.01	<0.01
Sodium - total		150	160	140
Nickel - total		<0.02	<0.02	<0.02
Antimony - total		<0.05	<0.05	<0.05
Selenium - total		0.07	0.10	0.11
Thallium - total		<0.1	<0.1	<0.1
Vanadium - total		<0.005	<0.005	<0.005
Zinc - total		<0.005	<0.005	<0.005
pH				
(pH Units)		11.3	8.3	9.7
Arsenic - total		<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001

Accu-Labs® Research, Inc.

ANALYSIS REPORT
DATE: 08/31/94 PAGE 8
Lab Job Number 2426-56170-15

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-56170-15-13	2426-56170-15-14	2426-56170-15-15
Sponsor Designation -	9	10	11
Date Collected -			

Determinations in mg/L unless noted

Lead - total	<0.005	<0.005	<0.005
Selenium - total	0.050	0.056	0.055
Total Dissolved Solids (@180 °C)	1,300	1,100	1,100

By: Eyda Hergenreder
Eyda Hergenreder
Metals Laboratory Supervisor

By: Susan J. Barker
Susan J. Barker
Inorganic Chemistry Supervisor

EH/SJB/rt

Accu-Labs Research, Inc.

Re: 2426-56170-5

Case Narrative

Selenium was analyzed by both ICP and graphite furnace.

QA results are as follows:

Reagent Blank:

ICP	<0.05 mg/L
HGA	<0.005 mg/L

Laboratory Control Sample:

ICP	(TV = 1.0 mg/L)	85%
HGA	(TV = 0.80 mg/L)	95%

Spike:

ICP	#10	89%	#15	92%	(TV = 1.0 mg/L)
HGA	#10	84%	#15	80%	(TV = 0.050 mg/L)

Duplicate:

ICP	#1	0.06 mg/L	and	0.06 mg/L	0%
	#11	0.07 mg/L	and	0.07 mg/L	0%
HGA	#1	0.044 mg/L	and	0.042 mg/L	5%
	#11	0.052 mg/L	and	0.052 mg/L	0%

Accu-Labs® Research, Inc.

4663 Table Mountain Drive Golden, Colorado 80403-1650
(303) 277-9514 FAX (303) 277-9512

Date: 09/02/94
Page 1

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc
Rocky Flats Env Tech Site
POB 464 Bldg 080
Golden, CO 80402-0464

Lab Job Number: 000120
Date Samples Received: 08/22/94
Customer PO Number: ASC233268JO3

ALR Designation:	94-A1134	94-A1135
Client Designation:	FEED SOLUTION	1A
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.044	0.038
Americium-241, total (pCi/L)	0.86 +/- 0.36	-0.03 +/- 0.10
Plutonium-239+240, total (pCi/L)	7.5 +/- 0.93	0.18 +/- 0.12
ALR Designation:	94-A1136	94-A1137
Client Designation:	1B	2A
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.037	0.0024
Americium-241, total (pCi/L)	-0.06 +/- 0.08	-0.06 +/- 0.08
Plutonium-239+240, total (pCi/L)	0.17 +/- 0.12	0.17 +/- 0.13
ALR Designation:	94-A1138	94-A1139
Client Designation:	2B	3A
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.0020	0.0042
Americium-241, total (pCi/L)	-0.01 +/- 0.12	0.01 +/- 0.14
Plutonium-239+240, total (pCi/L)	0.24 +/- 0.17	0.14 +/- 0.12

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000120
Date Samples Received: 08/22/94

ALR Designation:	94-A1140	94-A1141
Client Designation:	3B	4
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.0035	0.039
Americium-241, total (pCi/L)	-0.05 +/- 0.13	0.01 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.23 +/- 0.14	0.21 +/- 0.11
ALR Designation:	94-A1142	94-A1143
Client Designation:	5	6
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.0025	0.036
Americium-241, total (pCi/L)	-0.05 +/- 0.09	-0.03 +/- 0.10
Plutonium-239+240, total (pCi/L)	0.12 +/- 0.10	0.16 +/- 0.14
ALR Designation:	94-A1144	94-A1145
Client Designation:	7	8
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.0028	0.037
Americium-241, total (pCi/L)	0.05 +/- 0.18	-0.02 +/- 0.02
Plutonium-239+240, total (pCi/L)	0.12 +/- 0.08	-0.02 +/- 0.11

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

Accu-Labs Research, Inc

Date: 09/02/94
Page 3

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000120
Date Samples Received: 08/22/94

ALR Designation:	94-A1146	94-A1147
Client Designation:	9	10
Sample Location:		
Location II:		
Date/Time Collected		
Uranium, total (mg/L)	0.0034	0.036
Americium-241, total (pCi/L)	0.09 +/- 0.22	0.02 +/- 0.03
Plutonium-239+240, total (pCi/L)	0.19 +/- 0.13	0.02 +/- 0.11

ALR Designation:	94-A1148
Client Designation:	11
Sample Location:	
Location II:	
Date/Time Collected	
Uranium, total (mg/L)	0.0035
Americium-241, total (pCi/L)	0.00 +/- 0.01
Plutonium-239+240, total (pCi/L)	0.00 +/- 0.10

Variability of the radioactive disintegration process (counting error) at the 95% confidence level is 1.96 sigma and the level of significance may exceed that of the reported analytical result.

Scheduled sample disposal date: October 2, 1994.

Bud Summers
Radiochemistry Supervisor

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

Accu-Labs® Research, Inc.

4663 Table Mountain Drive Golden, Colorado 80403-1650
(303) 277-9514 FAX (303) 277-9512

ANALYSIS REPORT

DATE: 10/04/94 PAGE 1

J.C. LAUL
EG&G ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE
P O BOX 464 BLDG 881
GOLDEN, CO 80402-0464

Lab Job Number: 2426-56738-16
Date Samples Received: 09/21/94
Customer PO Number: ASC233268J03

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-1	2426-56738-16-2	2426-56738-16-3	2426-56738-16-4
	Sponsor Designation -	FEED SOLN	#0	#1	#1B
	Date Collected -	09/20/94	09/15/94	09/15/94	09/16/94
Determinations in mg/L unless noted					
Silver - total		0.028	0.008	0.010	0.007
Aluminum - total		20	0.2	0.5	0.4
Barium - total		0.23	<0.05	<0.05	<0.05
Beryllium - total		<0.005	<0.005	<0.005	<0.005
Calcium - total		98	11	1.0	1.1
Cadmium - total		<0.005	<0.005	<0.005	<0.005
Cobalt - total		0.006	<0.005	<0.005	<0.005
Chromium - total		0.025	0.008	0.009	0.006
Copper - total		0.023	<0.005	<0.005	<0.005
Iron - total		19	0.05	0.08	0.13
Potassium - total		6.6	180	390	370
Lithium - total		0.17	0.16	0.15	0.14
Magnesium - total		29	22	0.09	0.07
Manganese - total		0.24	<0.005	<0.005	<0.005
Molybdenum - total		<0.01	<0.01	<0.01	<0.01
Sodium - total		150	170	160	170
Nickel - total		<0.05	<0.05	<0.05	<0.05
Antimony - total		<0.05	<0.05	<0.05	<0.05
Selenium - total		<0.05	<0.05	<0.05	<0.05
Thallium - total		<0.5	<0.5	<0.5	<0.5
Vanadium - total		0.043	<0.005	<0.005	<0.005
Zinc - total		0.081	<0.005	<0.005	<0.005
pH					
	(pH Units)	8.0	9.4	11.4	11.4

APPENDIX B

ANALYTICAL REPORTS OF TREATED WATER FROM PHASE II TESTS

A N A L Y S I S R E P O R T

DATE: 10/04/94 PAGE 2

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-1	2426-56738-16-2	2426-56738-16-3	2426-56738-16-4
	Sponsor Designation -	FEED SOLN	#0	#1	#1B
	Date Collected -	09/20/94	09/15/94	09/15/94	09/16/94
Determinations in mg/L unless noted					
Arsenic - total		0.010	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001
Lead - total		0.013	<0.005	<0.005	<0.005
Selenium - total		0.040	0.058	0.055	0.056
Total Dissolved Solids (@180 °C)		1,000	1,100	1,500	1,400

A N A L Y S I S R E P O R T

DATE: 10/04/94 PAGE 3

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-5	2426-56738-16-6	2426-56738-16-7	2426-56738-16-8
	Sponsor Designation -	#2	#2B	#3	#4
	Date Collected -	09/15/94	09/16/94	09/14/94	09/14/94
Determinations in mg/L unless noted					
Silver - total		0.005	0.007	0.009	0.011
Aluminum - total		0.1	<0.1	<0.1	<0.1
Barium - total		<0.05	<0.05	0.07	0.08
Beryllium - total		<0.005	<0.005	<0.005	<0.005
Calcium - total		1.3	1.3	80	59
Cadmium - total		<0.005	<0.005	<0.005	<0.005
Cobalt - total		<0.005	<0.005	<0.005	<0.005
Chromium - total		<0.005	<0.005	0.011	0.008
Copper - total		<0.005	<0.005	<0.005	<0.005
Iron - total		0.19	0.26	<0.01	<0.01
Potassium - total		370	320	74	47
Lithium - total		0.14	0.15	0.15	0.15
Magnesium - total		0.07	0.12	25	25
Manganese - total		<0.005	<0.005	<0.005	<0.005
Molybdenum - total		<0.01	<0.01	<0.01	<0.01
Sodium - total		150	150	160	150
Nickel - total		<0.05	<0.05	<0.05	<0.05
Antimony - total		<0.05	<0.05	<0.05	<0.05
Selenium - total		<0.05	<0.05	<0.05	<0.05
Thallium - total		<0.5	<0.5	<0.5	<0.5
Vanadium - total		<0.005	<0.005	<0.005	<0.005
Zinc - total		<0.005	0.006	<0.005	<0.005
pH					
(pH Units)		11.8	11.8	8.5	8.6
Arsenic - total		<0.005	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001

A N A L Y S I S R E P O R T

DATE: 10/04/94 PAGE 4

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-5	2426-56738-16-6	2426-56738-16-7	2426-56738-16-8
	Sponsor Designation -	#2	#2B	#3	#4
	Date Collected -	09/15/94	09/16/94	09/14/94	09/14/94
Determinations in mg/L unless noted					
Lead - total		<0.005	<0.005	<0.005	<0.005
Selenium - total		0.056	0.059	0.049	0.059
Total Dissolved Solids (@180 °C)		1,400	1,300	1,100	1,000

A N A L Y S I S R E P O R T

DATE: 10/04/94 PAGE 5

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-9	2426-56738-16-10	2426-56738-16-11	2426-56738-16-12
	Sponsor Designation -	#9	#10	#11	#12
	Date Collected -	09/15/94	09/16/94	09/14/94	09/14/94
Determinations in mg/L unless noted					
Silver - total		<0.005	<0.005	0.005	0.007
Aluminum - total		<0.1	<0.1	<0.1	<0.1
Barium - total		<0.05	<0.05	<0.05	<0.05
Beryllium - total		<0.005	<0.005	<0.005	<0.005
Calcium - total		1.3	7.9	16	14
Cadmium - total		<0.005	<0.005	<0.005	<0.005
Cobalt - total		<0.005	<0.005	<0.005	<0.005
Chromium - total		<0.005	<0.005	<0.005	<0.005
Copper - total		<0.005	<0.005	0.006	<0.005
Iron - total		0.07	0.02	0.02	0.02
Potassium - total		340	160	100	150
Lithium - total		0.14	0.15	0.15	0.15
Magnesium - total		0.14	15	23	22
Manganese - total		<0.005	<0.005	<0.005	<0.005
Molybdenum - total		<0.01	<0.01	<0.01	<0.01
Sodium - total		150	150	150	160
Nickel - total		<0.05	<0.05	<0.05	<0.05
Antimony - total		<0.05	<0.05	<0.05	<0.05
Selenium - total		<0.05	0.06	0.06	<0.05
Thallium - total		<0.5	<0.5	<0.5	<0.5
Vanadium - total		<0.005	<0.005	<0.005	<0.005
Zinc - total		<0.005	<0.005	<0.005	<0.005
pH					
	(pH Units)	11.8	10.1	9.6	9.8
Arsenic - total		<0.005	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001

A N A L Y S I S R E P O R T

DATE: 10/04/94 PAGE 6

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-9	2426-56738-16-10	2426-56738-16-11	2426-56738-16-12
	Sponsor Designation -	#9	#10	#11	#12
	Date Collected -	09/15/94	09/16/94	09/14/94	09/14/94
Determinations in mg/L unless noted					
Lead - total		<0.005	<0.005	<0.005	<0.005
Selenium - total		0.054	0.065	0.061	0.059
Total Dissolved Solids (@180 °C)		1,300	1,000	1,000	1,100

A N A L Y S I S R E P O R T

DATE: 10/04/94 PAGE 7

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-13	2426-56738-16-14	2426-56738-16-15	2426-56738-16-16
	Sponsor Designation -	#13	#14	#15	#16
	Date Collected -	09/15/94	09/15/94	09/16/94	09/15/94
Determinations in mg/L unless noted					
Silver - total		0.008	<0.005	<0.005	0.009
Aluminum - total		<0.1	<0.1	0.6	<0.1
Barium - total		<0.05	<0.05	<0.05	<0.05
Beryllium - total		<0.005	<0.005	<0.005	<0.005
Calcium - total		11	1.4	0.5	9.2
Cadmium - total		<0.005	<0.005	<0.005	<0.005
Cobalt - total		<0.005	0.008	0.005	<0.005
Chromium - total		<0.005	<0.005	<0.005	<0.005
Copper - total		<0.005	<0.005	<0.005	<0.005
Iron - total		0.02	0.02	0.15	0.05
Potassium - total		130	350	5.8	180
Lithium - total		0.15	0.14	<0.01	0.15
Magnesium - total		20	0.13	<0.05	17
Manganese - total		<0.005	<0.005	<0.005	<0.005
Molybdenum - total		<0.01	<0.01	<0.01	<0.01
Sodium - total		150	150	3.6	170
Nickel - total		<0.05	<0.05	<0.05	<0.05
Antimony - total		<0.05	<0.05	<0.05	<0.05
Selenium - total		<0.05	<0.05	<0.05	<0.05
Thallium - total		<0.05	<0.05	<0.05	<0.05
Vanadium - total		<0.005	<0.005	<0.005	<0.005
Zinc - total		<0.005	<0.005	<0.005	<0.005
pH					
(pH Units)		10.2	11.9	8.6	10.0
Arsenic - total		<0.005	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001

ANALYSIS REPORT

DATE: 10/04/94 PAGE 8

Lab Job Number 2426-56738-16

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-56738-16-13	2426-56738-16-14	2426-56738-16-15	2426-56738-16-16
	Sponsor Designation -	#13	#14	#15	#16
	Date Collected -	09/15/94	09/15/94	09/16/94	09/15/94
Determinations in mg/L unless noted					
Lead - total		<0.005	<0.005	<0.005	<0.005
Selenium - total		0.059	0.056	<0.005	0.056
Total Dissolved Solids @180 °C		1,000	1,300	30	1,100

By: Eyda Hergenreder
Eyda Hergenreder
Metals Laboratory Supervisor

By: Susan J Barker
Susan J. Barker
Inorganic Chemistry Supervisor

EH/SJB/rt

Date: 10/10/94
Page 1

PRELIMINARY REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc
Rocky Flats Env Tech Site
POB 464 Bldg 080
Golden, CO 80402-0464

Lab Job Number: 000240
Date Samples Received: 09/21/94
Customer PO Number: ASC 233268JO3

ALR Designation:	94-A1976	94-A1977
Client Designation:	FRED-SOLN	#0
Sample Location:		
Location II:		
Date/Time Collected	09/20/94	09/15/94
Uranium, total (mg/L)	0.036	0.020
Americium-241, total (pCi/L)	1.1 +/- 0.44	0.03 +/- 0.11
Plutonium-239+240, total (pCi/L)	6.7 +/- 1.0	0.17 +/- 0.10

ALR Designation:	94-A1978	94-A1979
Client Designation:	#1	#1B
Sample Location:		
Location II:		
Date/Time Collected	09/15/94	09/16/94
Uranium, total (mg/L)	0.0011	0.0012
Americium-241, total (pCi/L)	0.01 +/- 0.11	0.03 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.15 +/- 0.09	0.12 +/- 0.08

ALR Designation:	94-A1980	94-A1981
Client Designation:	#2	#2B
Sample Location:		
Location II:		
Date/Time Collected	09/15/94	09/16/94
Uranium, total (mg/L)	0.0039	0.0015
Americium-241, total (pCi/L)	0.02 +/- 0.11	0.01 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.15 +/- 0.08	0.12 +/- 0.07

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

PRELIMINARY REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94

ALR Designation:	94-A1982	94-A1983
Client Designation:	#3	#4
Sample Location: Location III		
Date/Time Collected	09/14/94	09/14/94
Uranium, total (mg/L)	0.034	0.030
Americium-241, total (pCi/L)	0.04 +/- 0.11	0.02 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.96 +/- 0.21	0.22 +/- 0.09

ALR Designation:	94-A1984	94-A1985
Client Designation:	#9	#10
Sample Location: Location III		
Date/Time Collected	09/15/94	09/16/94
Uranium, total (mg/L)	0.0018	0.0069
Americium-241, total (pCi/L)	0.04 +/- 0.11	0.03 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.08 +/- 0.07	0.13 +/- 0.08

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

PRELIMINARY REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94

ALR Designation:	94-A1986	94-A1987
Client Designation:	#11	#12
Sample Location:		
Location #1:		
Date/Time Collected	09/14/94	09/14/94
Uranium, total (mg/L)	0.027	0.025
Americium-241, total (pCi/L)	0.00 +/- 0.01	0.02 +/- 0.03
Plutonium-239+240, total (pCi/L)	0.15 +/- 0.09	0.30 +/- 0.11

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

PRELIMINARY REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94

ARR Designation:	94-A1988	94-A1989
Client Designation:	#13	#14
Sample Location:		
Location ID:		
Date/Time Collected	09/15/94	09/15/94
Uranium, total (mg/L)	0.022	0.0018
Americium-241, total (pCi/L)	0.08 +/- 0.03	0.00 +/- 0.01
Plutonium-239+240, total (pCi/L)	1.8 +/- 0.28	0.00 +/- 0.01

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

Date: 10/10/94
Page 5

PRELIMINARY REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94

A&R Designation:	94-A1990	94-A1991
Client Designation:	#15	#16
Sample Location:		
Location ID:		
Date/Time Collected	09/16/94	09/15/94
Uranium, total (mg/L)	0.0001	0.0077
Americium-241, total (pCi/L)	0.01 +/- 0.02	0.03 +/- 0.03
Plutonium-239+240, total (pCi/L)	0.00 +/- 0.01	0.15 +/- 0.09

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

PRELIMINARY REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94

Variability of the radioactive disintegration process (counting error) at the 95% confidence level is 1.96 sigma and the level of significance may exceed that of the reported analytical result.

Scheduled sample disposal date: , .

for Bud Summers
Radiochemistry Supervisor

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

Accu-Labs® Research, Inc.
4663 Table Mountain Drive Golden, Colorado 80403-1650
(303) 277-9514 FAX (303) 277-9512

Date: 10/25/94
Page 1

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc
Rocky Flats Env Tech Site
POB 464 Bldg 080
Golden, CO 80402-0464

Lab Job Number: 000240
Date Samples Received: 09/21/94
Customer PO Number: ASC 233268JO3
CORRECTED REPORT

ALR Designation:	94-A1976	94-A1977
Client Designation:	FEED SOLN	#0
Sample Location:		
Location II:		
Date/Time Collected	09/20/94	09/15/94
Uranium, total (mg/L)	0.036	0.020
Americium-241, total (pCi/L)	1.1 +/- 0.44	0.03 +/- 0.11
Plutonium-239+240, total (pCi/L)	6.7 +/- 1.0	0.26 +/- 0.06

ALR Designation:	94-A1978	94-A1979
Client Designation:	#1	#1B
Sample Location:		
Location II:		
Date/Time Collected	09/15/94	09/16/94
Uranium, total (mg/L)	0.0011	0.0012
Americium-241, total (pCi/L)	0.01 +/- 0.11	0.03 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.12 +/- 0.03	0.12 +/- 0.04

ALR Designation:	94-A1980	94-A1981
Client Designation:	#2	#2B
Sample Location:		
Location II:		
Date/Time Collected	09/15/94	09/16/94
Uranium, total (mg/L)	0.0039	0.0015
Americium-241, total (pCi/L)	0.02 +/- 0.11	0.01 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.17 +/- 0.05	0.14 +/- 0.03

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94
CORRECTED REPORT

ALR Designation:	94-A1982	94-A1983
Client Designation:	#3	#4
Sample Location:		
Location II:		
Date/Time Collected	09/14/94	09/14/94
Uranium, total (mg/L)	0.034	0.030
Americium-241, total (pCi/L)	0.04 +/- 0.11	0.02 +/- 0.11
Plutonium-239+240, total (pCi/L)	1.1 +/- 0.10	0.36 +/- 0.05

ALR Designation:	94-A1984	94-A1985
Client Designation:	#9	#10
Sample Location:		
Location II:		
Date/Time Collected	09/15/94	09/16/94
Uranium, total (mg/L)	0.0018	0.0069
Americium-241, total (pCi/L)	0.04 +/- 0.11	0.03 +/- 0.11
Plutonium-239+240, total (pCi/L)	0.10 +/- 0.04	0.10 +/- 0.03

ALR Designation:	94-A1986	94-A1987
Client Designation:	#11	#12
Sample Location:		
Location II:		
Date/Time Collected	09/14/94	09/14/94
Uranium, total (mg/L)	0.027	0.025
Americium-241, total (pCi/L)	0.00 +/- 0.01	0.02 +/- 0.03
Plutonium-239+240, total (pCi/L)	0.19 +/- 0.05	0.20 +/- 0.05

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000240
Date Samples Received: 09/21/94
CORRECTED REPORT

ALR Designation:	94-A1988	94-A1989
Client Designation:	#13	#14
Sample Location:		
Location II:		
Date/Time Collected	09/15/94	09/15/94
Uranium, total (mg/L)	0.022	0.0018
Americium-241, total (pCi/L)	0.08 +/- 0.03	0.00 +/- 0.01
Plutonium-239+240, total (pCi/L)	1.8 +/- 0.28	0.00 +/- 0.01

ALR Designation:	94-A1990	94-A1991
Client Designation:	#15	#16
Sample Location:		
Location II:		
Date/Time Collected	09/16/94	09/15/94
Uranium, total (mg/L)	0.0001	0.0077
Americium-241, total (pCi/L)	0.01 +/- 0.02	0.03 +/- 0.03
Plutonium-239+240, total (pCi/L)	0.00 +/- 0.01	0.20 +/- 0.05

Variability of the radioactive disintegration process (counting error) at the 95% confidence level is 1.96 sigma and the level of significance may exceed that of the reported analytical result.

Scheduled sample disposal date: November 24, 1994.

Ginny Whiteford
for Bud Summers
Radiochemistry Supervisor

NOTES: When present, *** indicates that the analyte in question was not requested for that sample.

APPENDIX C

ANALYTICAL REPORTS OF THE PRODUCTS FROM PHASE III TESTS

Accu-Labs® Research, Inc.

663 Table Mountain Drive Golden, Colorado 80403-1650
303) 277-9514 FAX (303) 277-9512

COMPLETED REPORT

A N A L Y S I S R E P O R T

DATE: 11/29/94 PAGE 1

J.C. LAUL
EG&G ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE
P O BOX 464 BLDG 881
GOLDEN, CO 80402-0464

Lab Job Number: 2426-57356-5
Date Samples Received: 10/26/94
Customer PO Number: ASC233268JO3

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-57356-5-1	2426-57356-5-2	2426-57356-5-3	2426-57356-5-4
Sponsor Designation -	FEED SOLUTION	TEST #1	TEST #2	TEST #3
Date Collected -	10/20/94	10/21/94	10/21/94	10/26/94
Determinations in mg/L unless noted				
Silver - total	0.030	<0.005	<0.005	<0.005
Aluminum - total	20	<0.1	<0.1	<0.1
Barium - total	0.28	<0.05	<0.05	<0.05
Beryllium - total	<0.005	<0.005	<0.005	<0.005
Calcium - total	96	10	12	12
Cadmium - total	<0.005	<0.005	<0.005	<0.005
Cobalt - total	<0.01	<0.01	<0.01	<0.01
Chromium - total	0.026	<0.005	<0.005	<0.005
Copper - total	0.030	<0.005	<0.005	<0.005
Iron - total	22	0.02	0.02	0.02
Potassium - total	7.4	150	140	140
Lithium - total	0.15	0.14	0.14	0.14
Magnesium - total	31	8.4	10	10
Manganese - total	0.29	<0.005	<0.005	<0.005
Molybdenum - total	0.01	<0.01	<0.01	<0.01
Sodium - total	150	150	150	160
Nickel - total	<0.05	<0.05	<0.05	<0.05
Antimony - total	<0.05	<0.05	<0.05	<0.05
Selenium - total	0.10	0.08	<0.05	0.07
Thallium - total	<0.5	<0.5	<0.5	<0.5
Vanadium - total	0.045	<0.005	<0.005	<0.005
Zinc - total	0.093	<0.005	<0.005	<0.005
Alkalinity, Total (as CaCO3 to pH 4.5)	90	----	50	----
Carbonate (as CO3)	<5	----	24	----
Bicarbonate (as HCO3)	110	----	12	----

A N A L Y S I S R E P O R T

DATE: 11/29/94 PAGE 2

Lab Job Number 2426-57356-5

These samples to be disposed of 30 days after the date of this report.

	ALR Designation -	2426-57356-5-1	2426-57356-5-2	2426-57356-5-3	2426-57356-5-4
	Sponsor Designation -	FEED SOLUTION	TEST #1	TEST #2	TEST #3
	Date Collected -	10/20/94	10/21/94	10/21/94	10/26/94
Determinations in mg/L unless noted					
pH					
(pH Units)		8.1	9.8	9.7	9.9
Arsenic - total		0.010	<0.005	<0.005	<0.005
Mercury - total		<0.0001	<0.0001	<0.0001	<0.0001
Lead - total		0.012	<0.005	<0.005	<0.005
Selenium - total		0.021	0.056	0.055	0.056
Nitrite (as N)		<0.05	----	<0.05	----
Nitrate (as N)		110	----	110	----
Total Dissolved Solids (@180 °C)		960 [25]	970	950 [25]	990
Chloride		42	----	49	----
Sulfate (as SO4)		110	----	130	----

A N A L Y S I S R E P O R T

DATE: 11/29/94 PAGE 3

Lab Job Number 2426-57356-5

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-57356-5-5
Sponsor Designation -	TEST #4
Date Collected -	10/26/94

Determinations in mg/L unless noted

Silver - total	<0.005
Aluminum - total	<0.1
Barium - total	<0.05
Beryllium - total	<0.005
Calcium - total	13
Cadmium - total	<0.005
Cobalt - total	<0.01
Chromium - total	<0.005
Copper - total	<0.005
Iron - total	0.02
Potassium - total	140
Lithium - total	0.14
Magnesium - total	11
Manganese - total	<0.005
Molybdenum - total	<0.01
Sodium - total	160
Nickel - total	<0.05
Antimony - total	<0.05
Selenium - total	0.08
Thallium - total	<0.5
Vanadium - total	<0.005
Zinc - total	<0.005
pH	
(pH Units)	9.8
Arsenic - total	<0.005
Mercury - total	<0.0001

ANALYSIS REPORT

DATE: 11/29/94 PAGE 4

Lab Job Number 2426-57356-5

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-57356-5-5
Sponsor Designation -	TEST #4
Date Collected -	10/26/94

Determinations in mg/L unless noted

Lead - total	<0.005
Selenium - total	0.058
Total Dissolved Solids (@180 °C)	1,000

Notes:

[25] -- RESULT VERIFIED BY REANALYSIS.

By: Eyda Hergenreder

Eyda Hergenreder
Metals Laboratory Supervisor

By: Susan J. Barker

Susan J. Barker
Inorganic Chemistry Supervisor

EH/SJB/rt

Accu-Labs® Research, Inc.
663 Table Mountain Drive Golden, Colorado 80403-1650
303) 277-9514 FAX (303) 277-9512

ANALYSIS REPORT

DATE: 11/21/94 PAGE 1

J.C. LAUL
EG&G ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE
P O BOX 464 BLDG 881
GOLDEN, CO 80402-0464

Lab Job Number: 2426-57355-1
Date Samples Received: 10/26/94
Customer PO Number: ASC233268JO3

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-57355-1-1
Sponsor Designation -	TRU/CLEAR SOLID
Comments -	(PHASE 3)
Date Collected -	

Determinations in mg/kg unless noted

Silver - total	21
Aluminum - total	15,000
Barium - total	150
Beryllium - total	1.0
Calcium - total	55,000
Cadmium - total	0.6
Cobalt - total	6
Chromium - total	17
Copper - total	27
Iron - total	15,000
Potassium - total	3,500
Lithium - total	11
Magnesium - total	14,000
Manganese - total	200
Molybdenum - total	1
Sodium - total	580
Nickel - total	18
Antimony - total	<5
Selenium - total	<5
Thallium - total	<50
Vanadium - total	25
Zinc - total	60
Arsenic - total	7.2
Mercury - total	<0.1
Lead - total	11

ANALYSIS REPORT

DATE: 11/21/94 PAGE 2

Lab Job Number 2426-57355-1

These samples to be disposed of 30 days after the date of this report.

ALR Designation -	2426-57355-1-1
Sponsor Designation -	TRU/CLEAR SOLID
Comments -	(PHASE 3)
Date Collected -	

Determinations in mg/kg unless noted

Selenium - total	<5 [9]

Notes:

[9] -- HIGHER D.L. DUE TO SAMPLE MATRIX INTERFERENCE

By: Eyda Hergenreder

Eyda Hergenreder
Metals Laboratory Supervisor

EH/rt

Accu-Labs® Research, Inc.
663 Table Mountain Drive Golden, Colorado 80403-1650
(303) 277-9514 FAX (303) 277-9512

Date: 12/12/94

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc
Rocky Flats Env Tech Site
POB 464 Bldg 080
Golden, CO 80402-0464

Lab Job Number: 000383
Date Samples Received: 10/26/94
Customer PO Number: ASC233268JO3

ALR Designation:	94-A2873	94-A2874
Client Designation:	FEED SOLUTION	#1
Sample Location:		
Location II:		
Date/Time Collected	10/20/94	10/21/94
Uranium, total (mg/L)	0.040	0.0013
Americium-241, total (pCi/L)	0.81 +/- 0.20	0.00 +/- 0.01
Plutonium-239+240, total (pCi/L)	9.1 +/- 0.83	0.02 +/- 0.04

ALR Designation:	94-A2875	94-A2876
Client Designation:	#2	#3
Sample Location:		
Location II:		
Date/Time Collected	10/21/94	10/26/94
Uranium, total (mg/L)	0.0016	0.0017
Americium-241, total (pCi/L)	-0.02 +/- 0.05	0.00 +/- 0.01
Plutonium-239+240, total (pCi/L)	0.04 +/- 0.05	0.04 +/- 0.05

REPORT OF ANALYSIS

Mr Mike Rupert
EG&G Rocky Flats Inc

Lab Job Number: 000383
Date Samples Received: 10/26/94

ALR Designation:	94-A2877
Client Designation:	#4
Sample Location:	
Location II:	
Date/Time Collected	10/26/94

Uranium, total (mg/L)	0.0018
Americium-241, total (pCi/L)	0.00 +/- 0.20
Plutonium-239+240, total (pCi/L)	0.03 +/- 0.04

Variability of the radioactive disintegration process (counting error) at the 95% confidence level is 1.96 sigma and the level of significance may exceed that of the reported analytical result.

Scheduled sample disposal date: January 11, 1995.

Bud Summers
Radiochemistry Supervisor

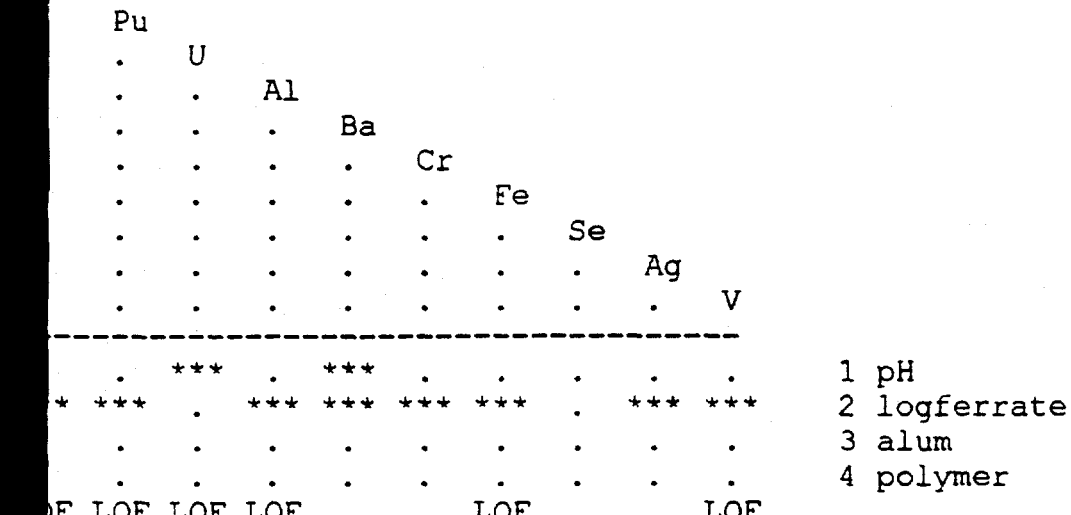
APPENDIX D

ECHIP OUTPUT OF PHASE I TESTS

OJECT NAME: RF3.ECP

eated: Thu Oct 27 14:02:54 1994

mmary results

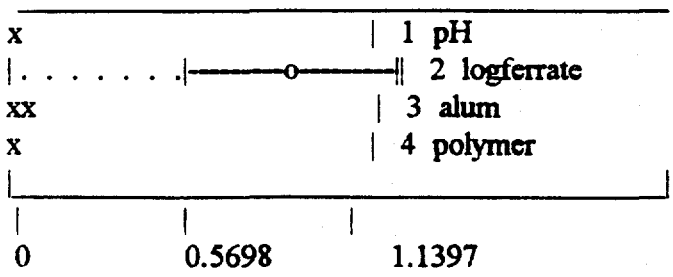


PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:47 1994

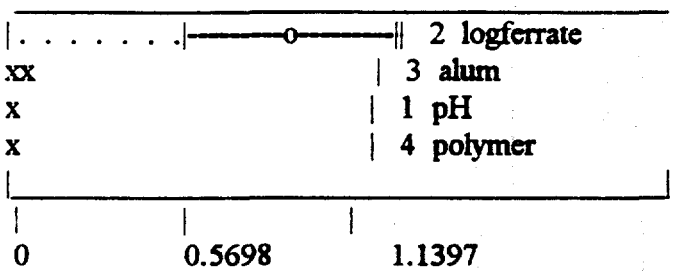
«××××××××××××» Effects graph for response 'Am'

LACK-OF-FIT



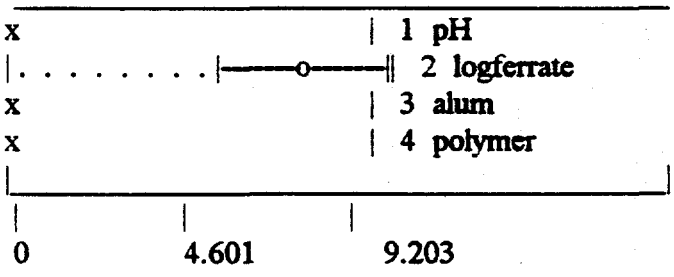
Pareto effects graph for response 'Am'

LACK-OF-FIT



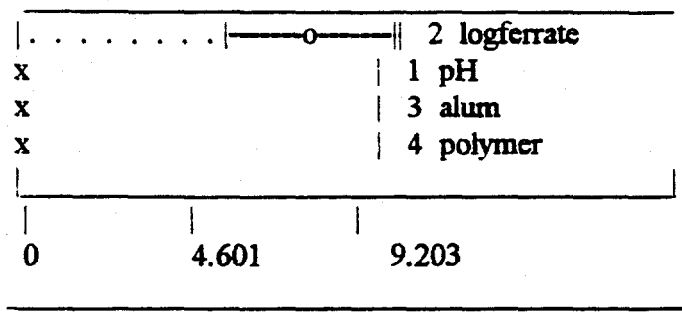
«××××××××××××» Effects graph for response 'Pu'

LACK-OF-FIT



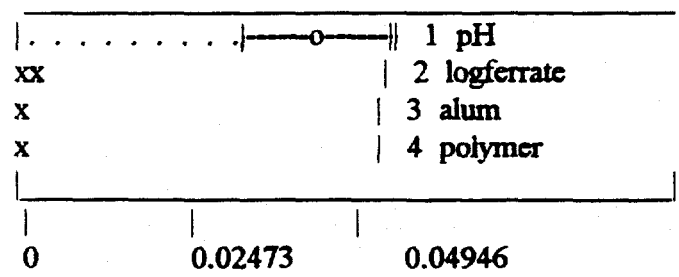
Pareto effects graph for response 'Pu'

LACK-OF-FIT



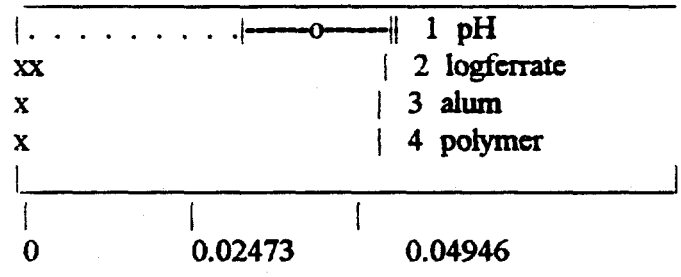
«××××××××××××» Effects graph for response 'U'

LACK-OF-FIT



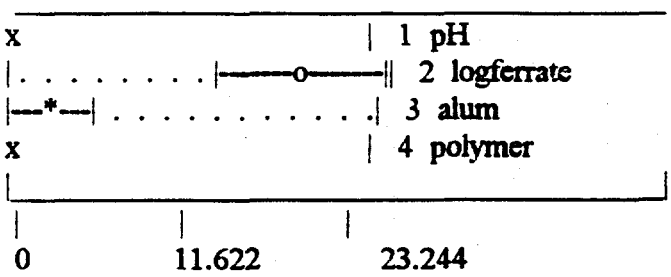
Pareto effects graph for response 'U'

LACK-OF-FIT



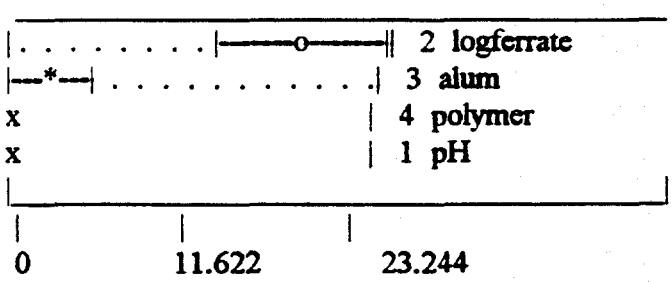
«××××××××××××» Effects graph for response 'Al'

LACK-OF-FIT

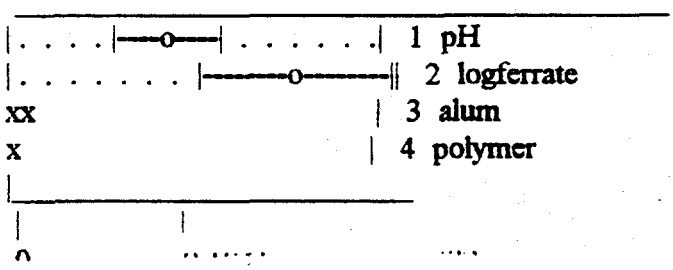


Pareto effects graph for response 'Al'

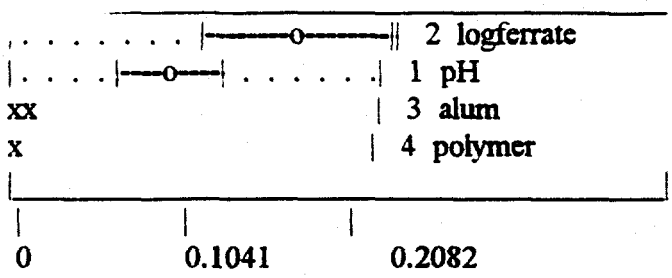
LACK-OF-FIT



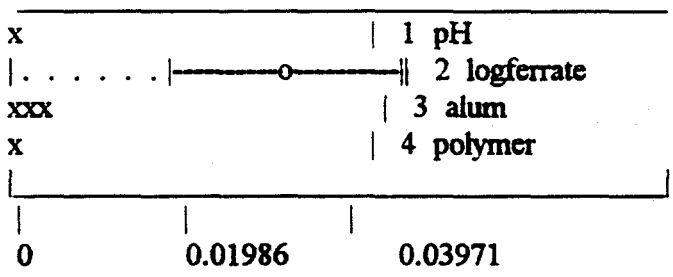
«××××××××××××» Effects graph for response 'Ba'



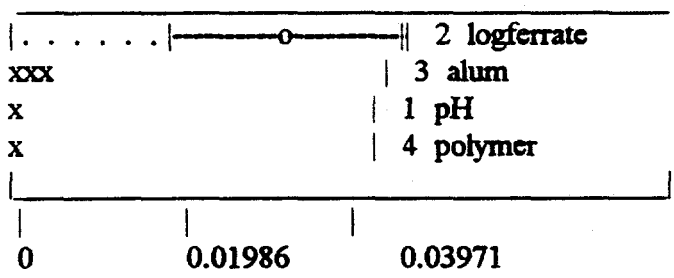
raph for response 'Ba'**



«××××××××××××» Effects graph for response 'Cr'

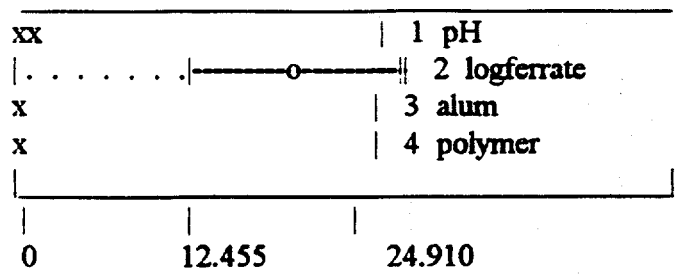


Pareto effects graph for response 'Cr'



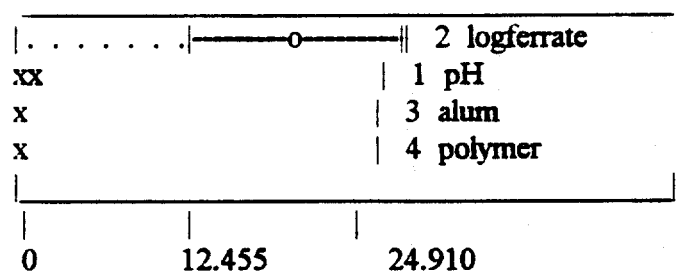
«××××××××××××» Effects graph for response 'Fe'

LACK-OF-FIT

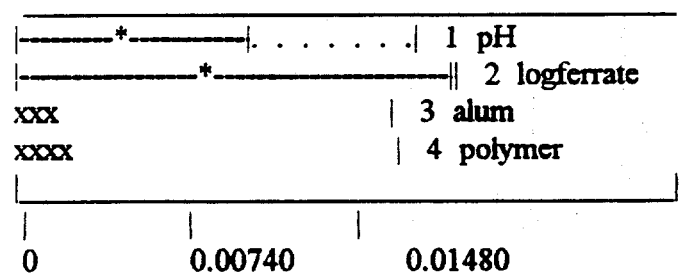


Pareto effects graph for response 'Fe'

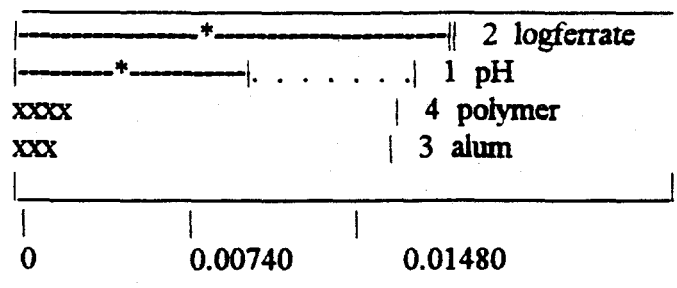
LACK-OF-FIT



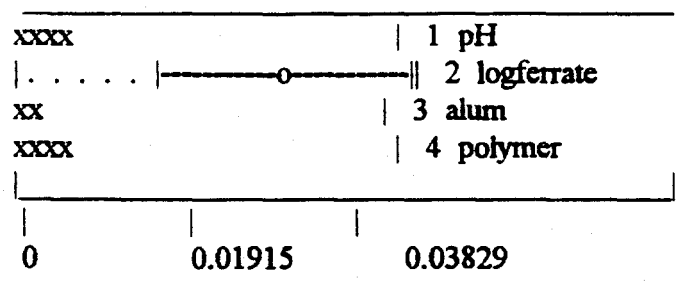
«××××××××××××» Effects graph for response 'Se'



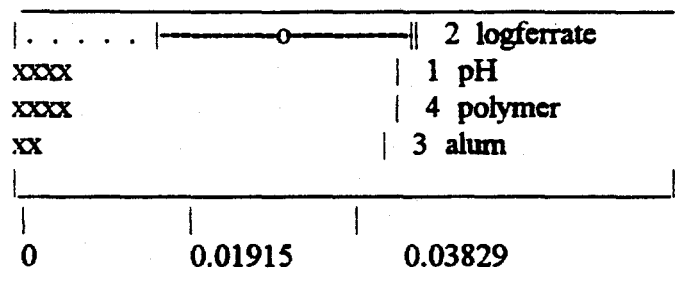
Pareto effects graph for response 'Se'



«××××××××××××» Effects graph for response 'Ag'

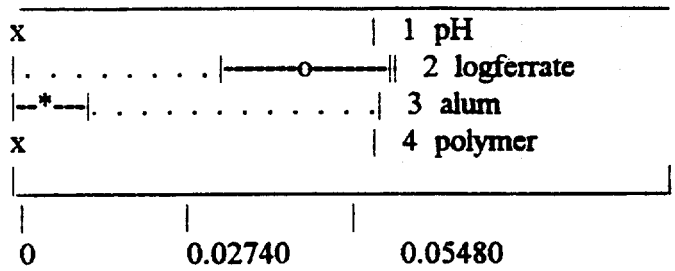


Pareto effects graph for response 'Ag'



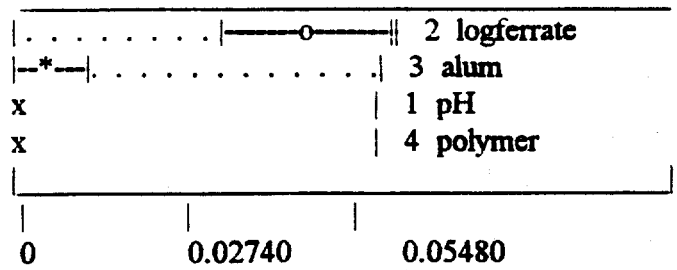
«××××××××××××» Effects graph for response 'V'

LACK-OF-FIT



Pareto effects graph for response 'V'

LACK-OF-FIT



PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:43 1994

«××××××××××××» Effects for response 'Am'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
0.3328			0 CONSTANT
-0.0186	0.1626		1 pH
-0.8666		***	2 logferrate
0.0397	0.2035		3 alum
-0.0099	0.1549		4 polymer

Residual SD = 0.096570
Replicate SD = 0.034157

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'Pu'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
3.068			0 CONSTANT
-0.211	1.146		1 pH
-7.429		***	2 logferrate
0.188	1.252		3 alum
0.100	1.043		4 polymer

Residual SD = 0.627420
Replicate SD = 0.046726

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'U'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
0.01796		0	CONSTANT
-0.04118		***	1 pH
-0.00231	0.01801		2 logferrate
0.00062	0.01003		3 alum
-0.00026	0.00860		4 polymer

Residual SD = 0.005551
Replicate SD = 0.000524

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'Al'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
7.999		0	CONSTANT
0.092	2.483		1 pH
-18.712		***	2 logferrate
1.891	4.610		3 alum
0.392	2.800		4 polymer

Residual SD = 1.602920
Replicate SD = 0.204124

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'Ba'

EFFECTS	RESLTN	SIG	TERM
0.0960			0 CONSTANT
-0.0925		***	1 pH
-0.1633		***	2 logferrate
-0.0081	0.0351		3 alum
0.0019	0.0258		4 polymer

Residual SD = 0.015913
Replicate SD = 0.000000

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'Cr'

EFFECTS	RESLTN	SIG	TERM
0.01214			0 CONSTANT
0.00049	0.00613		1 pH
-0.02901		***	2 logferrate
0.00246	0.00889		3 alum
-0.00036	0.00604		4 polymer

Residual SD = 0.003786
Replicate SD = 0.000000

N terms = 5
N unique trials = 12

N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'Fe'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
8.266		0	CONSTANT
0.976	4.140		1 pH
-18.909		***	2 logferrate
0.456	4.056		3 alum
0.342	3.530		4 polymer

Residual SD = 2.122410
Replicate SD = 0.090185

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«××××××××××××» Effects for response 'Se'

EFFECTS	RESLTN	SIG	TERM
0.04948		0	CONSTANT
0.00336	0.00781		1 pH
0.00636	0.01480		2 logferrate
-0.00099	0.00605		3 alum
-0.00143	0.00592		4 polymer

Residual SD = 0.002985
Replicate SD = 0.002082

N terms = 5
N unique trials = 12
N replicates = 3

N total trials = 15

«xxxxxxxxxxxxx» Effects for response 'Ag'

EFFECTS RESLTN SIG TERM

0.01334 0 CONSTANT
0.00308 0.00910 1 pH
-0.02690 *** 2 logferrate
0.00189 0.00873 3 alum
-0.00302 0.00907 4 polymer

Residual SD = 0.004031
Replicate SD = 0.002041

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«xxxxxxxxxxxxx» Effects for response 'V'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.01853 0 CONSTANT
0.00113 0.00633 1 pH
-0.04495 *** 2 logferrate
0.00365 0.00956 3 alum
0.00069 0.00592 4 polymer

Residual SD = 0.003485
Replicate SD = 0.000408

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:37 1994

«××××××××××××» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.332844			0	CONSTANT
-0.00477232	0.0165708	0.7792-	0.943	1 pH
-0.177047	0.0250332	0.0000	0.847	2 logferrate
0.000793209	0.00147026	0.6013-	0.841	3 alum
-0.00197069	0.0130205	0.8827-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.096570, Lack-Of-Fit P=0.0373 *
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.034157
Replicate DF = 3

R Squared = 0.872, P=0.0002 ***
Adj R Squared = 0.821
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 7.858 P=0.0042 **
- This term may be eliminated

«××××××××××××» Coefficients for response 'Pu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
3.06778			0	CONSTANT
-0.0540345	0.107661	0.6266-	0.943	1 pH
-1.51764	0.162642	0.0000	0.847	2 logferrate
0.003753	0.00955237	0.7026-	0.841	3 alum

0.0200388	0.0845945	0.8175-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.627420, Lack-Of-Fit P=0.0004 ***
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.046726
Replicate DF = 3

R Squared = 0.923, P=0.0000 ***
Adj R Squared = 0.892
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 9.825 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0179644			0	CONSTANT
-0.0105585	0.000952577	0.0000	0.943	1 pH
-0.000472097	0.00143904	0.7496-	0.847	2 logferrate
1.23131e-005	8.45186e-005	0.8871-	0.841	3 alum
-5.29126e-005	0.000748485	0.9450-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.005551, Lack-Of-Fit P=0.0007 ***
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000524
Replicate DF = 3

R Squared = 0.934, P=0.0000 ***
Adj R Squared = 0.907
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 9.843 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Al'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
7.99939			0	CONSTANT
0.0237025	0.275051	0.9330-	0.943	1 pH
-3.8227	0.415515	0.0000	0.847	2 logferrate
0.0378288	0.0244042	0.1522	0.841	3 alum
0.0784541	0.216121	0.7242-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 1.602920, Lack-Of-Fit P=0.0018 **
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.204124
Replicate DF = 3

R Squared = 0.910, P=0.0000 ***
Adj R Squared = 0.874
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 9.171 P=0.0001 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Ba'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0960052			0	CONSTANT
-0.0237139	0.00273057	0.0000	0.943	1 pH
-0.033352	0.00412502	0.0000	0.847	2 logferrate
-0.000161626	0.000242273	0.5198-	0.841	3 alum
0.000370484	0.00214554	0.8664-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.015913
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 3

R Squared = 0.960, P=0.0000 ***
Adj R Squared = 0.944
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Cr'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0121402			0	CONSTANT
0.000125132	0.000649636	0.8511-	0.943	1 pH
-0.00592617	0.000981394	0.0001	0.847	2 logferrate
4.92949e-005	5.76398e-005	0.4124-	0.841	3 alum
-7.12924e-005	0.00051045	0.8917-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.003786
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 3

R Squared = 0.820, P=0.0010 ***
Adj R Squared = 0.748
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 8.151 P=0.0021 **
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Fe'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
8.26555			0	CONSTANT
0.250179	0.364192	0.5077-	0.943	1 pH
-3.86291	0.550179	0.0000	0.847	2 logferrate
0.00912676	0.0323134	0.7834-	0.841	3 alum
0.0683267	0.286163	0.8161-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 2.122410, Lack-Of-Fit P=0.0001 ***
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.090185
Replicate DF = 3

R Squared = 0.860, P=0.0003 ***
Adj R Squared = 0.804
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 9.409 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Se'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0494791			0	CONSTANT
0.000861708	0.000512243	0.1234	0.943	1 pH
0.00129838	0.000773836	0.1243	0.847	2 logferrate
-1.97509e-005	4.54494e-005	0.6731-	0.841	3 alum
-0.000286753	0.000402493	0.4925-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.002985
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.002082
Replicate DF = 3

R Squared = 0.439, P=0.1772
Adj R Squared = 0.215
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Ag'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0133403			0	CONSTANT
0.000790988	0.000691696	0.2794-	0.943	1 pH
-0.00549468	0.00104493	0.0004	0.847	2 logferrate
3.78901e-005	6.13715e-005	0.5508-	0.841	3 alum
-0.000603806	0.000543498	0.2926-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.004031
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.002041
Replicate DF = 3

R Squared = 0.793, P=0.0019 **
Adj R Squared = 0.710
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 6.703 P=0.0308 *
- This term may be eliminated

«××××××××××××» Coefficients for response 'V'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0185256			0	CONSTANT
0.000289925	0.000598041	0.6383-	0.943	1 pH
-0.00918185	0.000903451	0.0000	0.847	2 logferrate
7.29692e-005	5.3062e-005	0.1991	0.841	3 alum
0.000137551	0.000469909	0.7757-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.003485, Lack-Of-Fit P=0.0014 **
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000408
Replicate DF = 3

R Squared = 0.925, P=0.0000 ***
Adj R Squared = 0.895
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 7.424 P=0.0098 **
- This term may be eliminated

PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:52 1994

«××××××××××××» ANOVA Table for response 'Am'

LACK-OF-FIT

Mean Squares	DF	P	
0.000773493	1	0.7792	pH
0.466476	1	0.0000	logferrate
0.00271437	1	0.6013	alum
0.000213633	1	0.8827	polymer
0.00932576	10		ERROR
0.00116667	3		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Pu'

LACK-OF-FIT

Mean Squares	DF	P	
0.0991608	1	0.6266	pH
34.276	1	0.0000	logferrate
0.0607647	1	0.7026	alum
0.022089	1	0.8175	polymer
0.393655	10		ERROR
0.00218333	3		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'U'

LACK-OF-FIT

Mean Squares	DF	P	
0.00378621	1	0.0000	pH
3.31676e-006	1	0.7496	logferrate
6.54074e-007	1	0.8871	alum
1.5401e-007	1	0.9450	polymer

3.08176e-005 10 ERROR

2.74999e-007 3 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Al'

LACK-OF-FIT

Mean Squares DF P

0.0190804 1 0.9330 pH
217.466 1 0.0000 logferrate
6.17359 1 0.1522 alum
0.338581 1 0.7242 polymer
2.56935 10 ERROR

0.0416667 3 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Ba'

Mean Squares DF P

0.0190987 1 0.0000 pH
0.0165537 1 0.0000 logferrate
0.000112698 1 0.5198 alum
7.5504e-006 1 0.8664 polymer
0.000253223 10 ERROR

0 3 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Cr'

Mean Squares DF P

5.31786e-007 1 0.8511 pH
0.000522636 1 0.0001 logferrate
1.04833e-005 1 0.4124 alum
2.79588e-007 1 0.8917 polymer
1.4333e-005 10 ERROR

0 3 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Fe'

LACK-OF-FIT

Mean Squares	DF	P	
2.12569	1	0.5077	pH
222.065	1	0.0000	logferrate
0.359358	1	0.7834	alum
0.25681	1	0.8161	polymer
4.50463	10		ERROR
0.00813333	3		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Se'

Mean Squares	DF	P	
2.52184e-005	1	0.1234	pH
2.50872e-005	1	0.1243	logferrate
1.68294e-006	1	0.6731	alum
4.52322e-006	1	0.4925	polymer
8.91147e-006	10		ERROR
4.33333e-006	3		REPLICATE ERROR

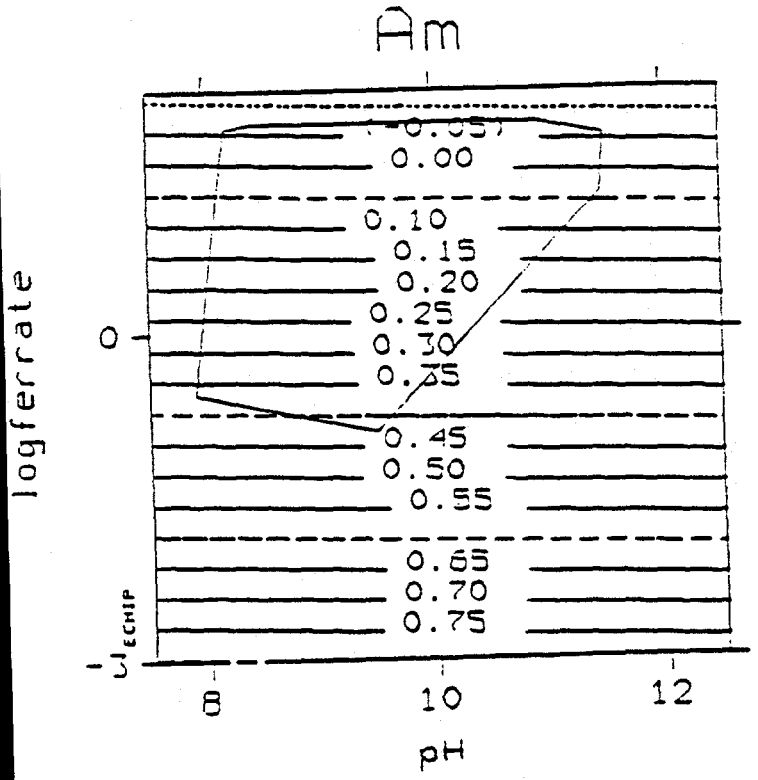
«××××××××××××» ANOVA Table for response 'Ag'

Mean Squares	DF	P	
2.1249e-005	1	0.2794	pH
0.000449299	1	0.0004	logferrate
6.19362e-006	1	0.5508	alum
2.00552e-005	1	0.2926	polymer
1.6249e-005	10		ERROR
4.16667e-006	3		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'V'

LACK-OF-FIT

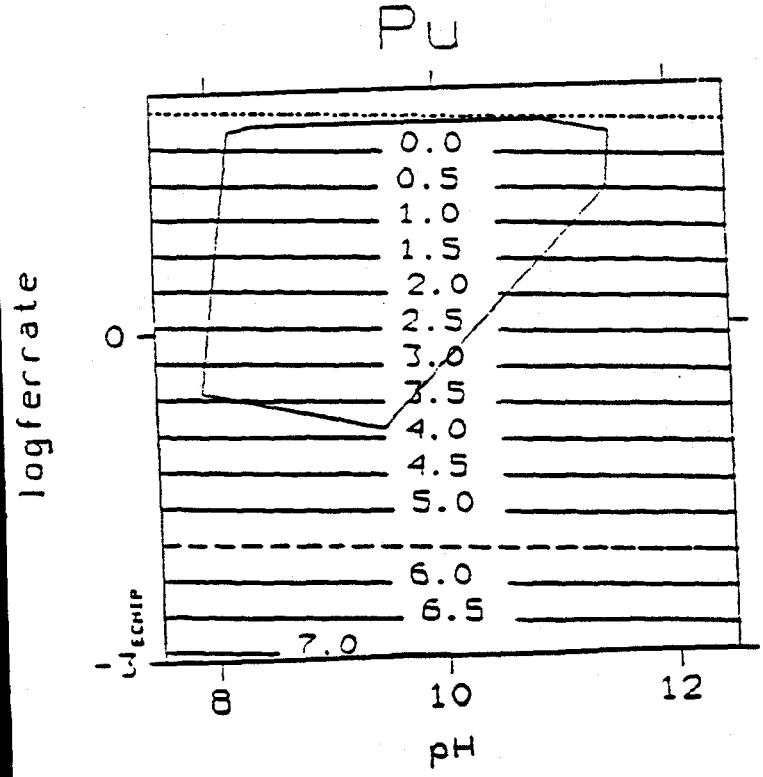
Mean Squares	DF	P	
2.85475e-006	1	0.6383	pH
0.00125462	1	0.0000	logferrate
2.29706e-005	1	0.1991	alum
1.04078e-006	1	0.7757	polymer
1.21468e-005	10		ERROR
1.66667e-007	3		REPLICATE ERROR



Lack Of Fit

alum = 25.000000

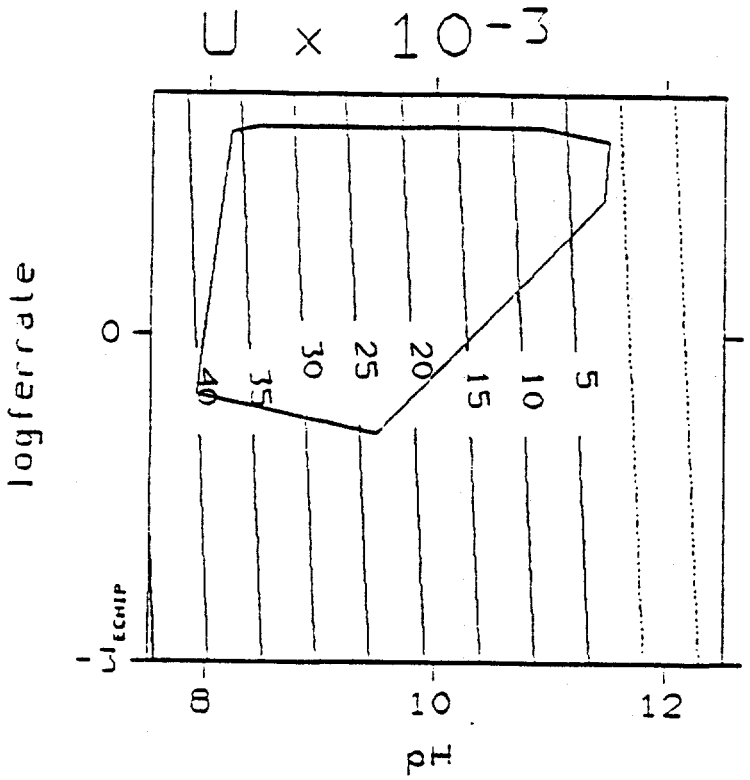
polymer = 2.500000



Lack Of Fit

alum = 25.000000

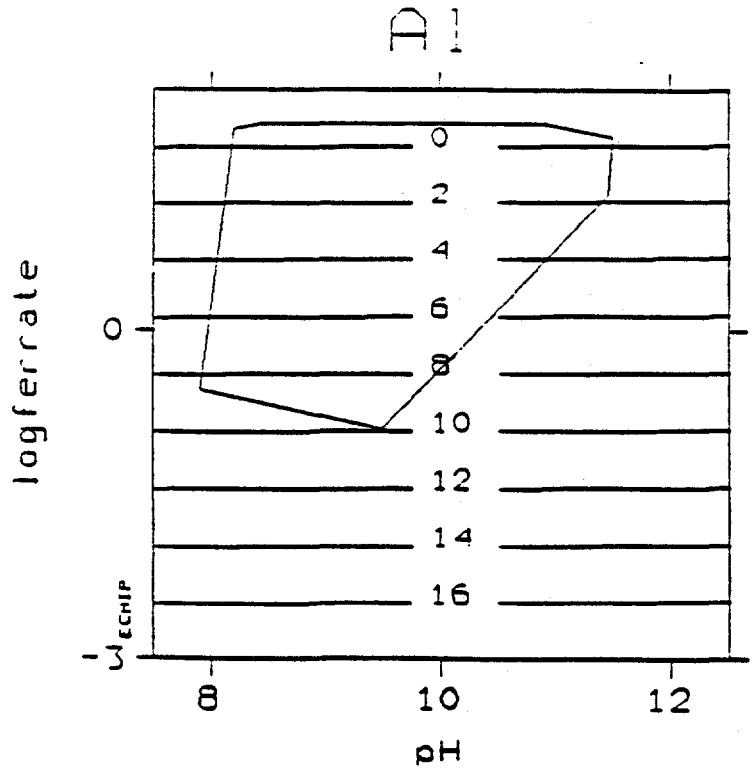
polymer = 2.500000



Lack Of Fit

alum = 25.000000

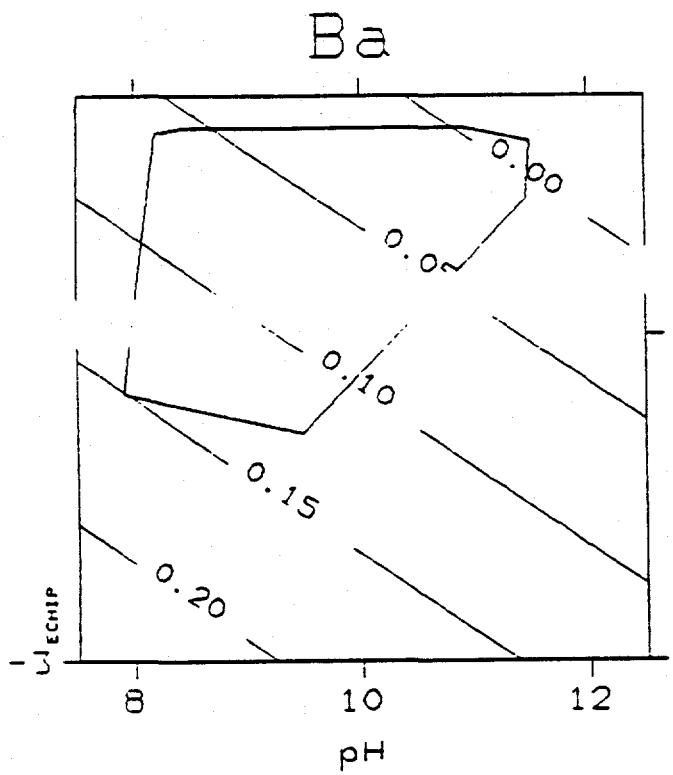
polymer = 2.500000



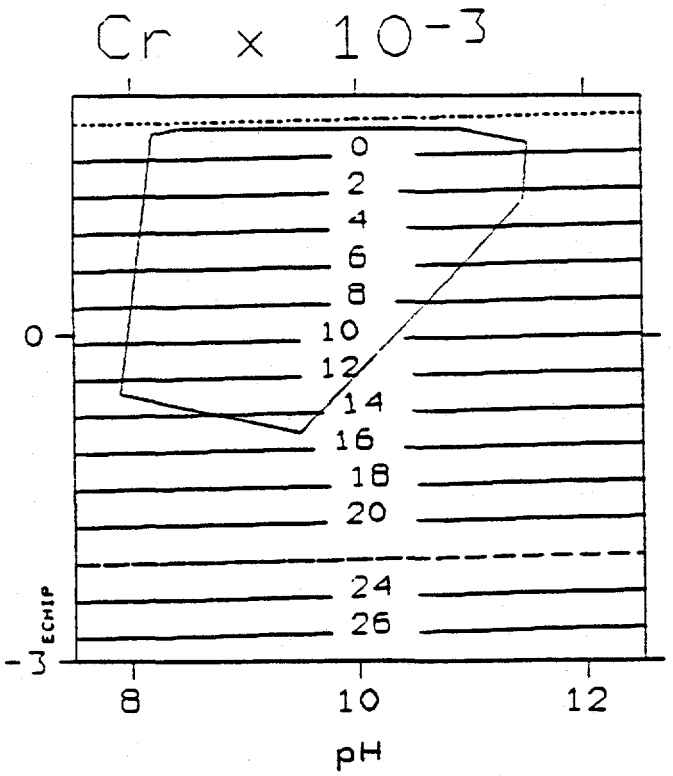
Lack Of Fit

alum = 25.000000

polymer = 2.500000

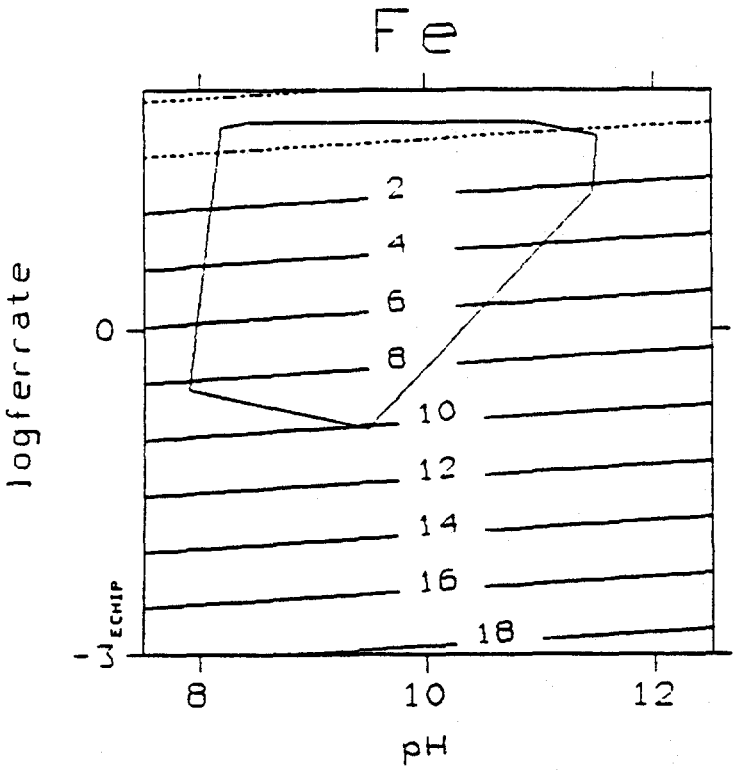


polymer = 2.500000



alum = 25.000000

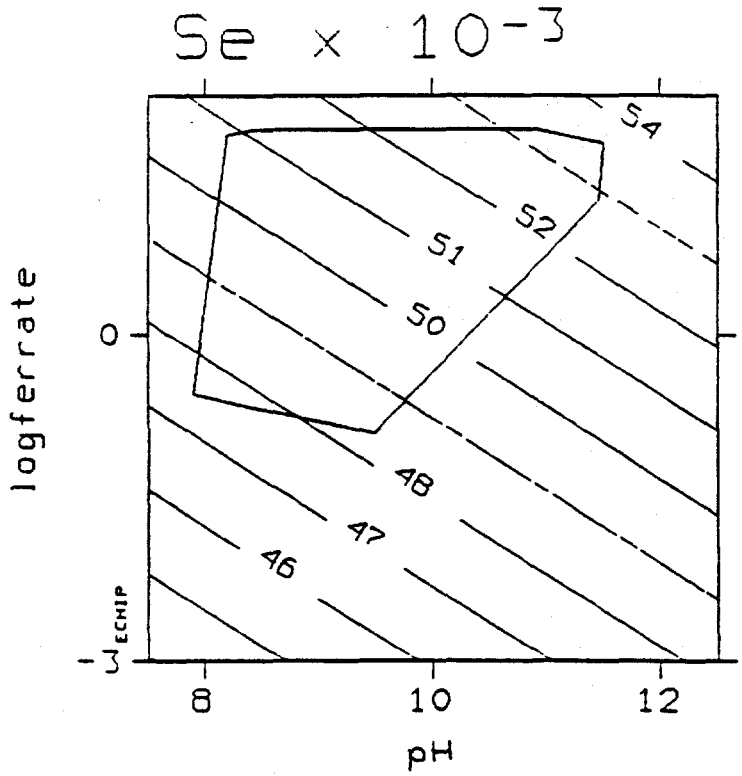
polymer = 2.500000



Lack Of Fit

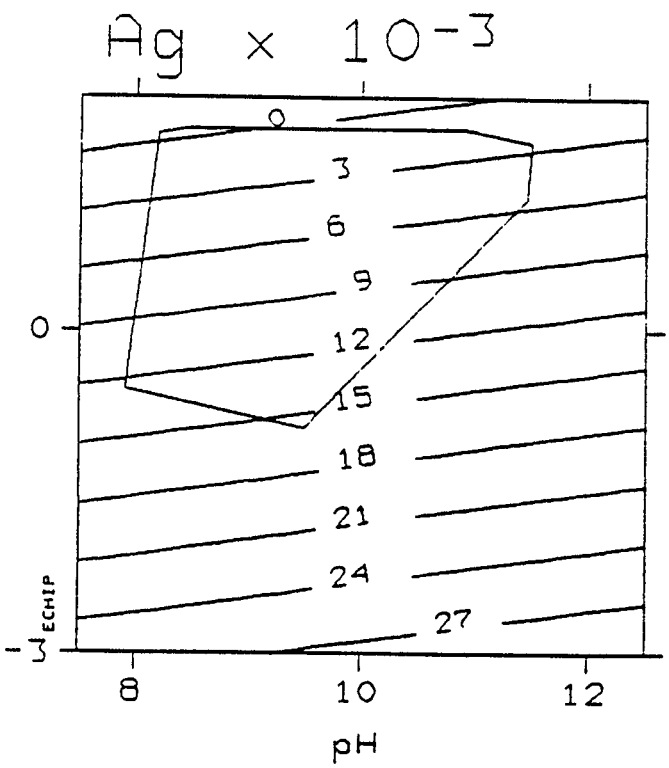
alum = 25.000000

polymer = 2.500000



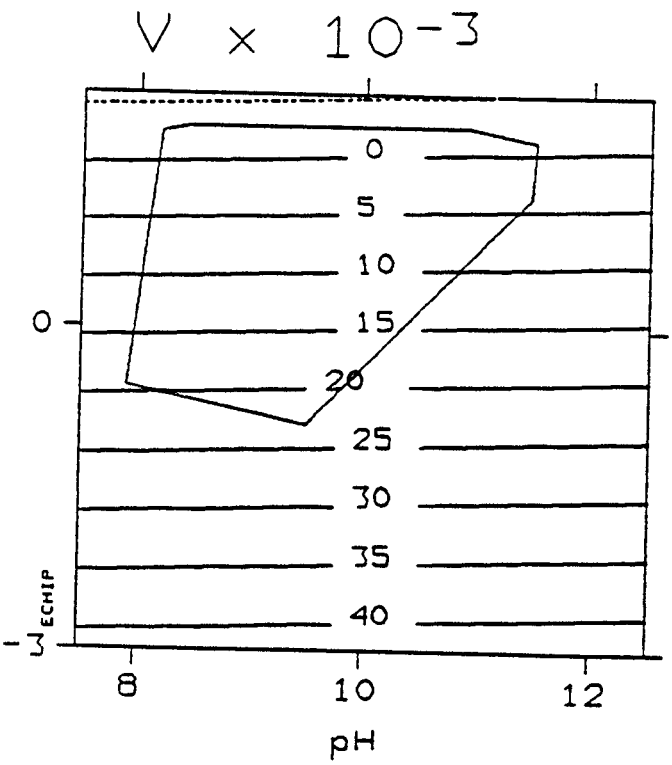
alum = 25.000000

polymer = 2.500000



alum = 25.000000

polymer = 2.500000



Lack Of Fit

alum = 25.000000

polymer = 2.500000

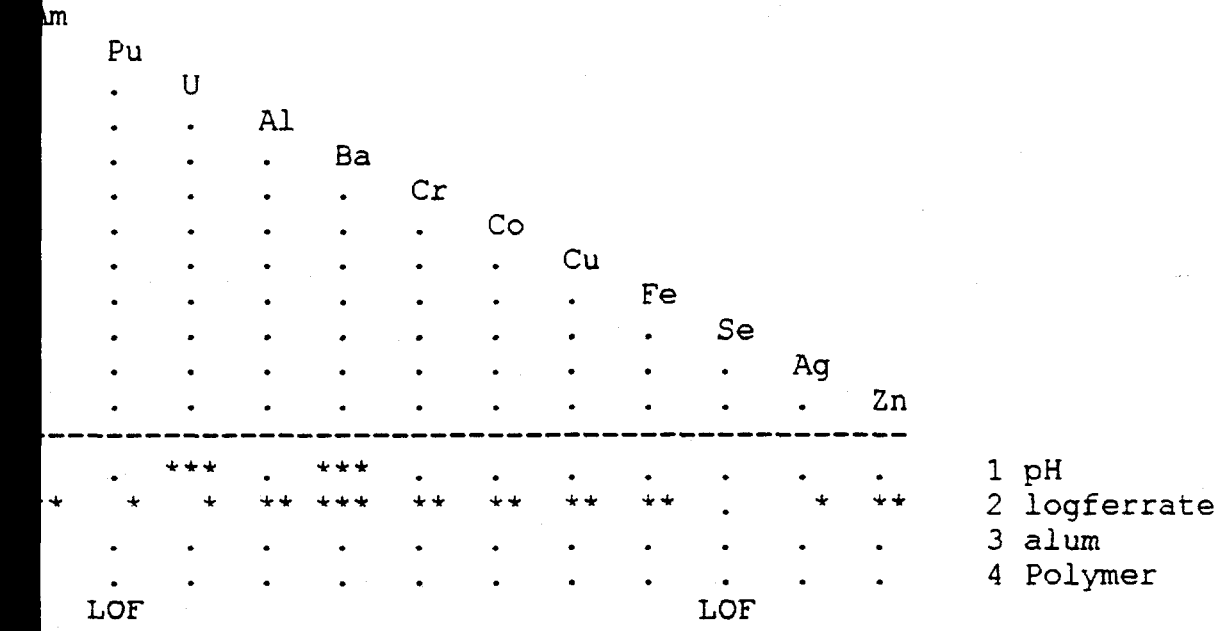
APPENDIX E

ECHIP OUTPUT OF PHASE I MODIFIED TEST PLAN

ROJECT NAME: ROCKYFLA.ECP

reated: Thu Nov 03 09:36:03 1994

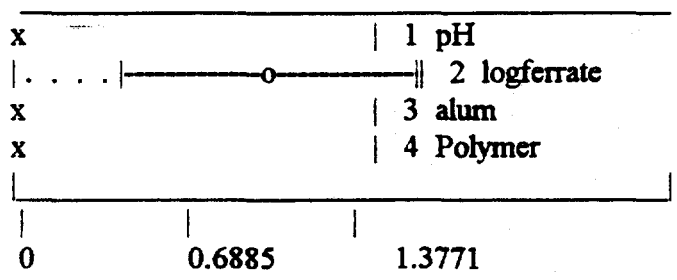
mmary results



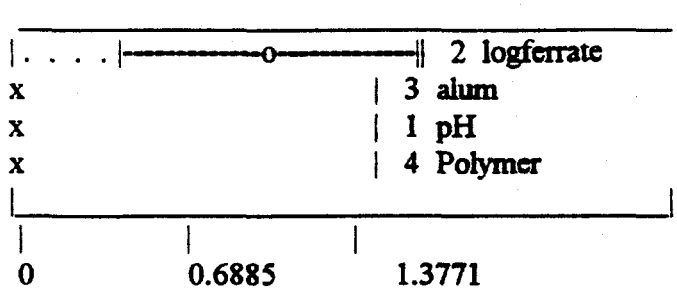
PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:35:54 1994

«××××××××××××» Effects graph for response 'Am'

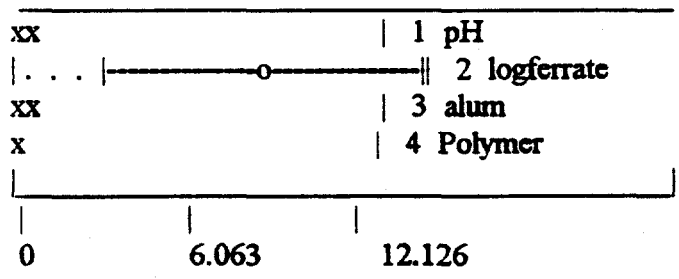


Pareto effects graph for response 'Am'



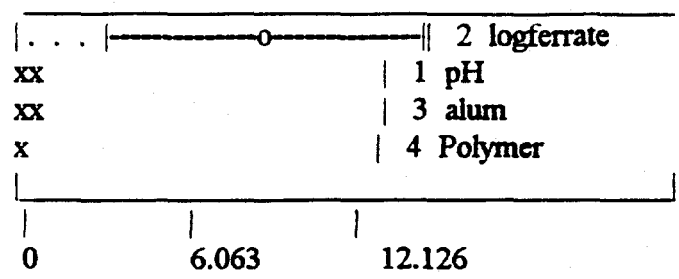
«××××××××××××» Effects graph for response 'Pu'

LACK-OF-FIT

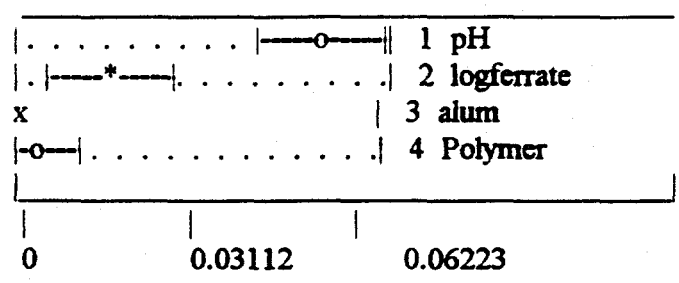


Pareto effects graph for response 'Pu'

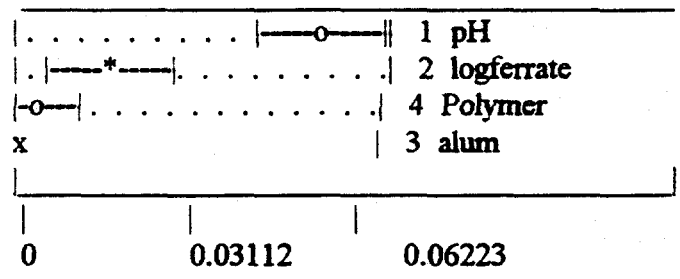
LACK-OF-FIT



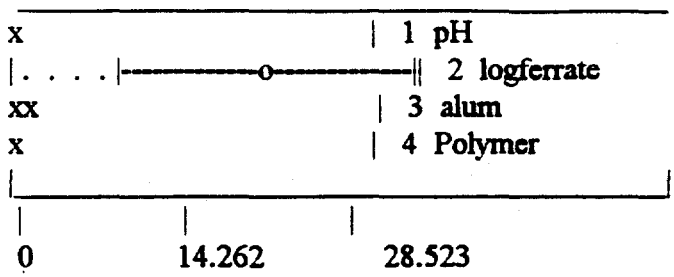
«××××××××××××» Effects graph for response 'U'



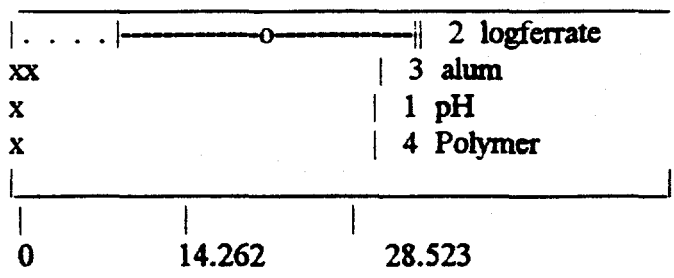
Pareto effects graph for response 'U'



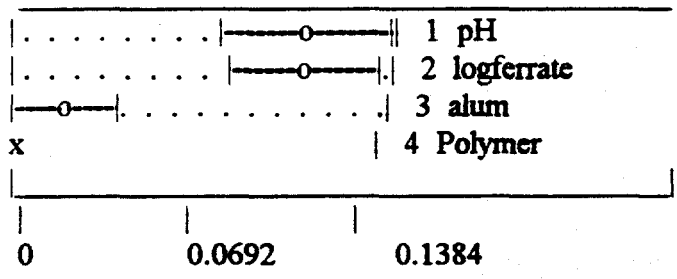
«××××××××××××» Effects graph for response 'Al'



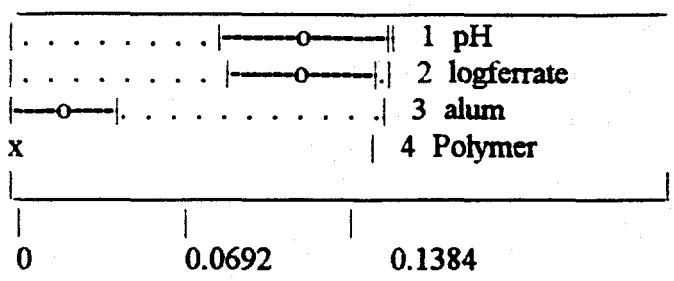
Pareto effects graph for response 'Al'



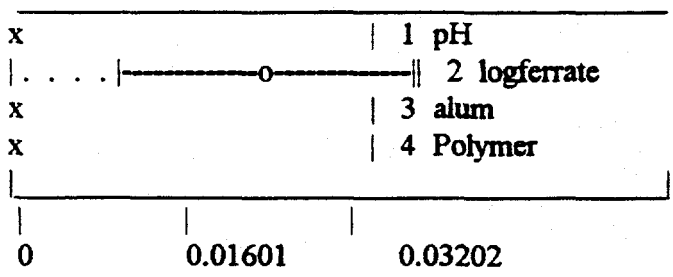
«××××××××××××» Effects graph for response 'Ba'



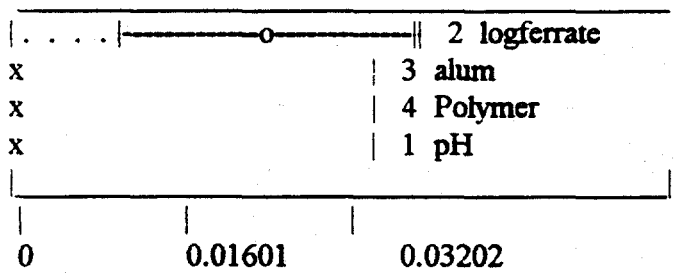
Pareto effects graph for response 'Ba'



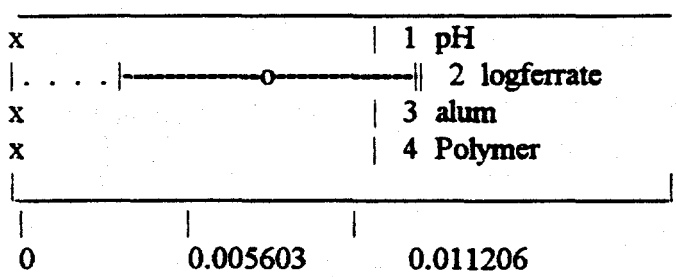
«××××××××××××» Effects graph for response 'Cr'



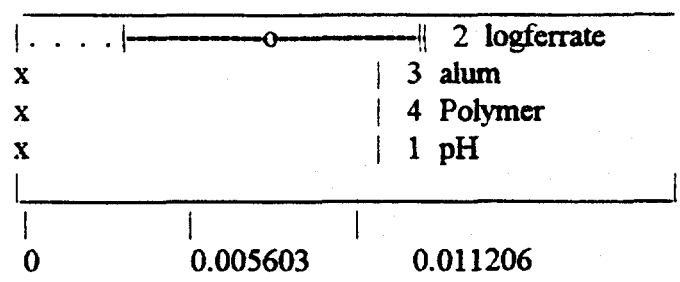
Pareto effects graph for response 'Cr'



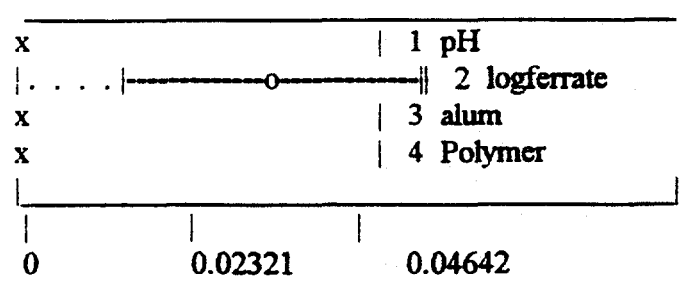
«××××××××××××» Effects graph for response 'Co'



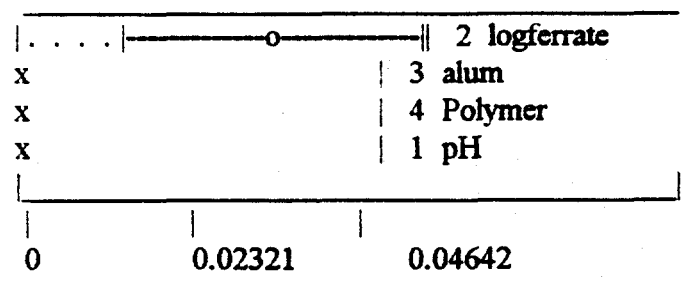
Pareto effects graph for response 'Co'



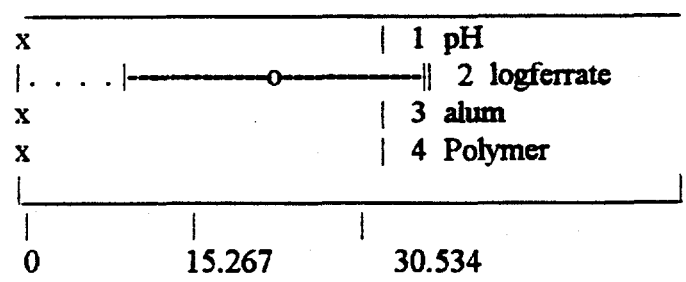
«××××××××××××» Effects graph for response 'Cu'



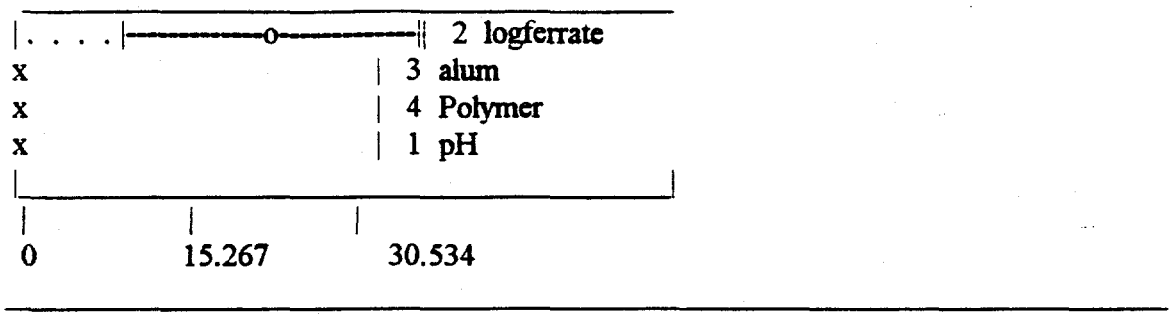
Pareto effects graph for response 'Cu'



«××××××××××××» Effects graph for response 'Fe'

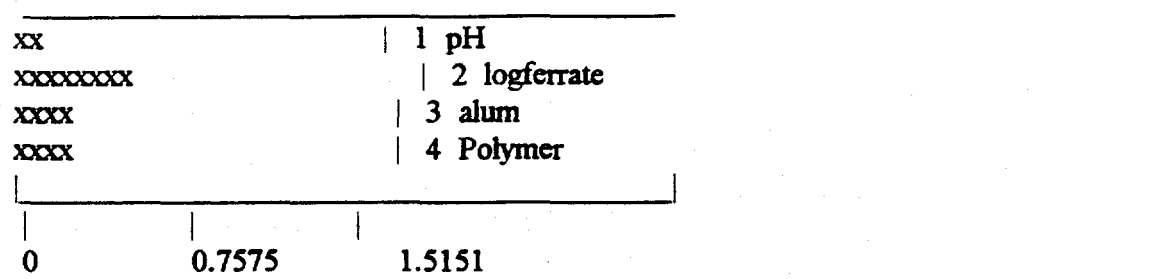


Pareto effects graph for response 'Fe'



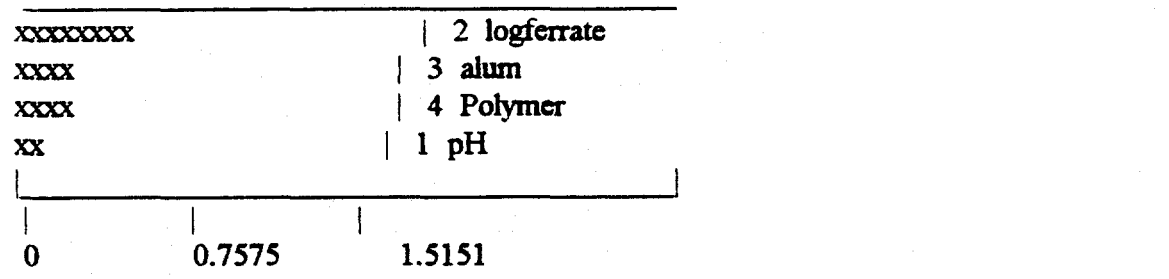
«××××××××××××××» Effects graph for response 'Se'

LACK-OF-FIT

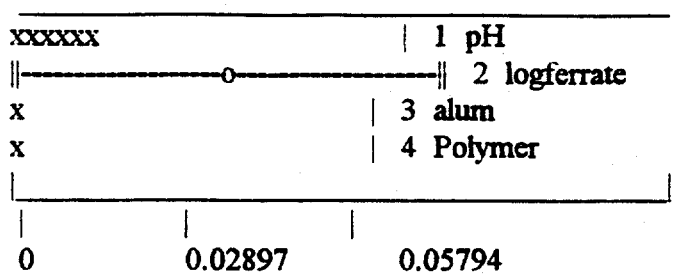


Pareto effects graph for response 'Se'

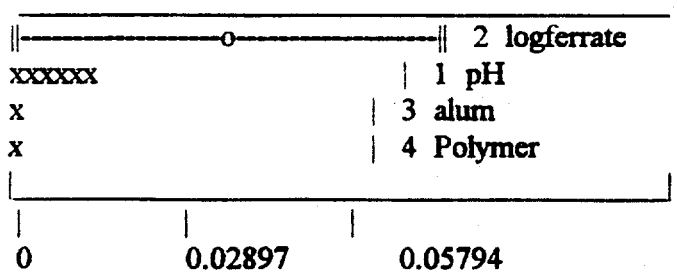
LACK-OF-FIT



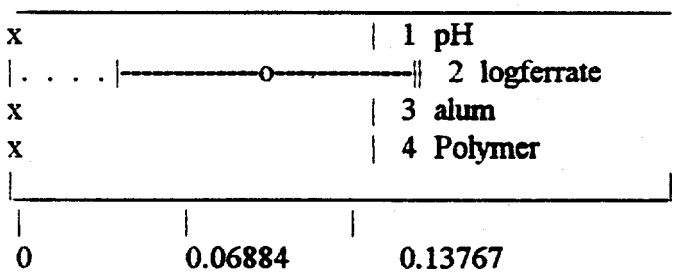
«××××××××××××» Effects graph for response 'Ag'



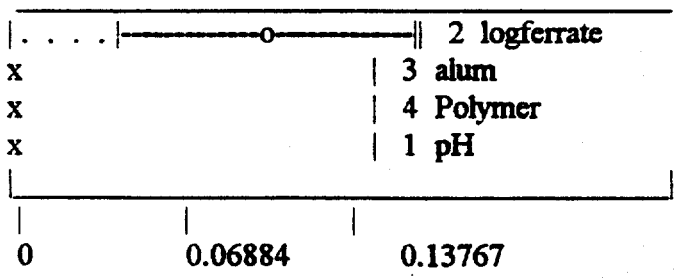
Pareto effects graph for response 'Ag'



«××××××××××××» Effects graph for response 'Zn'



Pareto effects graph for response 'Zn'



PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:35:49 1994

«××××××××××××» Effects for response 'Am'

EFFECTS	RESLTN	SIG	TERM
0.0025			0 CONSTANT
0.0070	0.5022		1 pH
-0.8970		**	2 logferrate
-0.0182	0.3385		3 alum
-0.0001	0.2859		4 Polymer

Residual SD = 0.091206
Replicate SD = 0.021213

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Pu'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
0.116			0 CONSTANT
-0.417	4.939		1 pH
-7.742		*	2 logferrate
0.381	3.307		3 alum
0.138	2.748		4 Polymer

Residual SD = 0.832848
Replicate SD = 0.007071

N terms = 5

N unique trials = 7
N replicates = 1
N total trials = 8

«xxxxxxxxxxxxx» Effects for response 'U'

EFFECTS	RESLTN	SIG	TERM
0.01970			0 CONSTANT
-0.05295		***	1 pH
0.01408		*	2 logferrate
0.00115	0.00716		3 alum
-0.00305	0.00841		4 Polymer

Residual SD = 0.001709
Replicate SD = 0.000707

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«xxxxxxxxxxxxx» Effects for response 'Al'

EFFECTS	RESLTN	SIG	TERM
0.514			0 CONSTANT
-0.652	10.538		1 pH
-18.939		**	2 logferrate
1.210	7.605		3 alum
0.543	6.249		4 Polymer

Residual SD = 1.820774
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1

N total trials = 8

«××××××××××××» Effects for response 'Ba'

EFFECTS	RESLTN	SIG	TERM
0.0386			0 CONSTANT
-0.1131		***	1 pH
-0.1111		***	2 logferrate
-0.0157	0.0322		3 alum
-0.0026	0.0172		4 Polymer

Residual SD = 0.004670
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Cr'

EFFECTS	RESLTN	SIG	TERM
0.00019			0 CONSTANT
-0.00047	0.01159		1 pH
-0.02123		**	2 logferrate
0.00064	0.00784		3 alum
0.00062	0.00705		4 Polymer

Residual SD = 0.002049
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Co'

EFFECTS	RESLTN	SIG	TERM
0.000067			0 CONSTANT
-0.000164	0.004058		1 pH
-0.007431		**	2 logferrate
0.000225	0.002744		3 alum
0.000219	0.002466		4 Polymer

Residual SD = 0.000717
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Cu'

EFFECTS	RESLTN	SIG	TERM
0.00028			0 CONSTANT
-0.00068	0.01681		1 pH
-0.03079		**	2 logferrate
0.00093	0.01137		3 alum
0.00091	0.01022		4 Polymer

Residual SD = 0.002971
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Fe'

EFFECTS RESLTN SIG TERM

0.261			0 CONSTANT
-0.292	10.957		1 pH
-20.194		**	2 logferrate
0.604	7.503		3 alum
0.602	6.757		4 Polymer

Residual SD = 1.964244
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Se'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.1132			0 CONSTANT
-0.0717	1.3587		1 pH
0.2674	1.5151		2 logferrate
-0.1506	0.9831		3 alum
-0.1488	0.8916		4 Polymer

Residual SD = 0.237037
Replicate SD = 0.002828

N terms = 5
N unique trials
N replicates

» Effects for response 'Ag'

EFFECTS RESLTN SIG TERM

0.00421 0 CONSTANT
0.00762 0.03636 1 pH
-0.03007 * 2 logferrate
-0.00135 0.01994 3 alum
-0.00022 0.01681 4 Polymer

Residual SD = 0.005294
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«××××××××××××» Effects for response 'Zn'

EFFECTS RESLTN SIG TERM

0.00083 0 CONSTANT
-0.00202 0.04985 1 pH
-0.09130 ** 2 logferrate
0.00277 0.03371 3 alum
0.00268 0.03029 4 Polymer

Residual SD = 0.008810
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:35:42 1994

«××××××××××××» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00247295			0	CONSTANT
0.00302501	0.0676545	0.9671-	0.803	1 pH
-0.183251	0.0308181	0.0095	0.679	2 logferrate
-0.000363665	0.0020131	0.8682-	0.802	3 alum
-2.14618e-005	0.0179623	0.9991-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.091206
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.021213
Replicate DF = 1

R Squared = 0.963, P=0.0174 *
Adj R Squared = 0.914
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Pu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.115677			0	CONSTANT
-0.181463	0.617791	0.7881-	0.803	1 pH
-1.58158	0.281417	0.0111	0.679	2 logferrate
0.00762947	0.0183827	0.7060-	0.802	3 alum
0.0276479	0.164024	0.8769-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.832848, Lack-Of-Fit P=0.0316 *
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.007071
Replicate DF = 1

R Squared = 0.957, P=0.0220 *
Adj R Squared = 0.899
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 2.996 P=0.0048 **
- This term may be eliminated

«××××××××××××» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0197023			0	CONSTANT
-0.0230218	0.0012679	0.0004	0.803	1 pH
0.00287712	0.000577554	0.0155	0.679	2 logferrate
2.3051e-005	3.7727e-005	0.5844-	0.802	3 alum
-0.000610998	0.000336628	0.1671	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.001709
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000707
Replicate DF = 1

R Squared = 0.992, P=0.0018 **
Adj R Squared = 0.981
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Al'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.513518			0	CONSTANT
-0.283369	1.35062	0.8473-	0.803	1 pH
-3.86907	0.615234	0.0081	0.679	2 logferrate
0.0242024	0.0401883	0.5895-	0.802	3 alum
0.108699	0.35859	0.7816-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 1.820774
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.963, P=0.0172 *
Adj R Squared = 0.914
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Ba'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0386266			0	CONSTANT
-0.0491524	0.00346426	0.0008	0.803	1 pH
-0.0226995	0.00157805	0.0007	0.679	2 logferrate
-0.000314993	0.000103081	0.0552	0.802	3 alum
-0.000520995	0.000919765	0.6107-	0.835	4 Polymer

N trials = 8

N terms = 5

Residual SD = 0.004670
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.998, P=0.0003 ***
Adj R Squared = 0.995
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 2.999 P=0.0013 **
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Cr'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.000192196			0	CONSTANT
-0.00020391	0.00151984	0.9018-	0.803	1 pH
-0.00433739	0.000692319	0.0082	0.679	2 logferrate
1.28812e-005	4.52237e-005	0.7943-	0.802	3 alum
0.000124873	0.000403519	0.7772-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.002049
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.964, P=0.0167 *
Adj R Squared = 0.916
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«××××××××××××» Coefficients for response 'Co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
6.72685e-005			0	CONSTANT
-7.13685e-005	0.000531943	0.9018-	0.803	1 pH
-0.00151809	0.000242311	0.0082	0.679	2 logferrate
4.50844e-006	1.58283e-005	0.7943-	0.802	3 alum
4.37054e-005	0.000141232	0.7772-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.000717
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.964, P=0.0167 *
Adj R Squared = 0.916
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«××××××××××××» Coefficients for response 'Cu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.000278684			0	CONSTANT
-0.000295669	0.00220377	0.9018-	0.803	1 pH
-0.00628922	0.00100386	0.0082	0.679	2 logferrate
1.86778e-005	6.55743e-005	0.7943-	0.802	3 alum
0.000181065	0.000585102	0.7772-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.002971
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.964, P=0.0167 *
Adj R Squared = 0.916
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Fe'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.261247			0	CONSTANT
-0.127093	1.45704	0.9360-	0.803	1 pH
-4.12549	0.663712	0.0084	0.679	2 logferrate
0.012078	0.043355	0.7987-	0.802	3 alum
0.120344	0.386845	0.7761-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 1.964244
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.963, P=0.0173 *
Adj R Squared = 0.914
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxxx» Coefficients for response 'Se'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.113216			0	CONSTANT
-0.0311594	0.175829	0.8706-	0.803	1 pH
0.0546185	0.080094	0.5442-	0.679	2 logferrate
-0.00301146	0.0052319	0.6052-	0.802	3 alum
-0.0297616	0.0466829	0.5691-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.237037, Lack-Of-Fit P=0.0316 *
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.002828
Replicate DF = 1

R Squared = 0.262, P=0.8834
Adj R Squared = 0.000
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0002 ***
- This term may be eliminated

«××××××××××××» Coefficients for response 'Ag'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00420908			0	CONSTANT
0.00331102	0.00392701	0.4611-	0.803	1 pH
-0.00614331	0.00178884	0.0414	0.679	2 logferrate
-2.69518e-005	0.00011685	0.8324-	0.802	3 alum
-4.32029e-005	0.00104263	0.9696-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.005294
Residual DF = 3

Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.881, P=0.0956
Adj R Squared = 0.722
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Zn'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.000826442			0	CONSTANT
-0.000876813	0.0065353	0.9018-	0.803	1 pH
-0.0186508	0.00297697	0.0082	0.679	2 logferrate
5.53893e-005	0.000194462	0.7943-	0.802	3 alum
0.000536952	0.00173513	0.7772-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.008810
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.964, P=0.0167 *
Adj R Squared = 0.916
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:36:01 1994

«××××××××××××» ANOVA Table for response 'Am'

Mean Squares	DF	P	
1.66303e-005	1	0.9671	pH
0.294119	1	0.0095	logferrate
0.000271465	1	0.8682	alum
1.18755e-008	1	0.9991	Polymer
0.00831845	3		ERROR
0.00045	1		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Pu'

LACK-OF-FIT

Mean Squares	DF	P	
0.0598446	1	0.7881	pH
21.9085	1	0.0111	logferrate
0.119481	1	0.7060	alum
0.0197079	1	0.8769	Polymer
0.693636	3		ERROR
5.00001e-005	1		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'U'

Mean Squares	DF	P	
0.000963222	1	0.0004	pH
7.25014e-005	1	0.0155	logferrate
1.09066e-006	1	0.5844	alum
9.62489e-006	1	0.1671	Polymer
2.92158e-006	3		ERROR

4.99998e-007 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Al'

Mean Squares	DF	P	
0.145933	1	0.8473	pH
131.113	1	0.0081	logferrate
1.20235	1	0.5895	alum
0.304624	1	0.7816	Polymer
3.31522	3		ERROR

0 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Ba'

Mean Squares	DF	P	
0.00439075	1	0.0008	pH
0.00451297	1	0.0007	logferrate
0.000203664	1	0.0552	alum
6.99816e-006	1	0.6107	Polymer
2.18107e-005	3		ERROR

0 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Cr'

Mean Squares	DF	P	
7.55658e-008	1	0.9018	pH
0.000164774	1	0.0082	logferrate
3.40586e-007	1	0.7943	alum
4.02022e-007	1	0.7772	Polymer
4.19801e-006	3		ERROR

0 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Co'

Mean Squares DF P

9.25681e-009 1 0.9018 pH
2.01848e-005 1 0.0082 logferrate
4.17218e-008 1 0.7943 alum
4.92477e-008 1 0.7772 Polymer
5.14256e-007 3 ERROR

0 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Cu'

Mean Squares DF P

1.58877e-007 1 0.9018 pH
0.000346437 1 0.0082 logferrate
7.16083e-007 1 0.7943 alum
8.45251e-007 1 0.7772 Polymer
8.82631e-006 3 ERROR

0 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Fe'

Mean Squares DF P

0.0293557 1 0.9360 pH
149.068 1 0.0084 logferrate
0.299435 1 0.7987 alum
0.37339 1 0.7761 Polymer
3.85825 3 ERROR

0 1 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Se'

LACK-OF-FIT

Mean Squares DF P

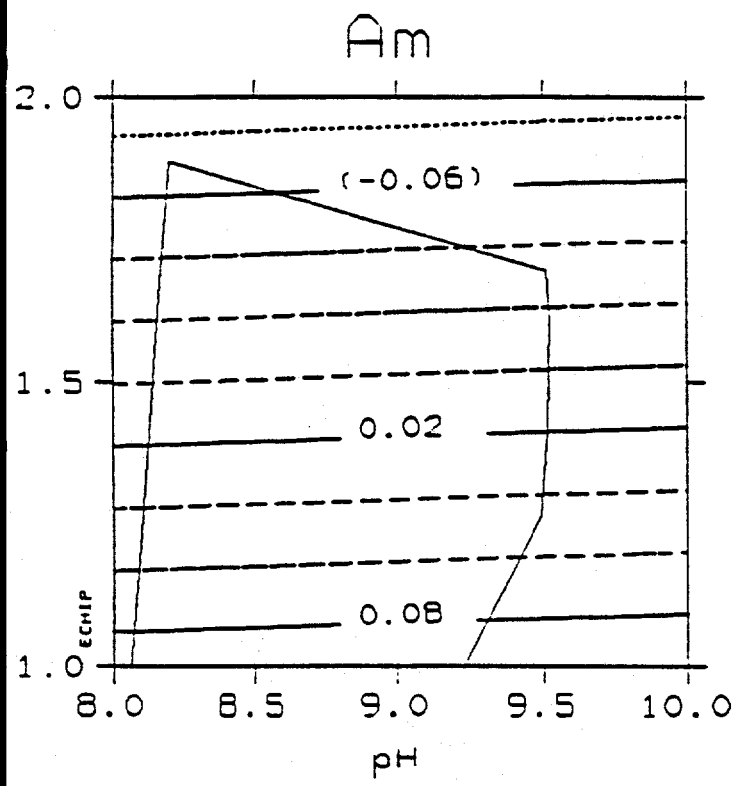
0.00176452	1	0.8706	pH
0.0261283	1	0.5442	logferrate
0.0186151	1	0.6052	alum
0.0228365	1	0.5691	Polymer
0.0561864	3		ERROR
8e-006	1		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Ag'

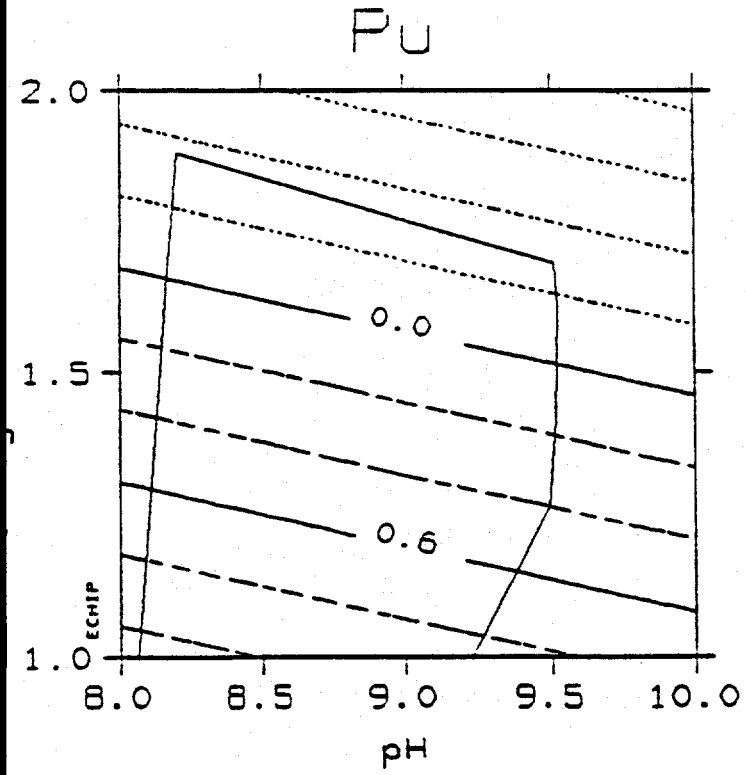
Mean Squares	DF	P	
1.99238e-005	1	0.4611	pH
0.00033055	1	0.0414	logferrate
1.49103e-006	1	0.8324	alum
4.81218e-008	1	0.9696	Polymer
2.80268e-005	3		ERROR
0	1		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Zn'

Mean Squares	DF	P	
1.39721e-006	1	0.9018	pH
0.00304667	1	0.0082	logferrate
6.29744e-006	1	0.7943	alum
7.43339e-006	1	0.7772	Polymer
7.76212e-005	3		ERROR
0	1		REPLICATE ERROR

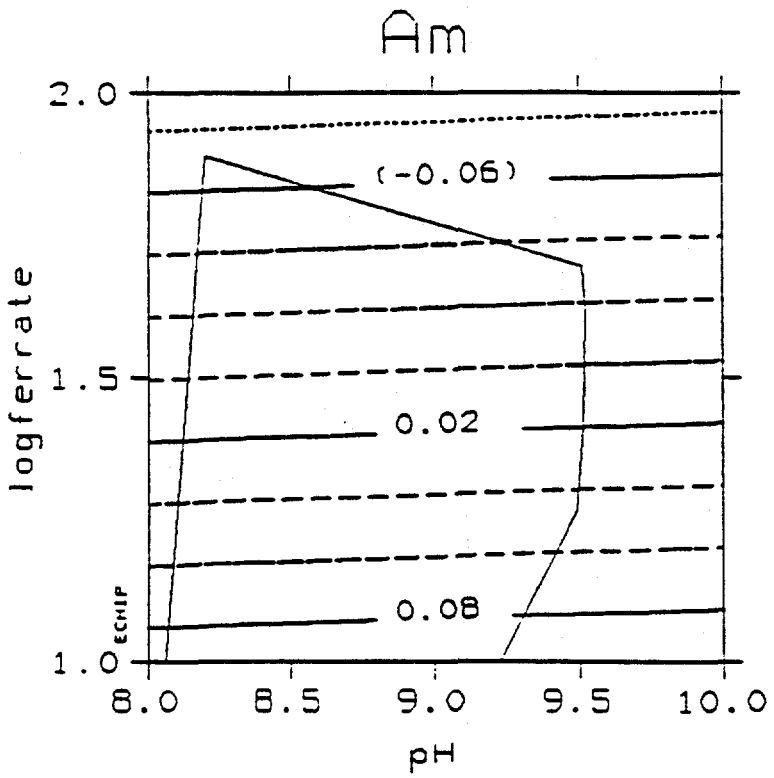


alum = 27.500000
Polymer = 2.5000



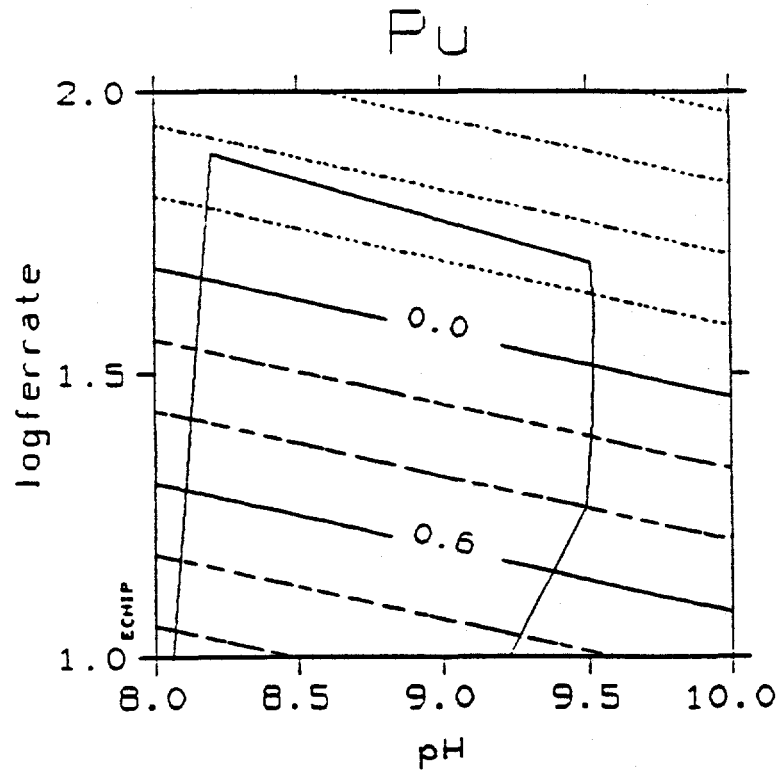
Lack Of Fit

alum = 27.500000
Polymer = 2.5000



alum = 27.500000

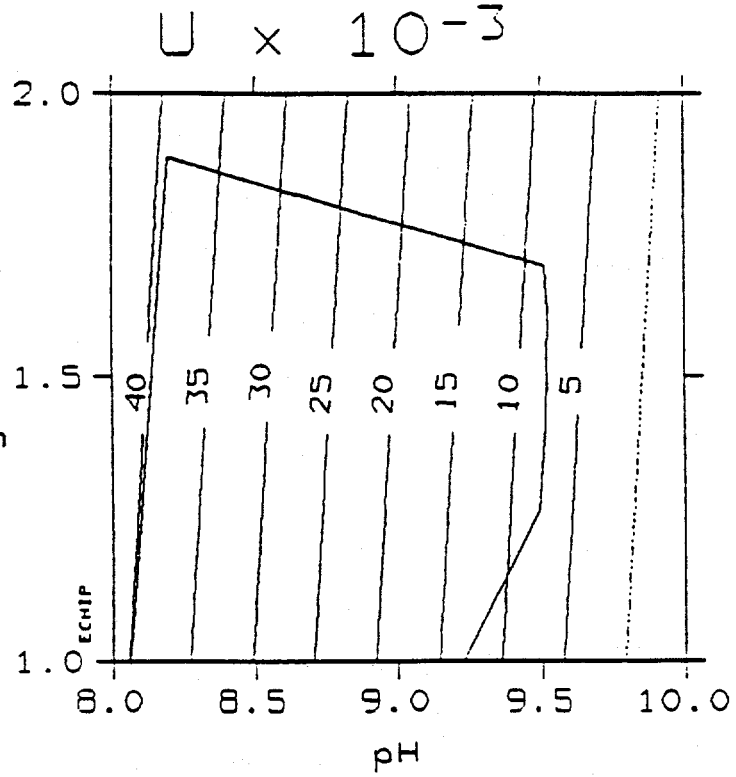
Polymer = 2.5000



Lack Of Fit

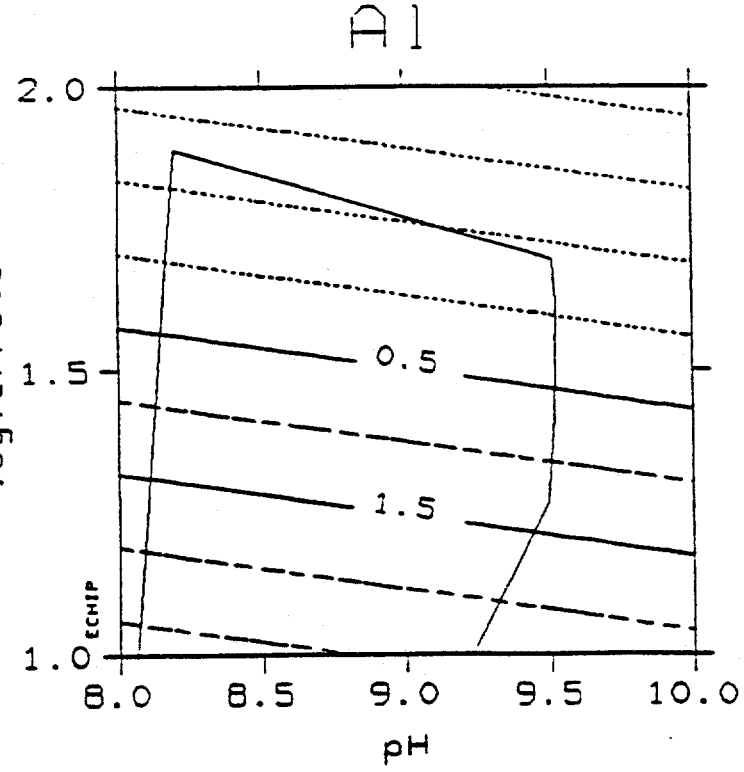
alum = 27.500000

Polymer = 2.5000



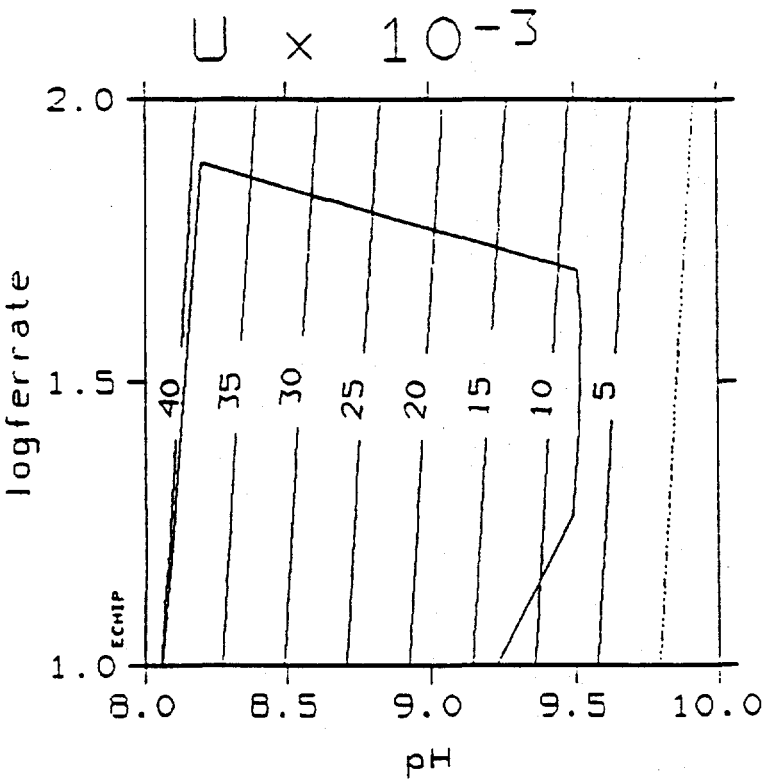
alum = 27.500000

Polymer = 2.5000

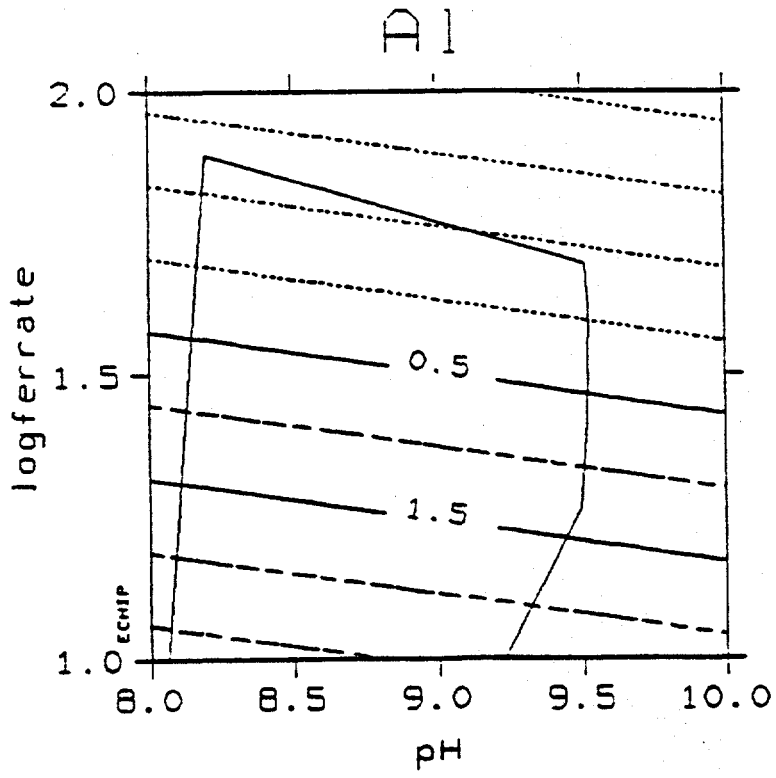


alum = 27.500000

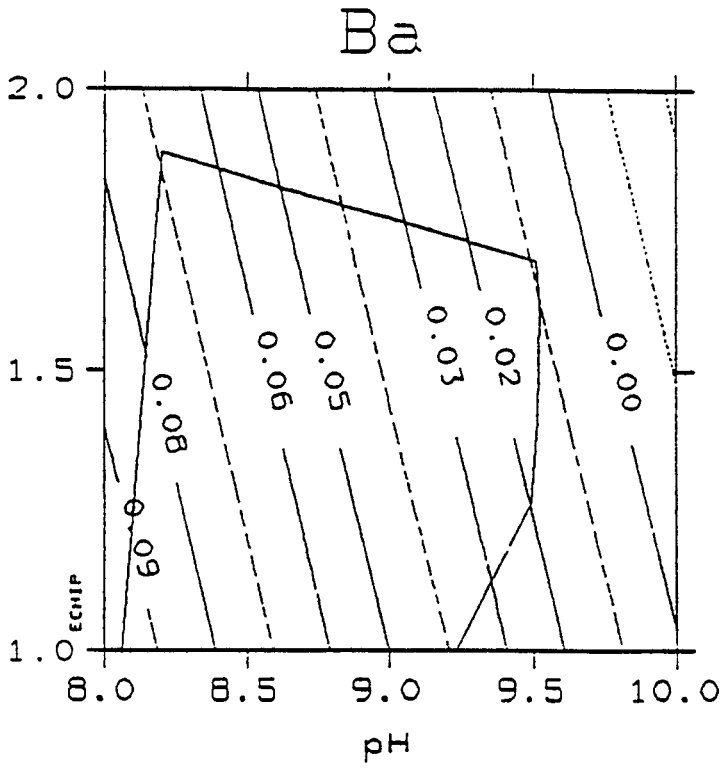
Polymer = 2.5000



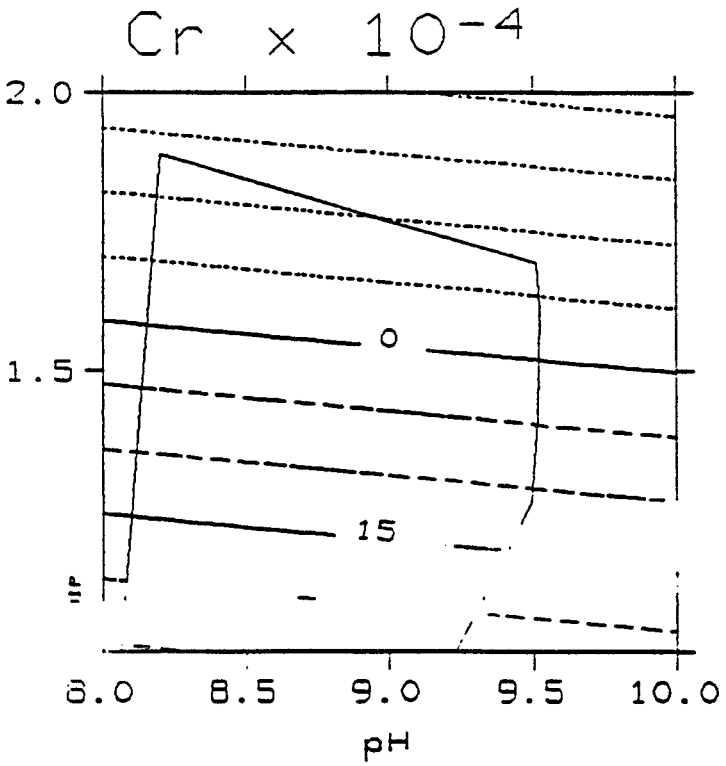
alum = 27.500000
Polymer = 2.5000



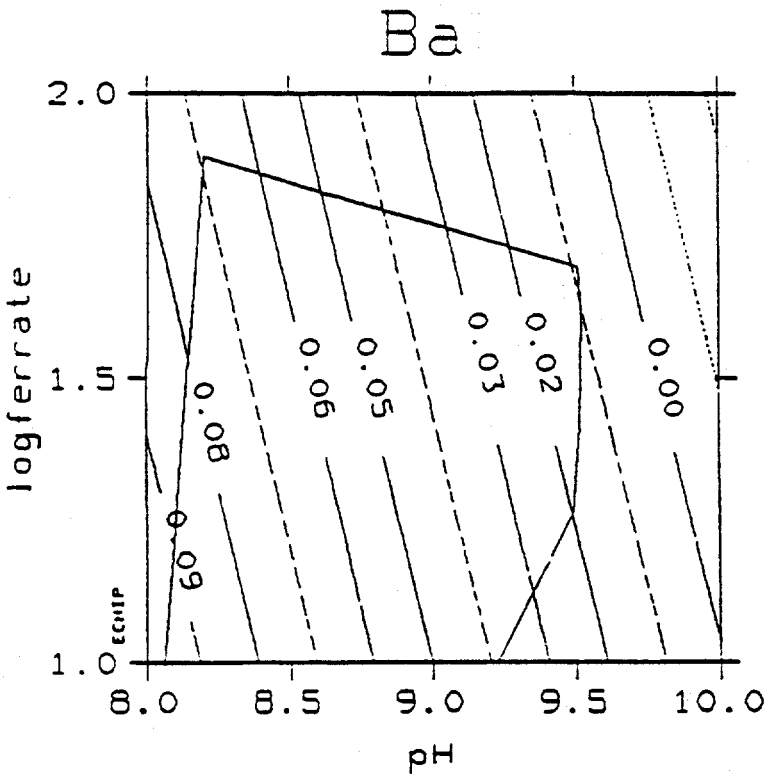
alum = 27.500000
Polymer = 2.5000



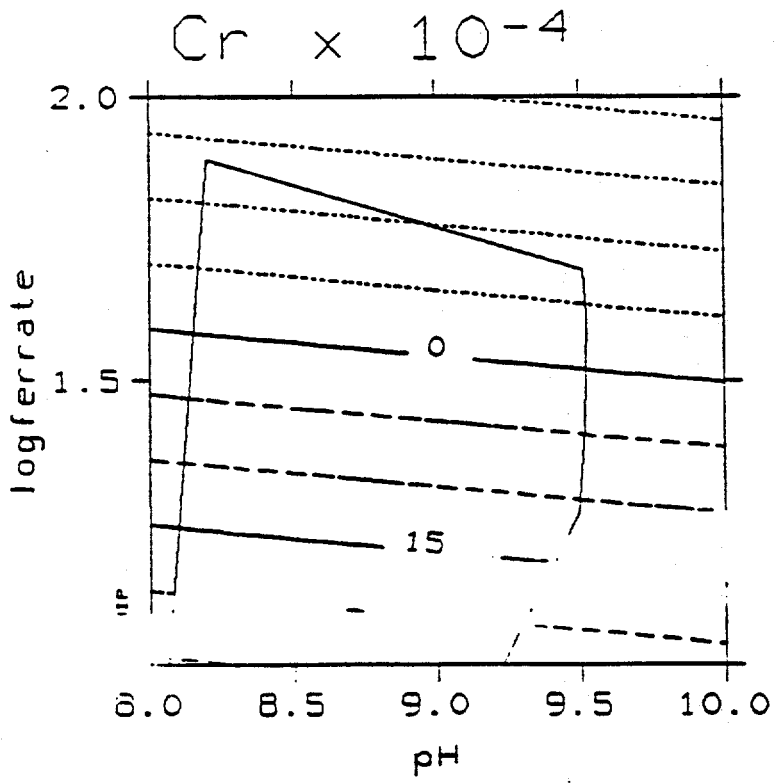
alum = 27.500000
Polymer = 2.5000



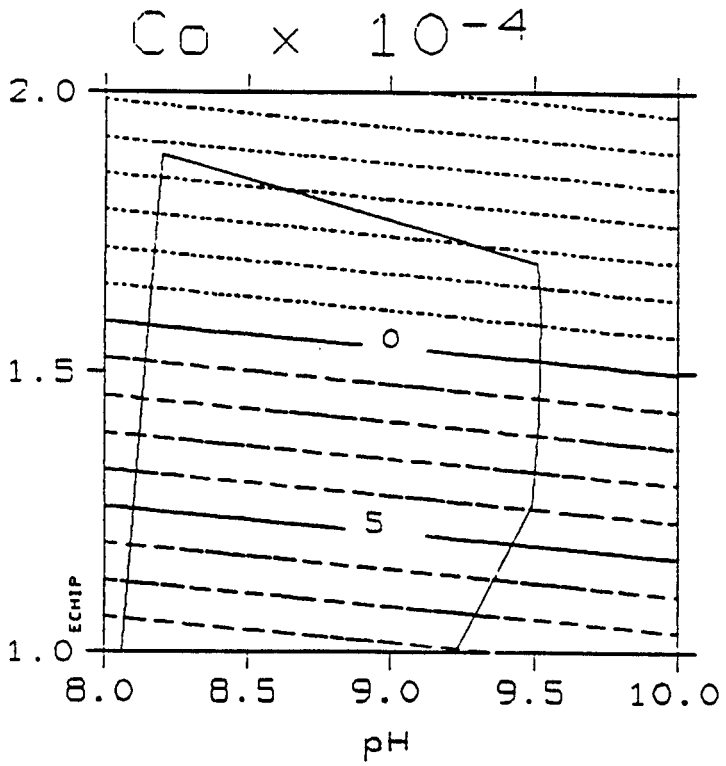
alum = 27.500000
Polymer = 2.5000



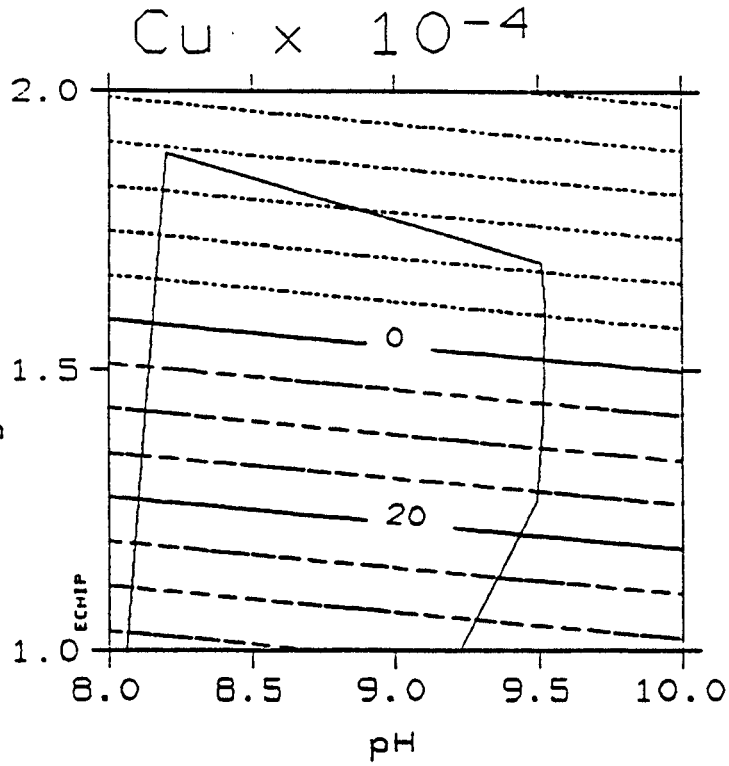
alum = 27.500000
Polymer = 2.5000



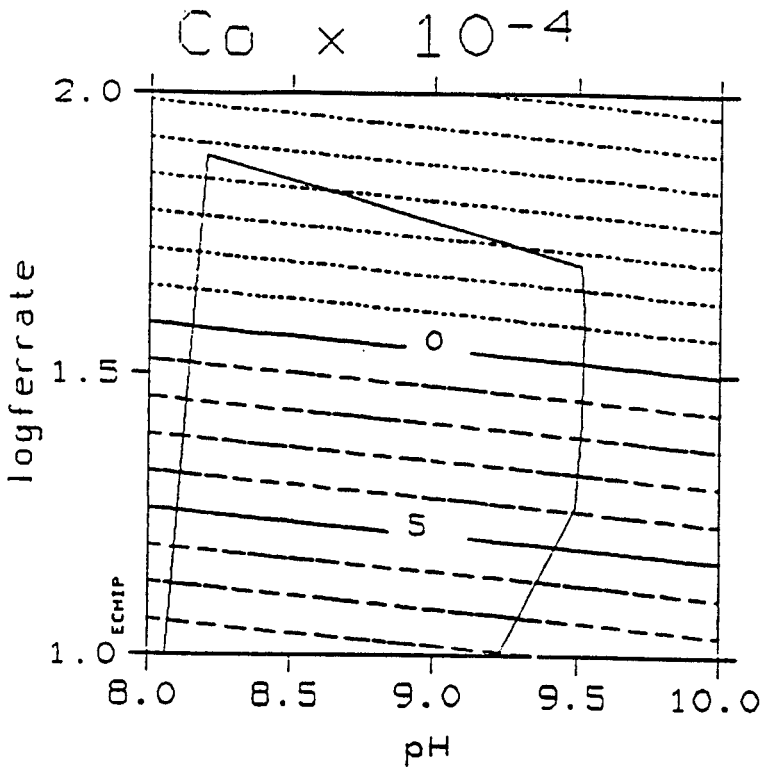
alum = 27.500000
Polymer = 2.5000



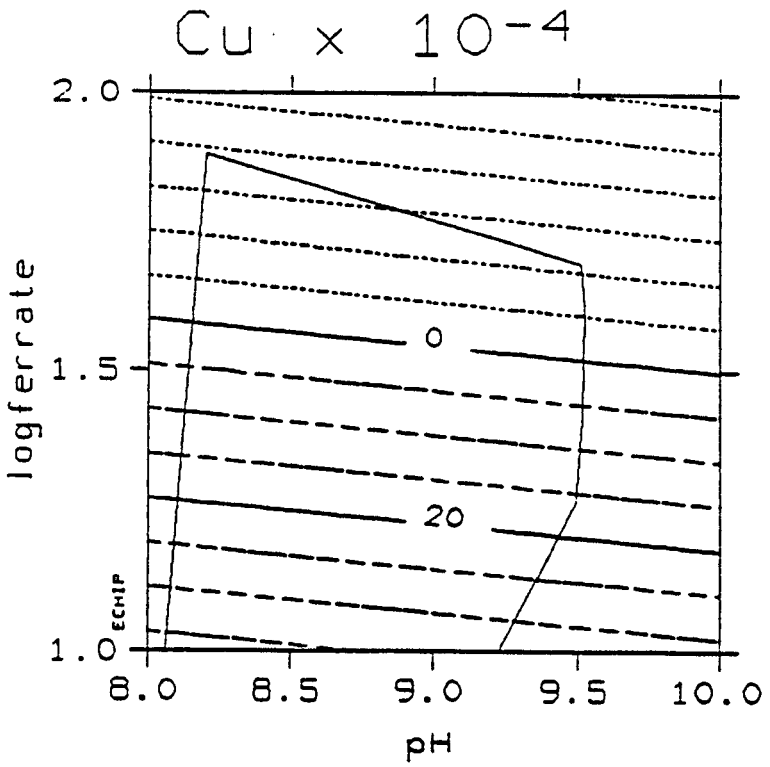
alum = 27.500000
Polymer = 2.5000



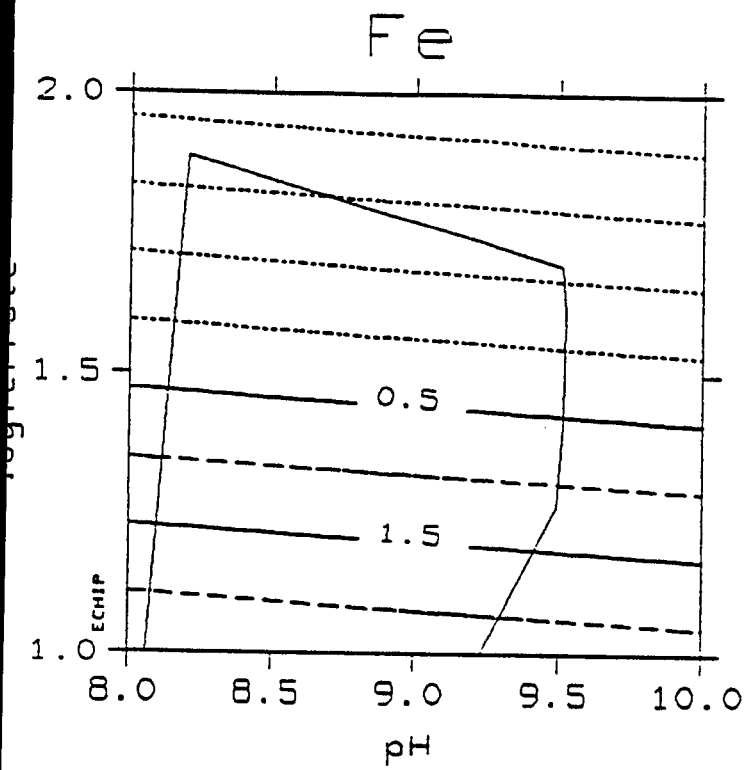
alum = 27.500000
Polymer = 2.5000



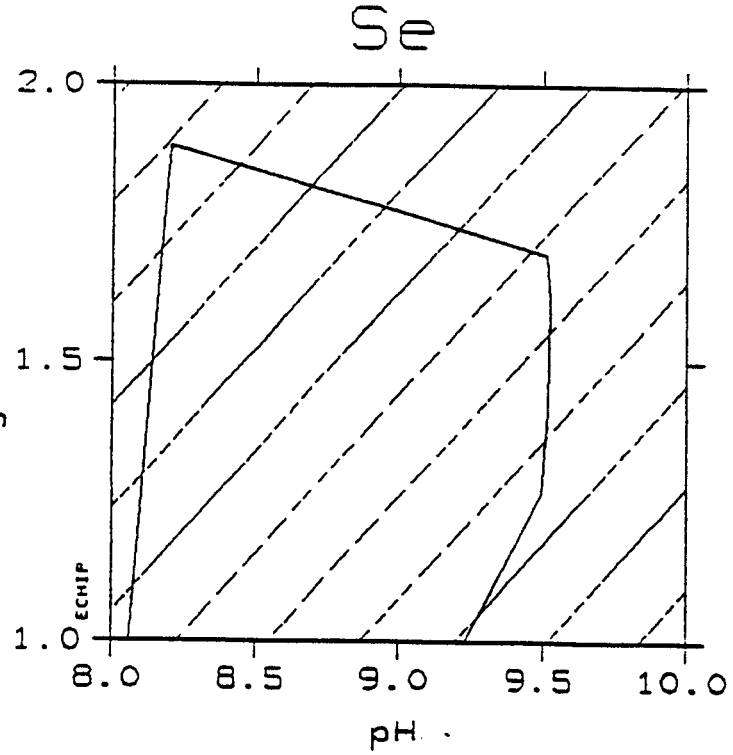
alum = 27.500000
Polymer = 2.5000



alum = 27.500000
Polymer = 2.5000

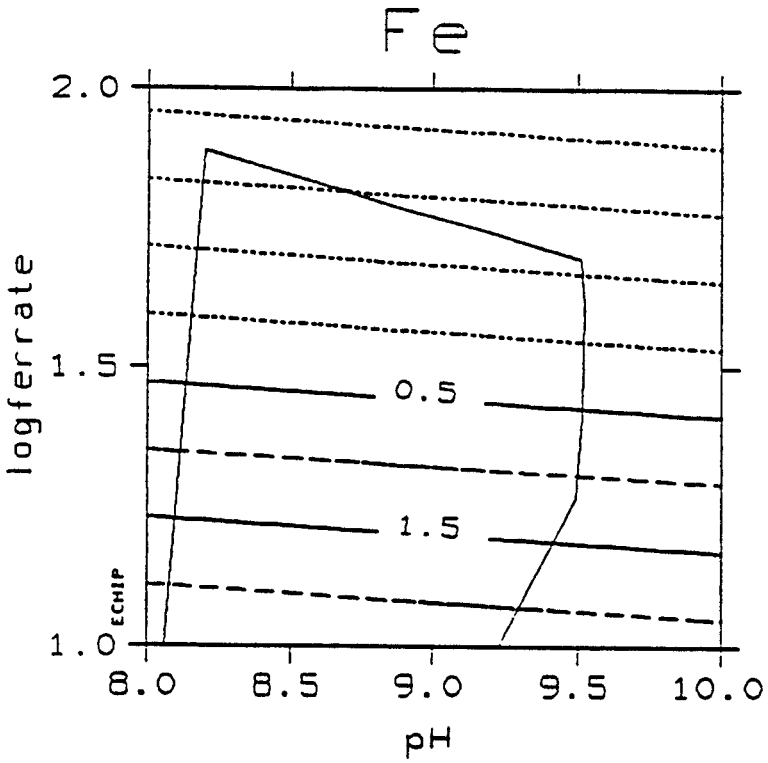


alum = 27.500000
Polymer = 2.5000



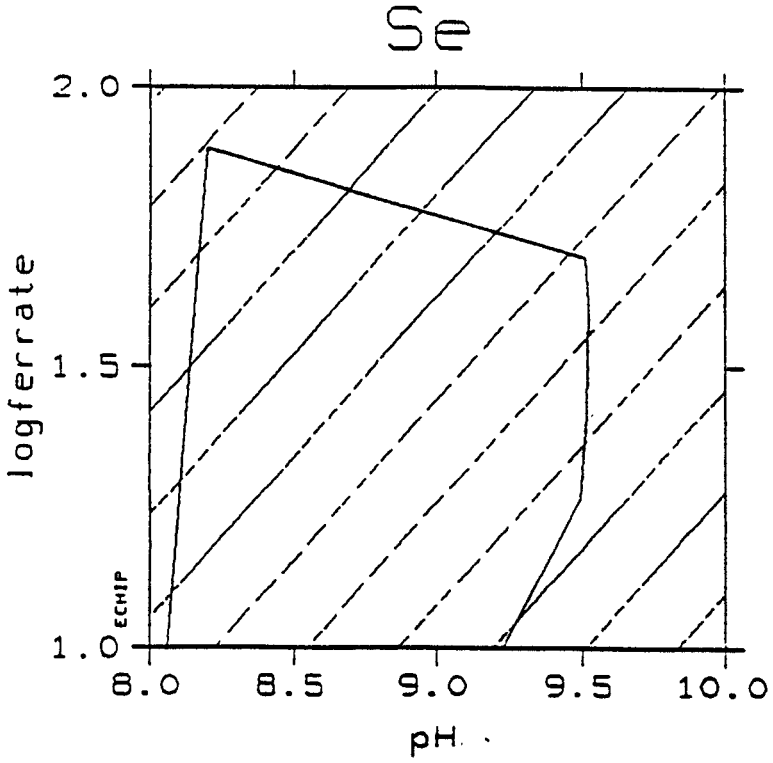
Lack Of Fit

alum = 27.500000
Polymer = 2.5000



alum = 27.500000

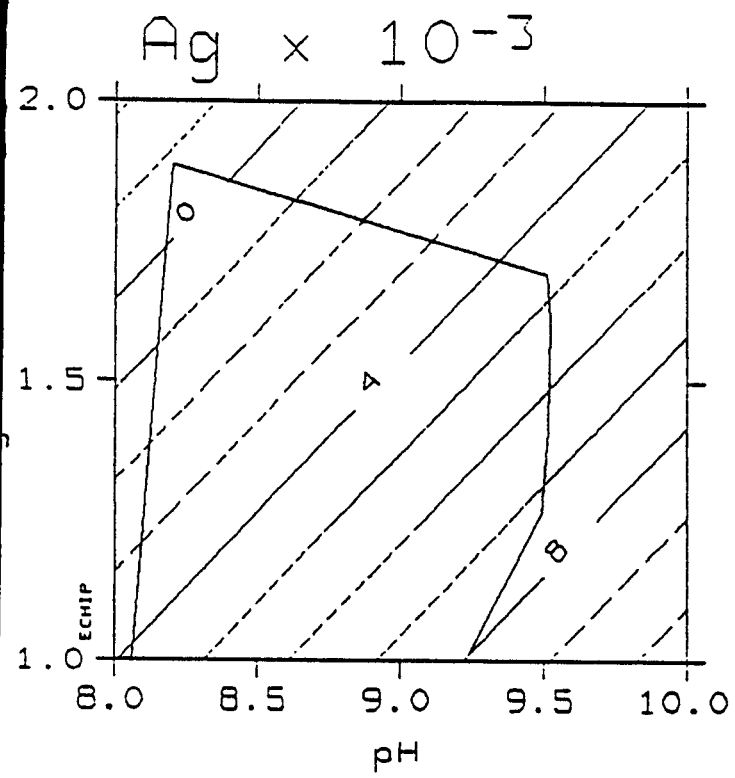
Polymer = 2.5000



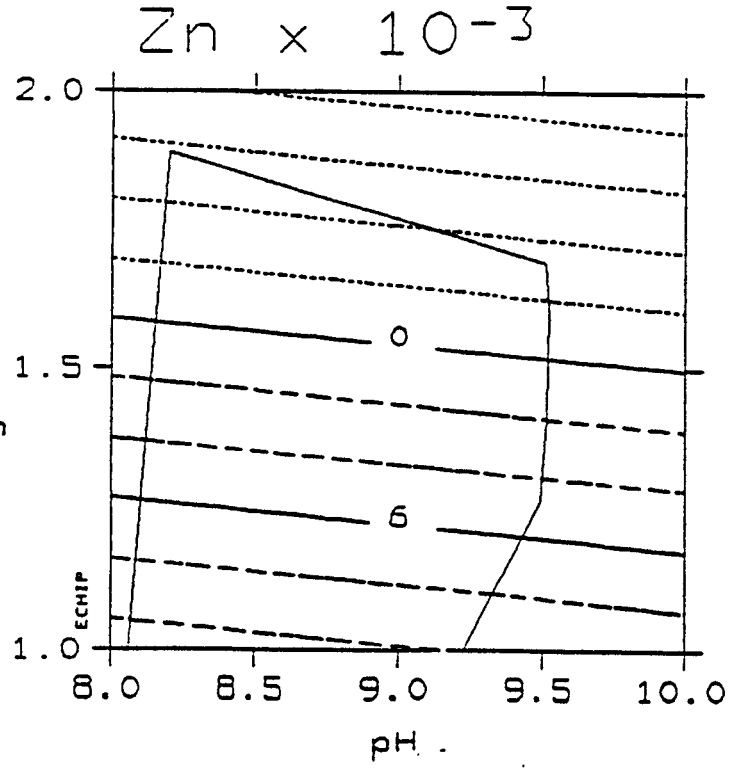
Lack Of Fit

alum = 27.500000

Polymer = 2.5000



alum = 27.500000
Polymer = 2.5000



alum = 27.500000
Polymer = 2.5000

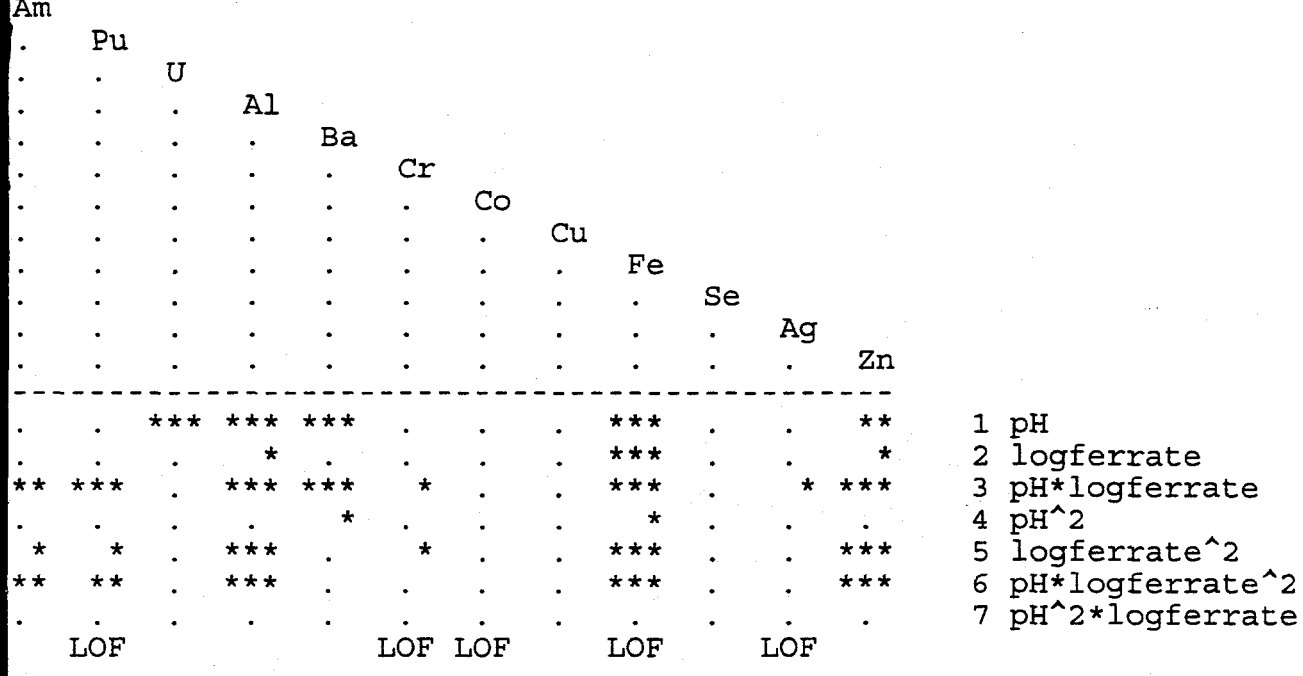
APPENDIX F

ECHIP OUTPUT OF PHASE II MODIFIED TEST PLAN

ROJECT NAME: NEWDATA.ECP

reated: Thu Dec 15 22:04:42 1994

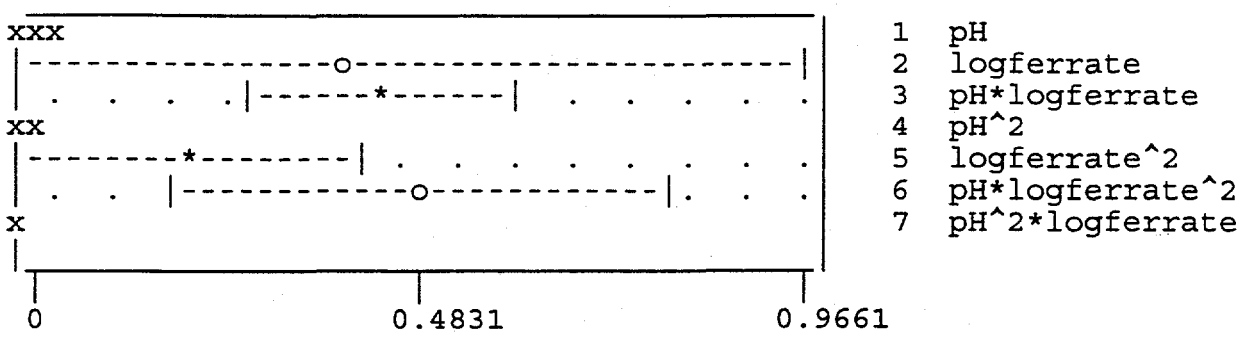
ummary results



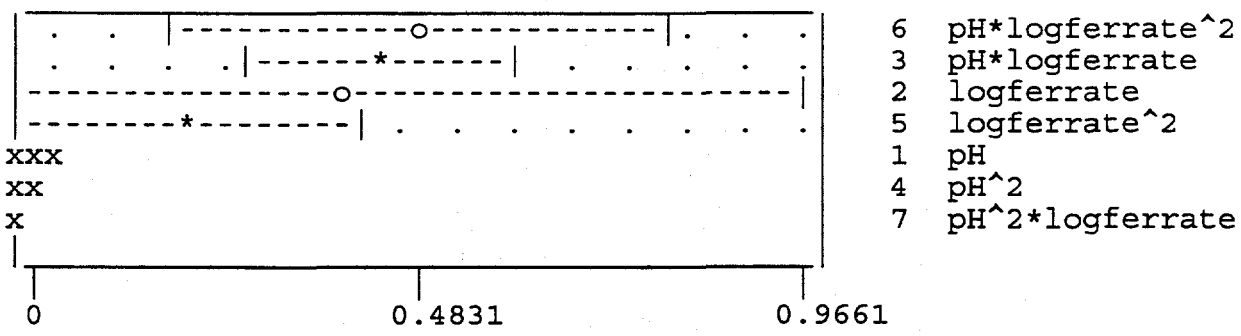
PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:30 1994

«xxxxxxxxxxxxx» Effects graph for response 'Am'



Pareto effects graph for response 'Am'

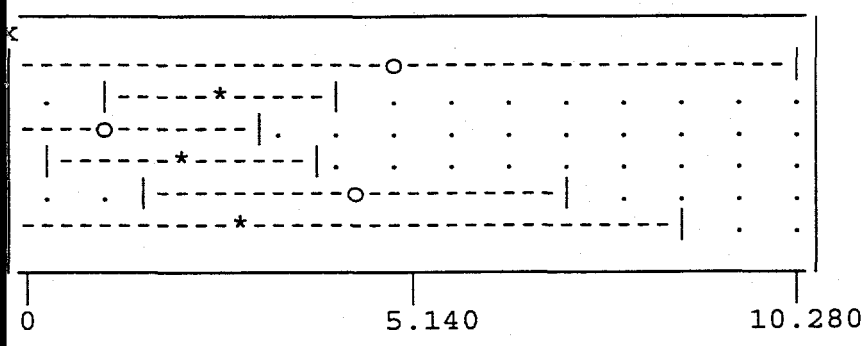


PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:30 1994

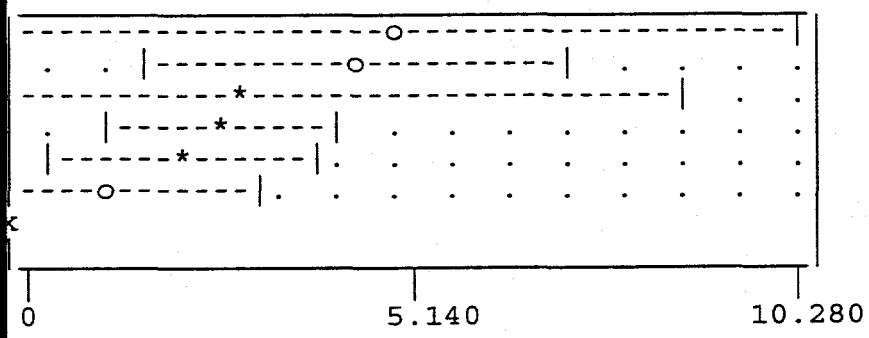
xxxxxxxxxxxxx» Effects graph for response 'Pu'

LACK-OF-FIT



Pareto effects graph for response 'Pu'

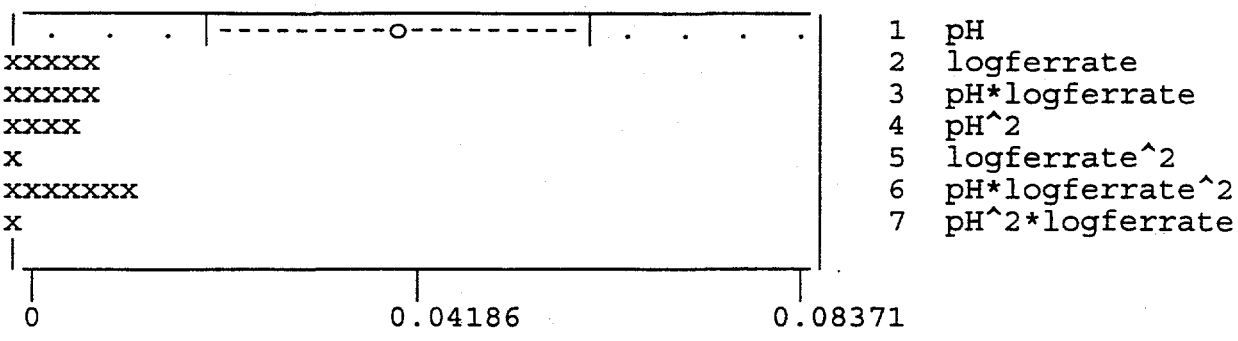
LACK-OF-FIT



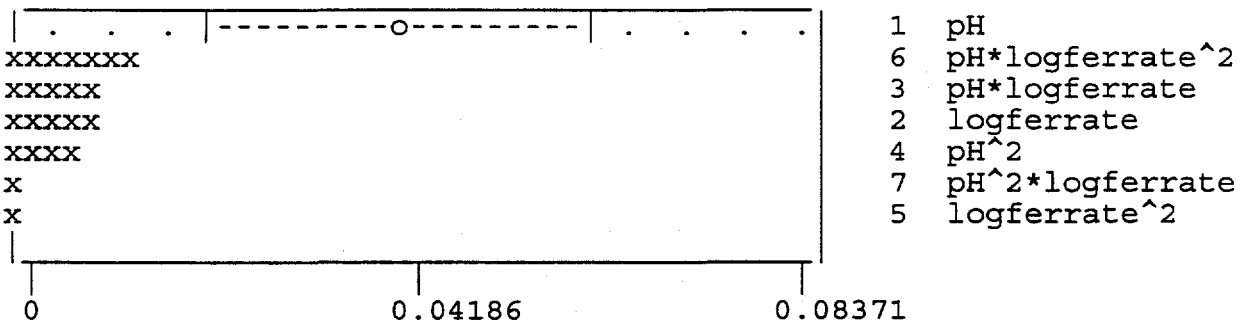
PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:30 1994

«xxxxxxxxxxxxx» Effects graph for response 'U'



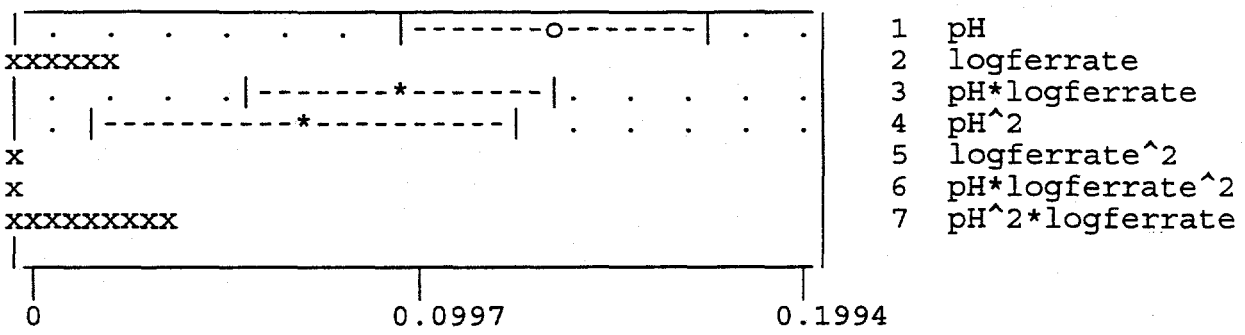
Pareto effects graph for response 'U'



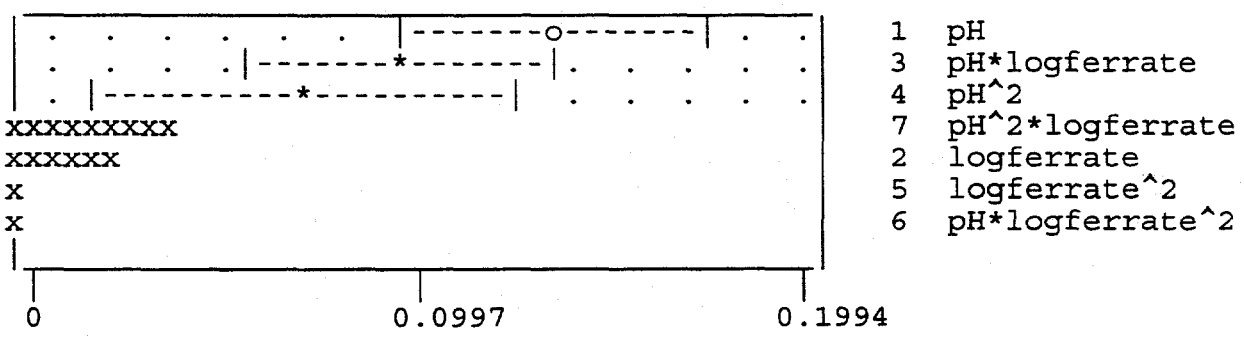
PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:30 1994

«xxxxxxxxxxxxx» Effects graph for response 'Ba'



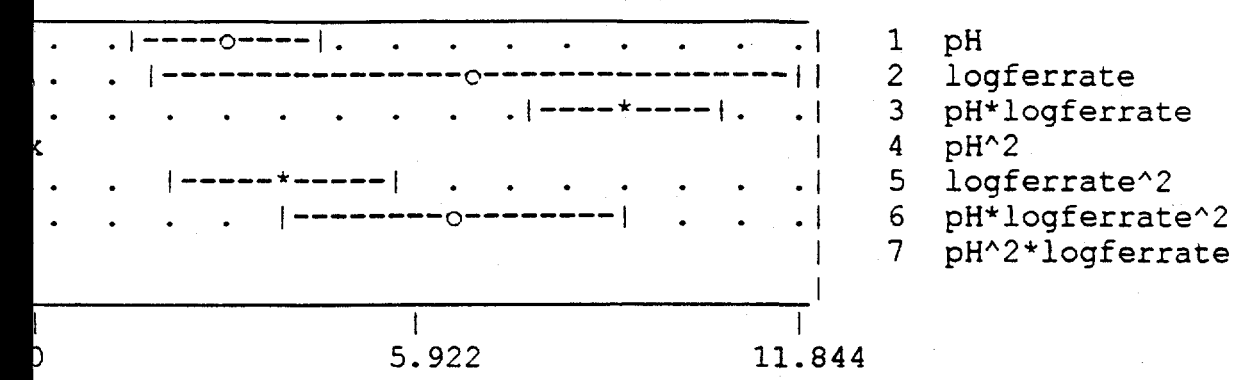
Pareto effects graph for response 'Ba'



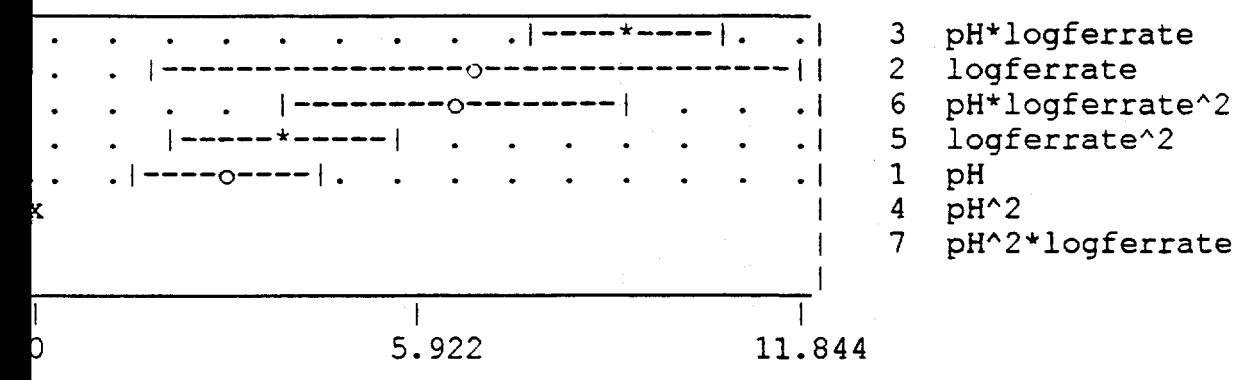
ROJECT NAME: 2NDRF.ECP

reated: Tue Nov 01 13:48:27 1994

××××××××××» Effects graph for response 'Al'



*Pareto effects graph for response 'Al'**

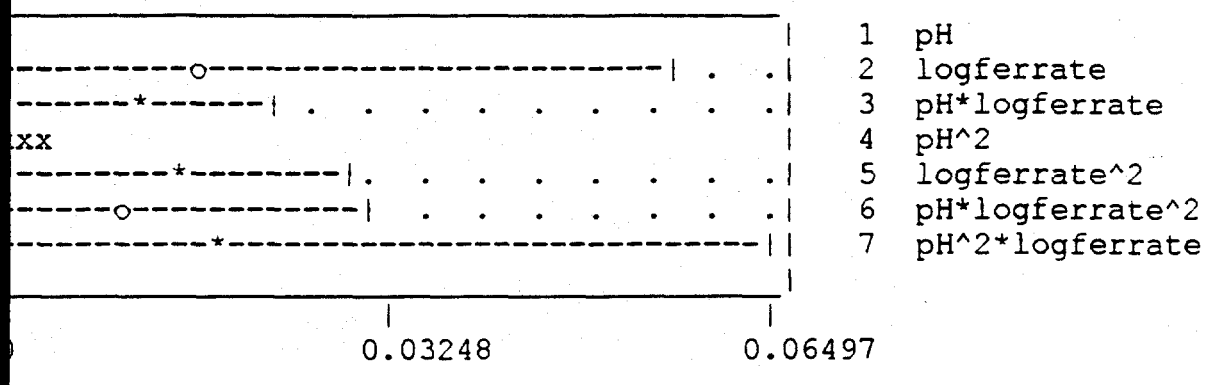


OJECT NAME: 2NDRF.ECP

eated: Tue Nov 01 13:48:27 1994

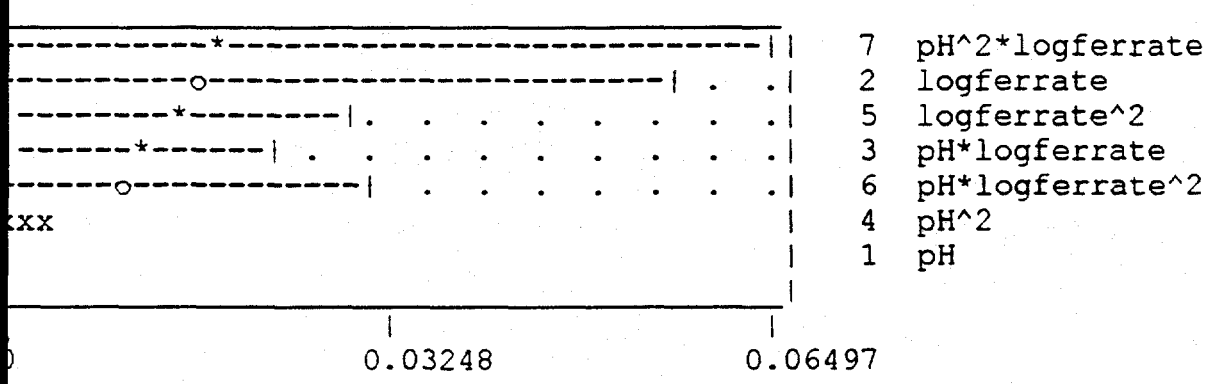
××××××××××» Effects graph for response 'Cr'

CK-OF-FIT



Pareto effects graph for response 'Cr'**

CK-OF-FIT

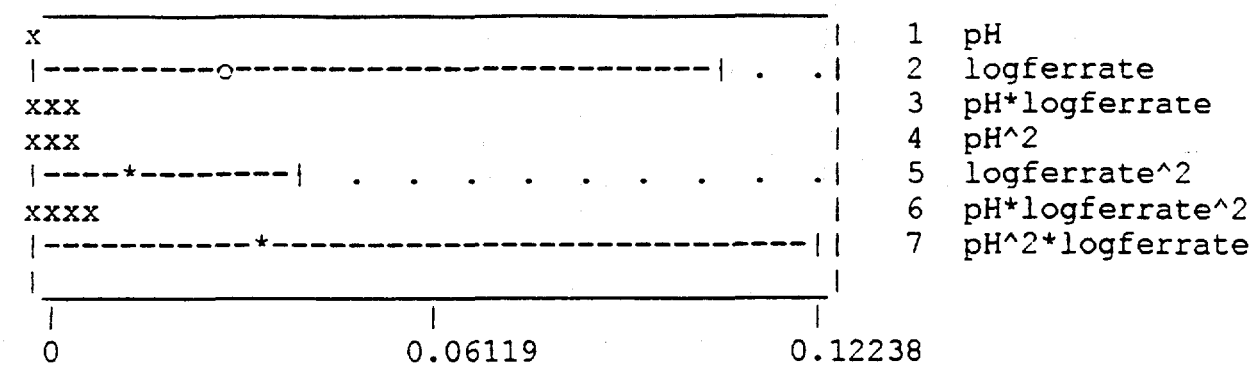


PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

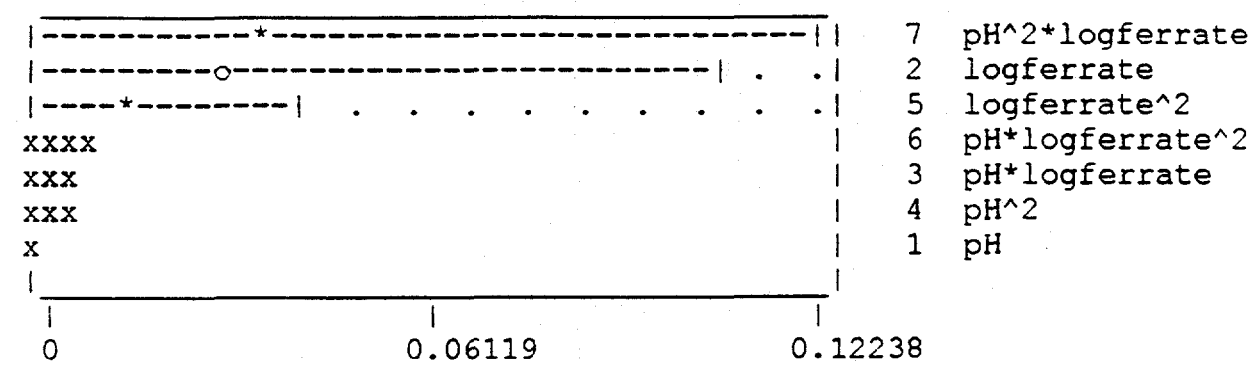
«××××××××××××» Effects graph for response 'Co'

LACK-OF-FIT: Replicates too large



Pareto effects graph for response 'Co'

LACK-OF-FIT: Replicates too large

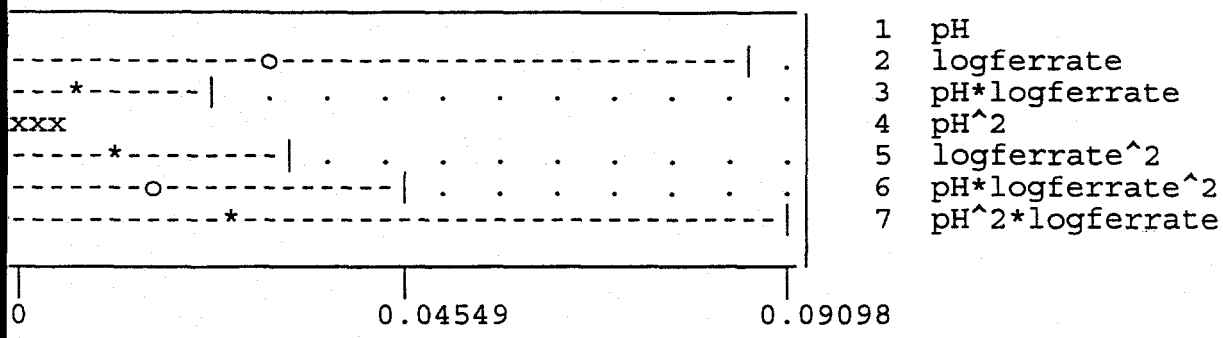


□

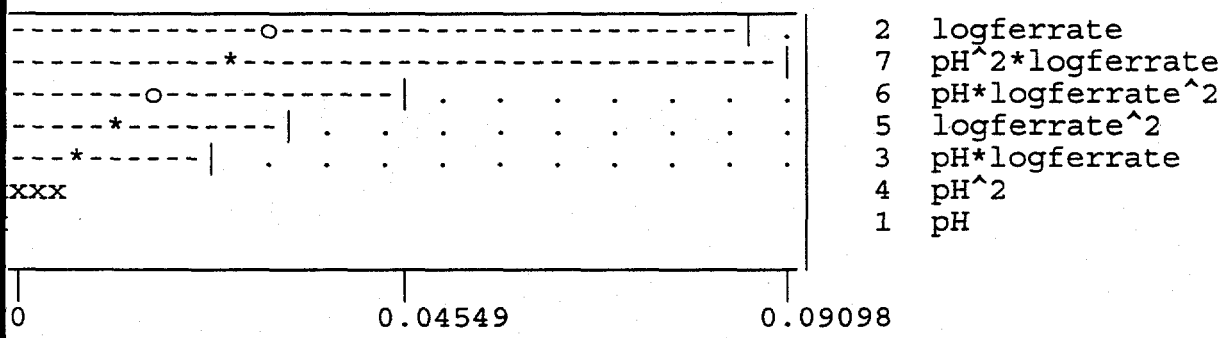
ROJECT NAME: NEWDATA.ECP

reated: Thu Dec 15 22:04:30 1994

xxxxxxxxxxxx» Effects graph for response 'Cu'



*Pareto effects graph for response 'Cu'**

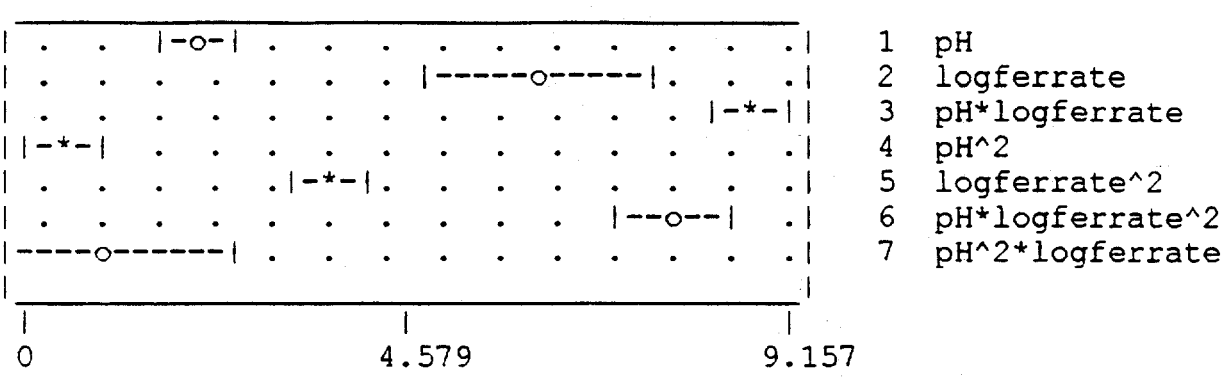


PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

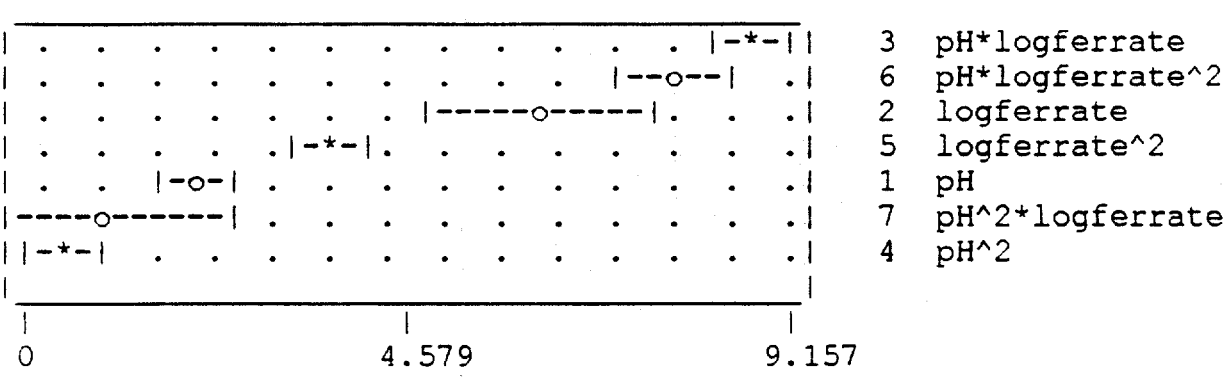
«××××××××××××» Effects graph for response 'Fe'

LACK-OF-FIT



Pareto effects graph for response 'Fe'

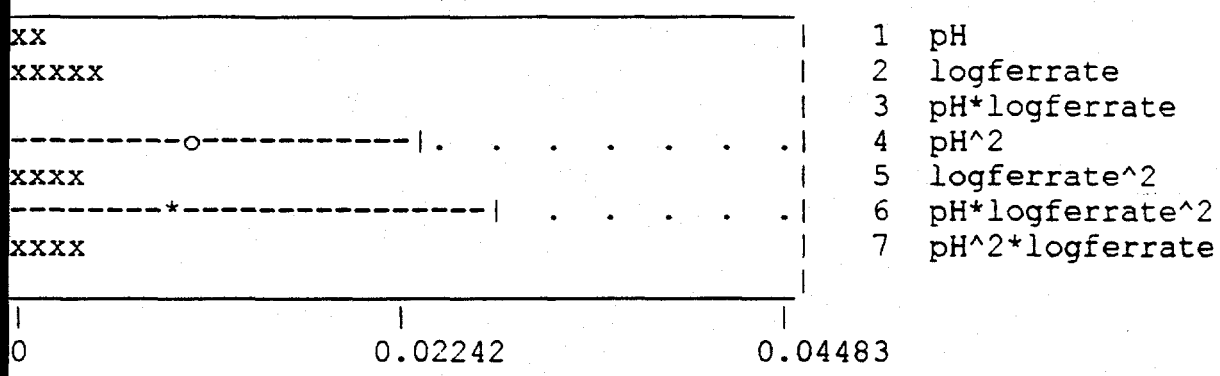
LACK-OF-FIT



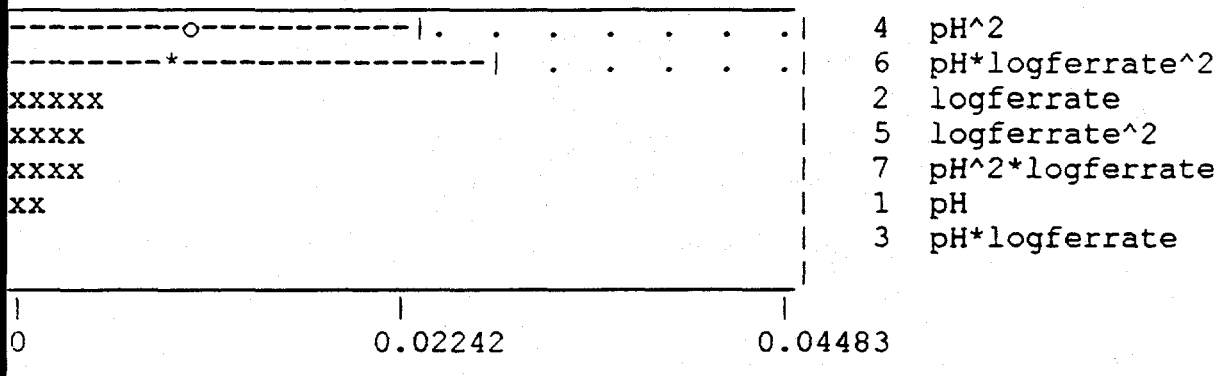
ROJECT NAME: 2NDRF.ECP

reated: Tue Nov 01 13:48:27 1994

xxxxxxxxxxxx» Effects graph for response 'Se'



*Pareto effects graph for response 'Se'**

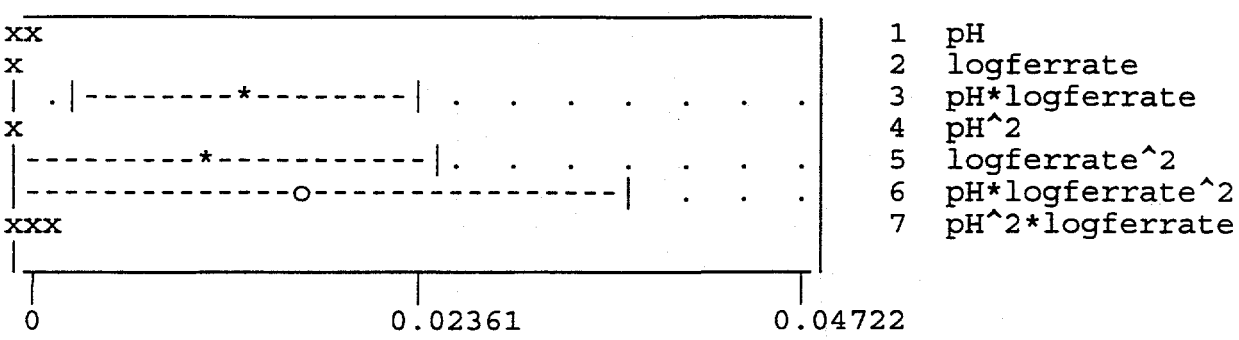


PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:30 1994

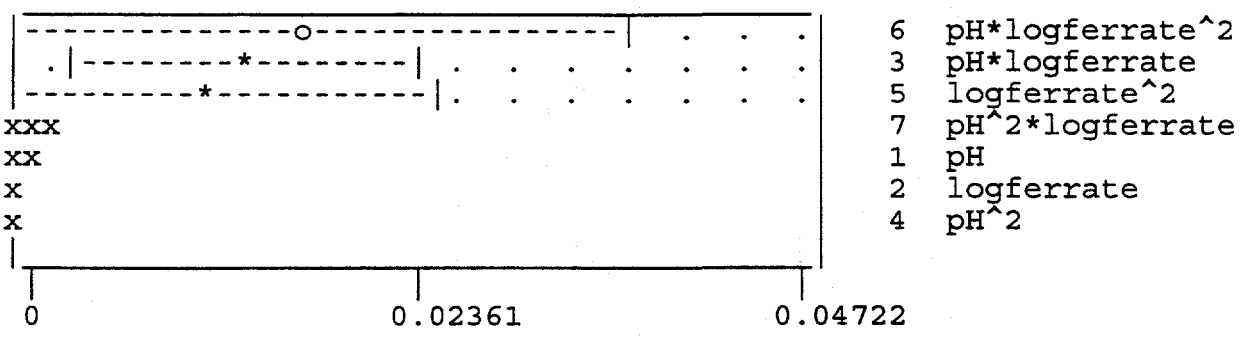
«xxxxxxxxxxxxx» Effects graph for response 'Ag'

LACK-OF-FIT



Pareto effects graph for response 'Ag'

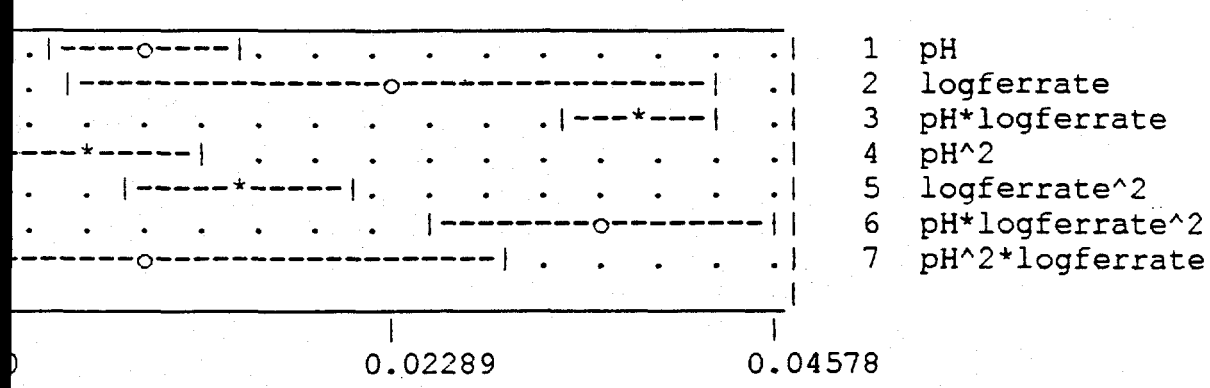
LACK-OF-FIT



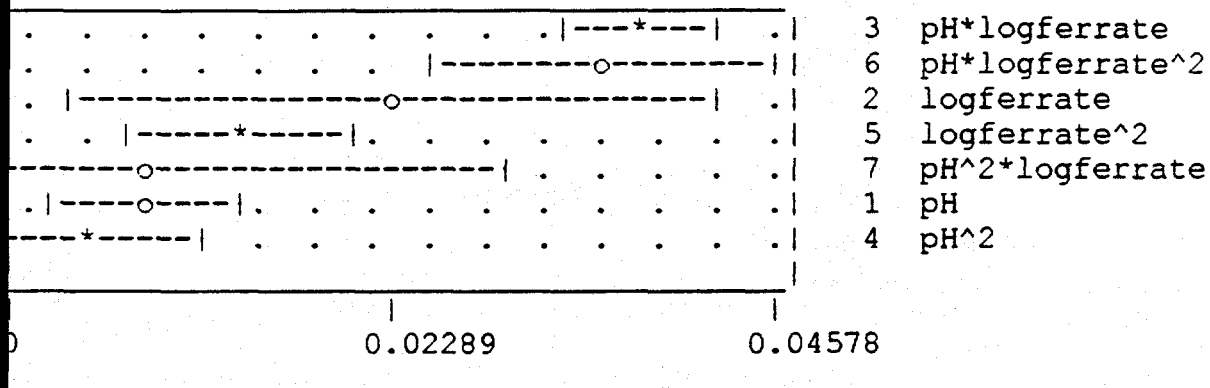
ROJECT NAME: 2NDRF.ECP

reated: Tue Nov 01 13:48:27 1994

××××××××××» Effects graph for response 'Zn'



Pareto effects graph for response 'Zn'**



PROJECT NAME: NEWDATA.ECP
Created: Thu Dec 15 22:04:23 1994

«××××××××××××» Effects for response 'Am'

EFFECTS	RESLTN	SIG	TERM
0.0827			0 CONSTANT
-0.0545	0.2204		1 pH
-0.3867	0.9661		2 logferrate
0.4385		***	3 pH*logferrate
-0.0367	0.2657		4 pH^2
0.2109		*	5 logferrate^2
-0.4909		**	6 pH*logferrate^2
0.0067	0.6676		7 pH^2*logferrate

Residual SD = 0.050896
Replicate SD = 0.064194

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Pu'
LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
1.216			0 CONSTANT
-0.234	1.729		1 pH
-5.059	10.280		2 logferrate
2.782		***	3 pH*logferrate
-1.238	3.300		4 pH^2
2.267		*	5 logferrate^2
-4.419		**	6 pH*logferrate^2
2.838	8.793		7 pH^2*logferrate

Residual SD = 0.458580
Replicate SD = 0.205097
N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'U'

EFFECTS	RESLTN	SIG	TERM
0.01581		0	CONSTANT
-0.04025		***	1 pH
-0.00868	0.08082		2 logferrate
-0.00931	0.02875		3 pH*logferrate
0.00832	0.03682		4 pH^2
0.00095	0.02586		5 logferrate^2
0.01350	0.05157		6 pH*logferrate^2
-0.00143	0.08371		7 pH^2*logferrate

Residual SD = 0.006337
Replicate SD = 0.004837

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Al'

EFFECTS	RESLTN	SIG	TERM
0.829		0	CONSTANT
-3.030		***	1 pH
-6.870		*	2 logferrate
9.204		***	3 pH*logferrate
0.522	2.487		4 pH^2
4.048		***	5 logferrate^2
-6.717		***	6 pH*logferrate^2
0.130	5.804		7 pH^2*logferrate

Residual SD = 0.436947
Replicate SD = 0.541218

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Ba'

EFFECTS	RESLTN	SIG	TERM
0.0047			0 CONSTANT
-0.1371		***	1 pH
-0.0260	0.1651		2 logferrate
0.0957		***	3 pH*logferrate
0.0720		*	4 pH^2
0.0033	0.0513		5 logferrate^2
0.0029	0.0763		6 pH*logferrate^2
-0.0408	0.1994		7 pH^2*logferrate

Residual SD = 0.012215
Replicate SD = 0.009129

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Cr'

LACK-OF-FIT

EFFECTS	RESLTN	SIG	TERM
0.00193			0 CONSTANT
-0.00136	0.01297		1 pH
-0.01665	0.05719		2 logferrate
0.01246		*	3 pH*logferrate
-0.00513	0.02114		4 pH^2
0.01618		*	5 logferrate^2
-0.01022	0.03161		6 pH*logferrate^2
0.01872	0.06497		7 pH^2*logferrate

Residual SD = 0.003561
Replicate SD = 0.001458

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Co'
LACK-OF-FIT: Replicates too large

EFFECTS RESLTN SIG TERM

0.00353 0 CONSTANT
0.00285 0.02498 1 pH
-0.03016 0.10743 2 logferrate
-0.00667 0.02749 3 pH*logferrate
-0.00665 0.03717 4 pH^2
0.01414 0.04082 5 logferrate^2
-0.01091 0.05168 6 pH*logferrate^2
0.03425 0.12238 7 pH^2*logferrate

Residual SD = 0.006787
Replicate SD = 0.008664

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Cu'
EFFECTS RESLTN SIG TERM

0.00554 0 CONSTANT
-0.00198 0.01798 1 pH
-0.03138 0.08724 2 logferrate
0.00856 0.02361 3 pH*logferrate
-0.00692 0.02899 4 pH^2
0.01269 0.03198 5 logferrate^2
-0.01794 0.04742 6 pH*logferrate^2
0.02726 0.09098 7 pH^2*logferrate

Residual SD = 0.004907
Replicate SD = 0.005965

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Fe'
LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.736		0	CONSTANT
-2.257	***	1	pH
-6.187	***	2	logferrate
8.814	***	3	pH*logferrate
0.603	*	4	pH^2
3.682	***	5	logferrate^2
-7.793	***	6	pH*logferrate^2
-1.105	2.561	7	pH^2*logferrate

Residual SD = 0.112087
Replicate SD = 0.022958

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Se'
EFFECTS RESLTN SIG TERM

0.06306		0	CONSTANT
0.00257	0.01266	1	pH
-0.00647	0.04170	2	logferrate
0.00007	0.00956	3	pH*logferrate
-0.01042	0.02433	4	pH^2
-0.00492	0.01708	5	logferrate^2
0.00988	0.02848	6	pH*logferrate^2
0.00465	0.04483	7	pH^2*logferrate

Residual SD = 0.003095
Replicate SD = 0.002570

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Ag'
LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.00182 0 CONSTANT
0.00205 0.01327 1 pH
0.00117 0.04034 2 logferrate
0.01411 * 3 pH*logferrate
-0.00082 0.01629 4 pH^2
0.01177 0.02530 5 logferrate^2
-0.01658 0.03725 6 pH*logferrate^2
-0.00255 0.04722 7 pH^2*logferrate

Residual SD = 0.003440
Replicate SD = 0.001791

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«××××××××××××» Effects for response 'Zn'

EFFECTS RESLTN SIG TERM

0.00246 0 CONSTANT
-0.00842 ** 1 pH
-0.02378 * 2 logferrate
0.03833 *** 3 pH*logferrate
0.00469 0.01206 4 pH^2
0.01451 *** 5 logferrate^2
-0.03594 *** 6 pH*logferrate^2
-0.00860 0.02986 7 pH^2*logferrate

Residual SD = 0.001638
Replicate SD = 0.001953

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:15 1994

«××××××××××××» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0826716			0	CONSTANT
-0.0139783	0.0199616	0.4945-	0.386	1 pH
-0.0743695	0.0522782	0.1753	0.125	2 logferrate
0.0374804	0.00625938	0.0000	0.586	3 pH*logferrate
-0.00920837	0.0269164	0.7370-	0.283	4 pH^2
0.0234324	0.010429	0.0401	0.387	5 logferrate^2
-0.0139852	0.0040872	0.0038	0.363	6 pH*logferrate^2
0.0003703	0.0170927	0.9830-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.050896
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.064194
Replicate DF = 8

R Squared = 0.978, P=0.0000 ***
Adj R Squared = 0.968
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Pu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.21618			0	CONSTANT

-0.0598873	0.179856	0.7438-	0.386	1 pH
-0.972948	0.471033	0.0566	0.125	2 logferrate
0.23776	0.0563977	0.0007	0.586	3 pH*logferrate
-0.310207	0.24252	0.2203	0.283	4 pH^2
0.251865	0.0939665	0.0171	0.387	5 logferrate^2
-0.125909	0.0368262	0.0038	0.363	6 pH*logferrate^2
0.156475	0.154007	0.3257	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.458580, Lack-Of-Fit P=0.0024 **
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.205097
Replicate DF = 8

R Squared = 0.965, P=0.0000 ***
Adj R Squared = 0.948
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 11.024 P=0.0005 ***
- This term may be eliminated

«××××××××××××» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0158053			0	CONSTANT
-0.0103195	0.00248531	0.0009	0.386	1 pH
-0.00166904	0.00650886	0.8011-	0.125	2 logferrate
-0.000795818	0.00077932	0.3234-	0.586	3 pH*logferrate
0.00208594	0.00335121	0.5430-	0.283	4 pH^2
0.000105974	0.00129846	0.9360-	0.387	5 logferrate^2
0.000384568	0.000508874	0.4615-	0.363	6 pH*logferrate^2
-7.88849e-005	0.00212811	0.9709-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.006337
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.004837
Replicate DF = 8

R Squared = 0.882, P=0.0000 ***
Adj R Squared = 0.827
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Al'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.829257			0	CONSTANT
-0.776877	0.171372	0.0004	0.386	1 pH
-1.32112	0.448813	0.0101	0.125	2 logferrate
0.786633	0.0537372	0.0000	0.586	3 pH*logferrate
0.130862	0.23108	0.5796-	0.283	4 pH^2
0.449755	0.0895338	0.0002	0.387	5 logferrate^2
-0.191373	0.035089	0.0001	0.363	6 pH*logferrate^2
0.00719295	0.146742	0.9616-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.436947
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.541218
Replicate DF = 8

R Squared = 0.996, P=0.0000 ***
Adj R Squared = 0.994
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.004
- This term may be eliminated

«××××××××××××» Coefficients for response 'Ba'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00468056			0	CONSTANT
-0.0351515	0.00479076	0.0000	0.386	1 pH
-0.0049995	0.0125467	0.6959-	0.125	2 logferrate
0.00817627	0.00150224	0.0001	0.586	3 pH*logferrate
0.0180554	0.0064599	0.0136	0.283	4 pH^2
0.000366793	0.00250295	0.8854-	0.387	5 logferrate^2
8.37549e-005	0.000980923	0.9331-	0.363	6 pH*logferrate^2
-0.00225014	0.00410221	0.5914-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.012215
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.009129
Replicate DF = 8

R Squared = 0.980, P=0.0000 ***
Adj R Squared = 0.970
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Cr'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00192824			0	CONSTANT
-0.000349606	0.00139669	0.8057-	0.386	1 pH
-0.00320234	0.00365786	0.3951	0.125	2 logferrate
0.00106513	0.000437963	0.0280	0.586	3 pH*logferrate
-0.00128459	0.00188332	0.5056-	0.283	4 pH^2
0.00179797	0.000729707	0.0263	0.387	5 logferrate^2
-0.000291075	0.000285978	0.3249	0.363	6 pH*logferrate^2

0.00103225 0.00119596 0.4017 0.119 7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.003561, Lack-Of-Fit P=0.0012 **
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.001458
Replicate DF = 8

R Squared = 0.821, P=0.0001 ***
Adj R Squared = 0.737
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00353368			0	CONSTANT
0.000730427	0.00266198	0.7875-	0.386	1 pH
-0.00579985	0.00697156	0.4185	0.125	2 logferrate
-0.000570431	0.00083472	0.5048-	0.586	3 pH*logferrate
-0.00166572	0.00358944	0.6493-	0.283	4 pH^2
0.00157075	0.00139076	0.2765	0.387	5 logferrate^2
-0.00031069	0.000545049	0.5771-	0.363	6 pH*logferrate^2
0.00188815	0.00227939	0.4205	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.006787, Lack-Of-Fit (Residual SD too small) P=0.9842
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.008664
Replicate DF = 8

R Squared = 0.262, P=0.6286
Adj R Squared = 0.000
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.114
- This term may be eliminated

«××××××××××××» Coefficients for response 'Cu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00553942			0	CONSTANT
-0.00050666	0.00192467	0.7959-	0.386	1 pH
-0.00603385	0.00504059	0.2499	0.125	2 logferrate
0.000731448	0.000603521	0.2443	0.586	3 pH*logferrate
-0.0017336	0.00259525	0.5143-	0.283	4 pH^2
0.00140995	0.00100555	0.1812	0.387	5 logferrate^2
-0.000511024	0.000394082	0.2143	0.363	6 pH*logferrate^2
0.001503	0.00164805	0.3762	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.004907
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.005965
Replicate DF = 8

R Squared = 0.766, P=0.0008 ***
Adj R Squared = 0.656
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.733
- This term may be eliminated

«××××××××××××» Coefficients for response 'Fe'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.73601			0	CONSTANT

-0.578731	0.0439609	0.0000	0.386	1 pH
-1.18978	0.115131	0.0000	0.125	2 logferrate
0.7533	0.0137849	0.0000	0.586	3 pH*logferrate
0.15101	0.0592773	0.0223	0.283	4 pH^2
0.409111	0.0229675	0.0000	0.387	5 logferrate^2
-0.222022	0.00900114	0.0000	0.363	6 pH*logferrate^2
-0.0609325	0.0376427	0.1263	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.112087, Lack-Of-Fit P=0.0000 ***
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.022958
Replicate DF = 8

R Squared = 1.000, P=0.0000 ***
Adj R Squared = 1.000
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

«××××××××××××» Coefficients for response 'Se'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.063064			0	CONSTANT
0.000660229	0.00121369	0.5944-	0.386	1 pH
-0.00124334	0.00317857	0.7012-	0.125	2 logferrate
6.10894e-006	0.000380577	0.9874-	0.586	3 pH*logferrate
-0.00261039	0.00163655	0.1315	0.283	4 pH^2
-0.000546443	0.000634094	0.4024-	0.387	5 logferrate^2
0.000281589	0.000248506	0.2749	0.363	6 pH*logferrate^2
0.000256357	0.00103925	0.8085-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.003095
Residual DF = 15

Residual SD used for tests

Replicate SD = 0.002570
Replicate DF = 8

R Squared = 0.812, P=0.0002 ***
Adj R Squared = 0.725
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Ag'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00182398			0	CONSTANT
0.000525543	0.00134934	0.7024-	0.386	1 pH
0.000225203	0.00353385	0.9500-	0.125	2 logferrate
0.00120628	0.000423115	0.0121	0.586	3 pH*logferrate
-0.000204527	0.00181947	0.9120-	0.283	4 pH^2
0.00130797	0.000704968	0.0833	0.387	5 logferrate^2
-0.000472437	0.000276282	0.1079	0.363	6 pH*logferrate^2
-0.000140412	0.00115541	0.9049-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.003440, Lack-Of-Fit P=0.0075 **
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.001791
Replicate DF = 8

R Squared = 0.874, P=0.0000 ***
Adj R Squared = 0.815
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«××××××××××××» Coefficients for response 'Zn'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00245686			0	CONSTANT
-0.00215909	0.000642332	0.0043	0.386	1 pH
-0.00457306	0.00168223	0.0159	0.125	2 logferrate
0.00327574	0.000201417	0.0000	0.586	3 pH*logferrate
0.0011765	0.000866127	0.1944	0.283	4 pH^2
0.00161198	0.000335588	0.0002	0.387	5 logferrate^2
-0.00102404	0.00013152	0.0000	0.363	6 pH*logferrate^2
-0.00047393	0.000550014	0.4024	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.001638
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.001953
Replicate DF = 8

R Squared = 0.997, P=0.0000 ***
Adj R Squared = 0.995
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

PROJECT NAME: NEWDATA.ECP

Created: Thu Dec 15 22:04:40 1994

«××××××××××××» ANOVA Table for response 'Am'

Mean Squares	DF	P	
0.000924551	2	0.7056	pH
0.0072931	2	0.0916	logferrate
0.169553	3	0.0000	pH*logferrate
0.00259042	15		ERROR
0.00412083	8		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Pu'

LACK-OF-FIT

Mean Squares	DF	P	
0.205826	2	0.3985	pH
0.762436	2	0.0519	logferrate
8.25564	3	0.0000	pH*logferrate
0.210296	15		ERROR
0.0420646	8		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'U'

Mean Squares	DF	P	
0.000346394	2	0.0032	pH
2.38225e-006	2	0.9426	logferrate
9.20154e-005	3	0.1198	pH*logferrate
4.01549e-005	15		ERROR
2.33996e-005	8		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Al'

Mean Squares	DF	P	
1.96707	2	0.0015	pH
2.84013	2	0.0003	logferrate
57.8535	3	0.0000	pH*logferrate
0.190923	15		ERROR
0.292917	8		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Ba'

Mean Squares	DF	P	
0.00419049	2	0.0000	pH
1.96049e-005	2	0.8779	logferrate
0.00379787	3	0.0000	pH*logferrate
0.000149206	15		ERROR
8.33333e-005	8		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Cr'

LACK-OF-FIT

Mean Squares	DF	P	
3.84755e-006	2	0.7427	pH
6.51058e-005	2	0.0200	logferrate
9.73178e-005	3	0.0024	pH*logferrate
1.26818e-005	15		ERROR
2.125e-006	8		REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Co'

LACK-OF-FIT: Replicates too large

Mean Squares DF P

5.84316e-006 2 0.8818 pH
3.01016e-005 2 0.5344 logferrate
2.25227e-005 3 0.6952 pH*logferrate
4.60669e-005 15 ERROR

7.50625e-005 8 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Cu'

Mean Squares DF P

7.17466e-006 2 0.7466 pH
2.37343e-005 2 0.3961 logferrate
9.10799e-005 3 0.0334 pH*logferrate
2.40819e-005 15 ERROR

3.55833e-005 8 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Fe'

LACK-OF-FIT

Mean Squares DF P

1.08903 2 0.0000 pH
2.36762 2 0.0000 logferrate
59.825 3 0.0000 pH*logferrate
0.0125635 15 ERROR

0.000527083 8 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Se'

Mean Squares DF P

1.25244e-005 2 0.2995 pH
2.17754e-005 2 0.1372 logferrate
1.18247e-005 3 0.3318 pH*logferrate

9.57617e-006 15 ERROR

6.60417e-006 8 REPLICATE ERROR

«××××××××××××» ANOVA Table for response 'Ag'

LACK-OF-FIT

Mean Squares DF P

9.09522e-007 2 0.9264 pH
6.75063e-005 2 0.0144 logferrate
0.000185596 3 0.0001 pH*logferrate
1.18365e-005 15 ERROR

3.20833e-006 8 REPLICATE ERROR

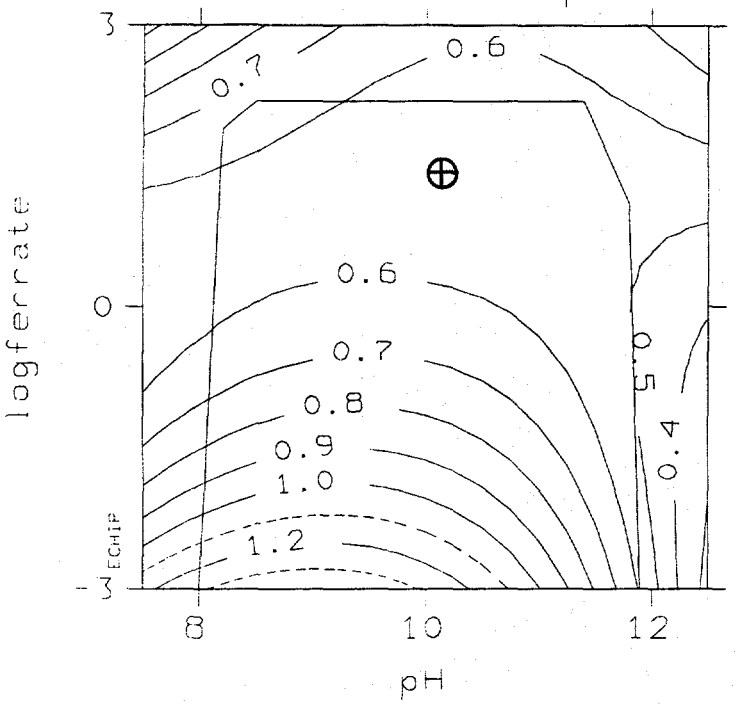
«××××××××××××» ANOVA Table for response 'Zn'

Mean Squares DF P

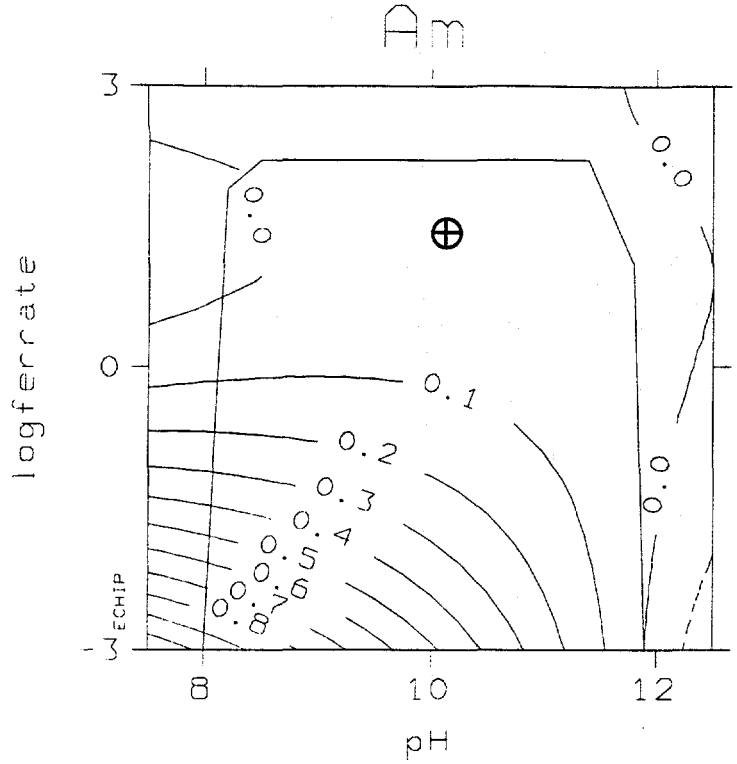
1.59665e-005 2 0.0125 pH
3.74525e-005 2 0.0004 logferrate
0.00118497 3 0.0000 pH*logferrate
2.68224e-006 15 ERROR

3.8125e-006 8 REPLICATE ERROR

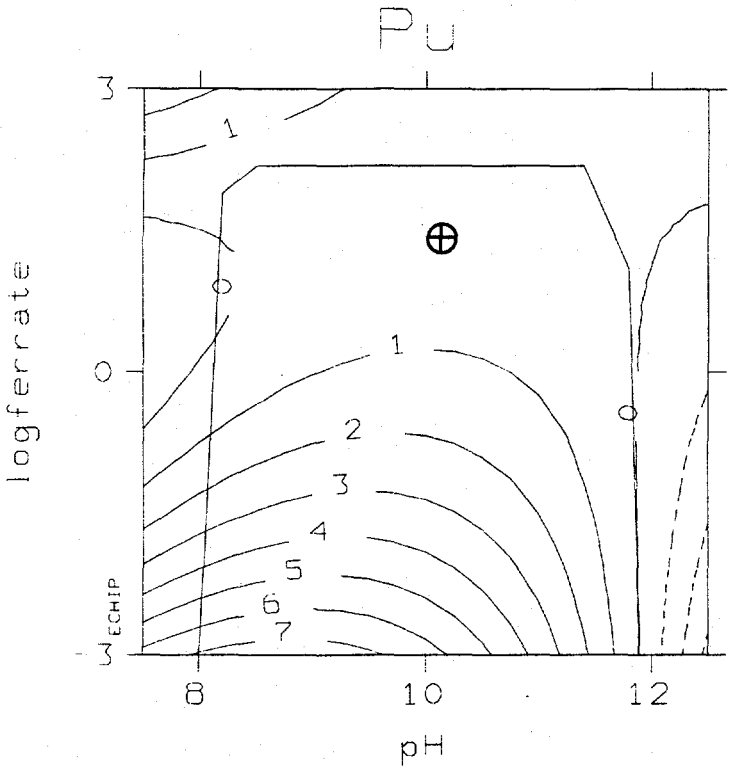
Combined Responses



pH=10.20	logferra= 1.36
Value 0.54	

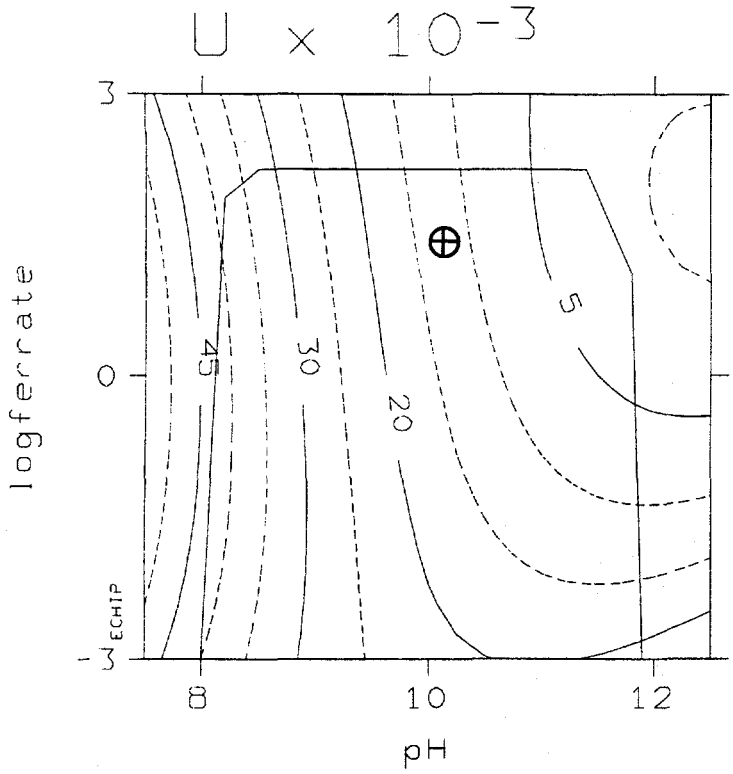


pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
0.027	**-0.090**	**0.143**

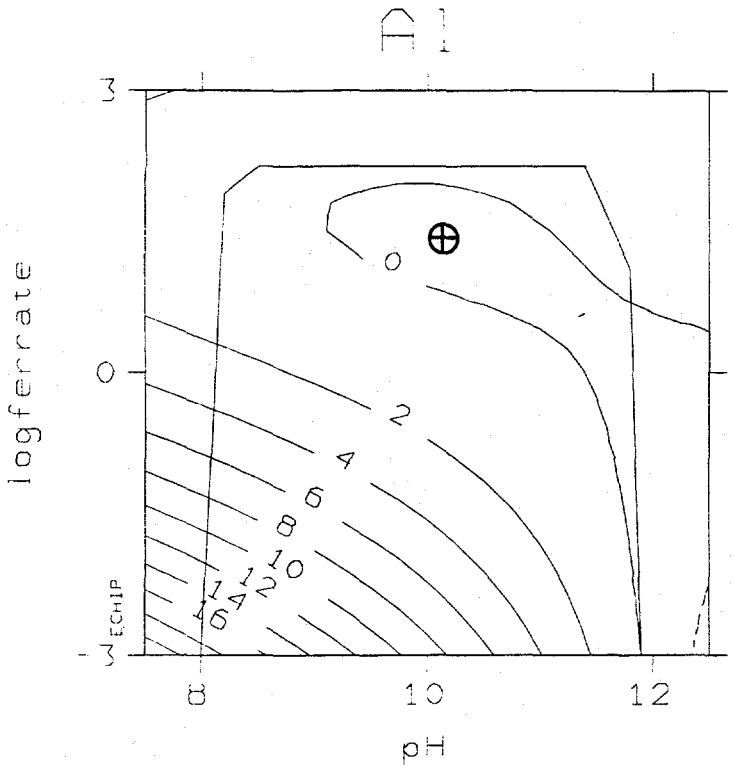


Lack Of Fit

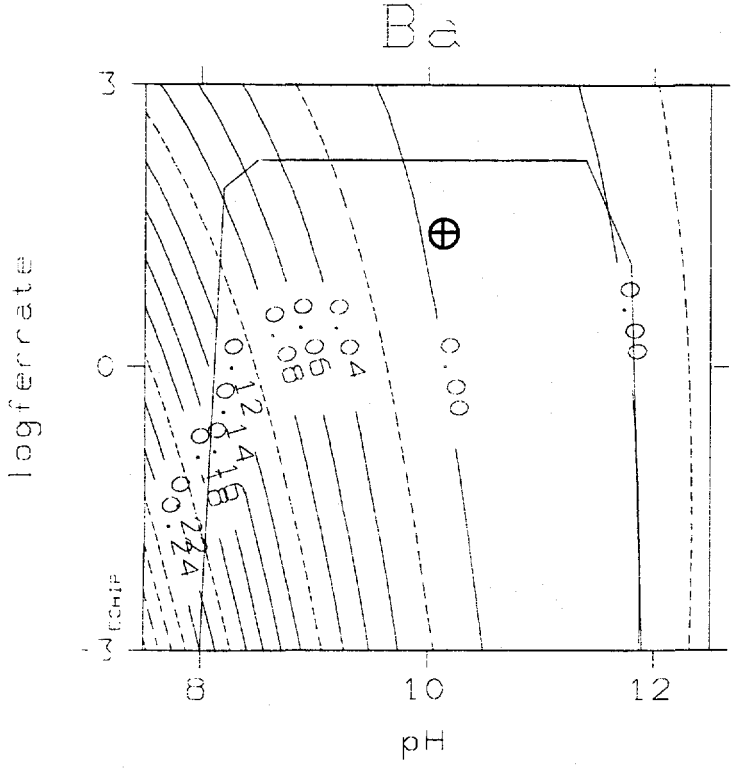
pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
0.36	**-0.69**	**1.41**



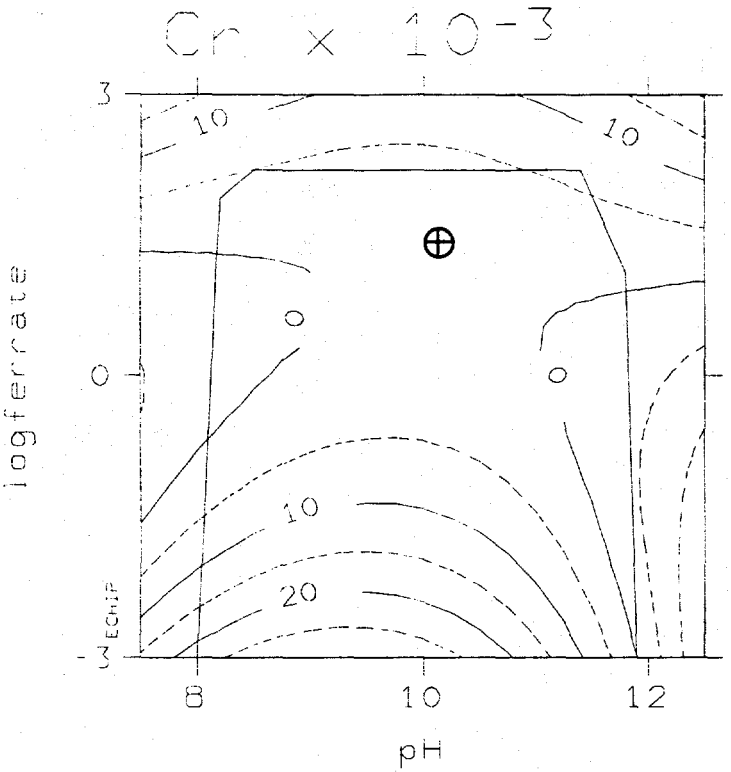
pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
0.0117	**-0.0029**	**0.0262**



pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
-0.14	**-1.14**	**0.86**

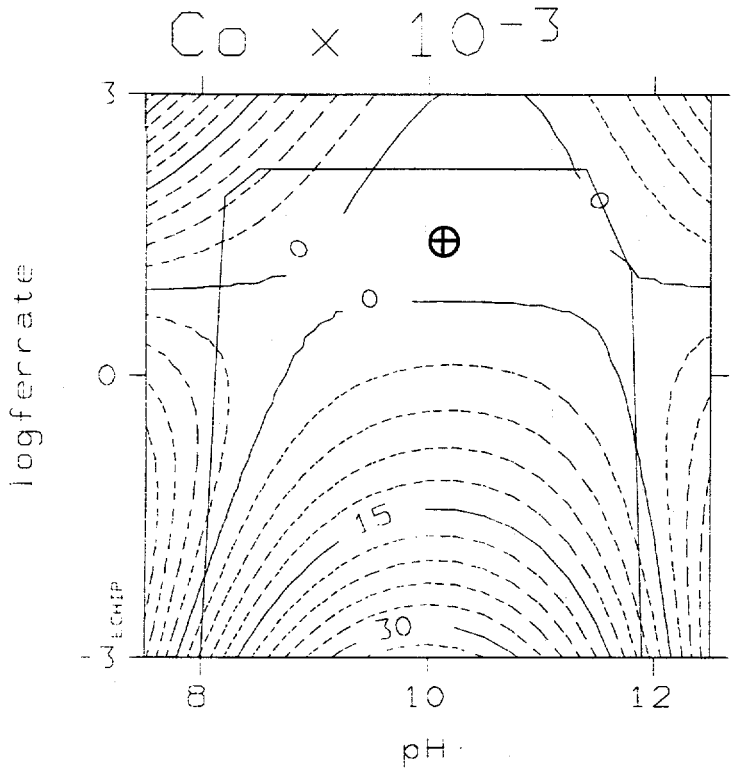


pH=10.20		logferra= 1.36
Value	Low Limit	High Limit
-0.006	-0.034	0.022



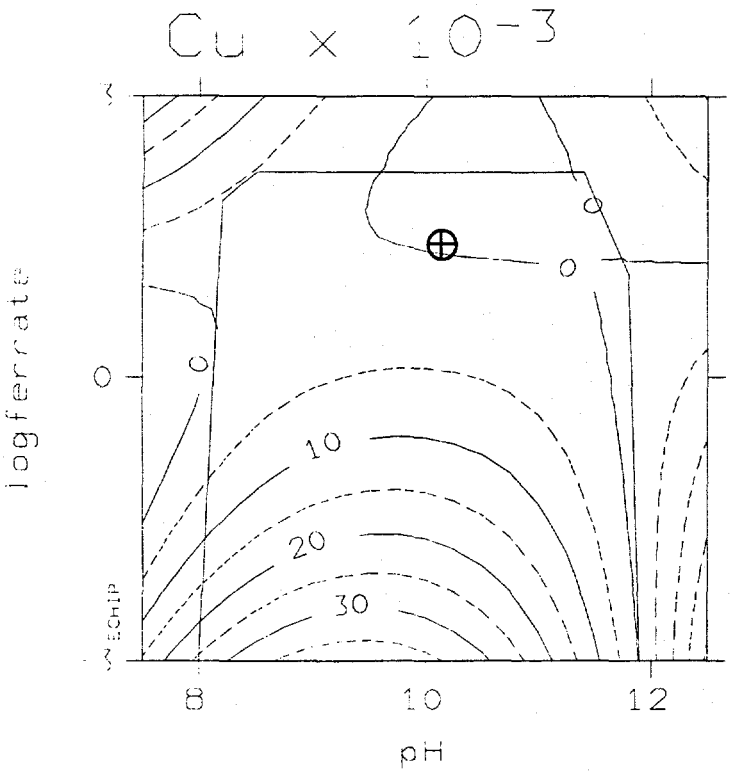
Lack Of Fit

pH=10.20		logferra= 1.36
Value	Low Limit	High Limit
0.0010	-0.0071	0.0092



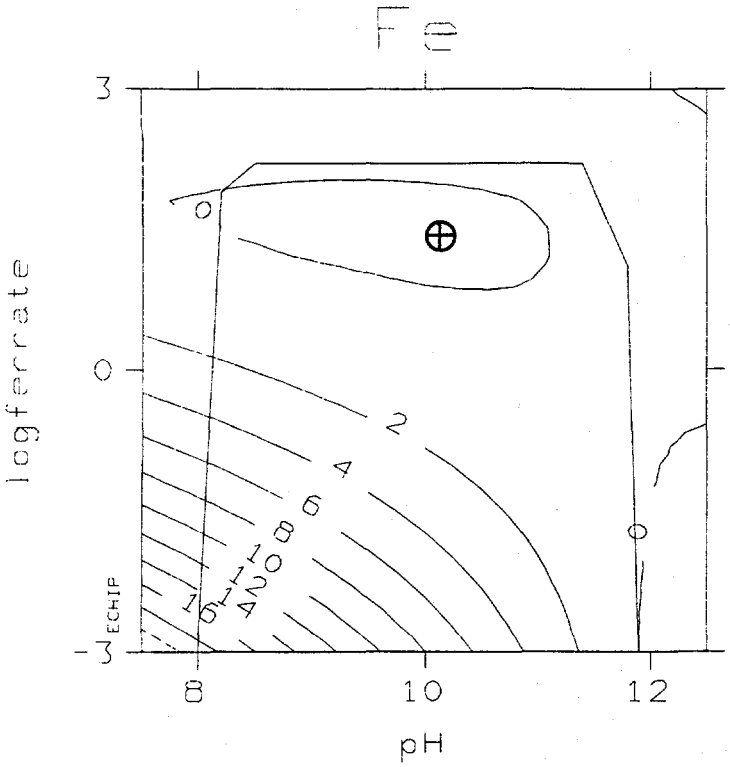
Lack Of Fit

pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
-0.0015	**-0.0171**	**0.0140**

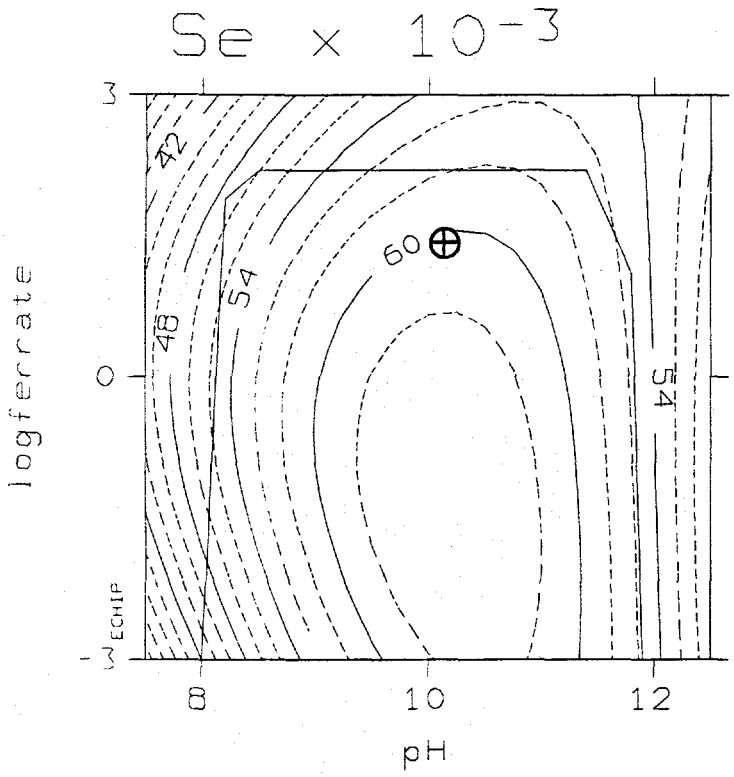


pH=10.20		logferra= 1.36
Value	Low Limit	High Limit
-0.0001	-0.0114	0.0111

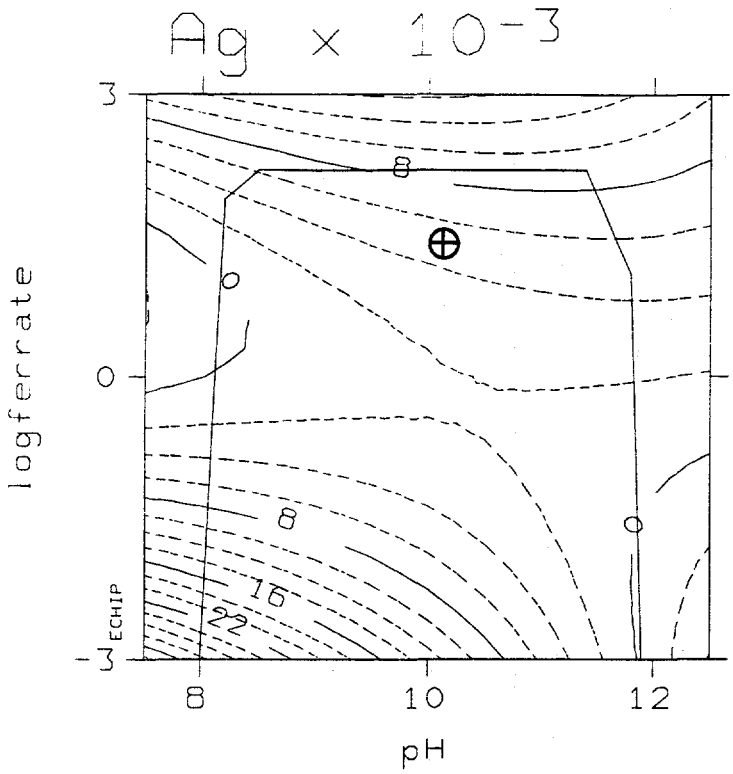
Lack Of Fit



pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
-0.12	**-0.37**	**0.14**

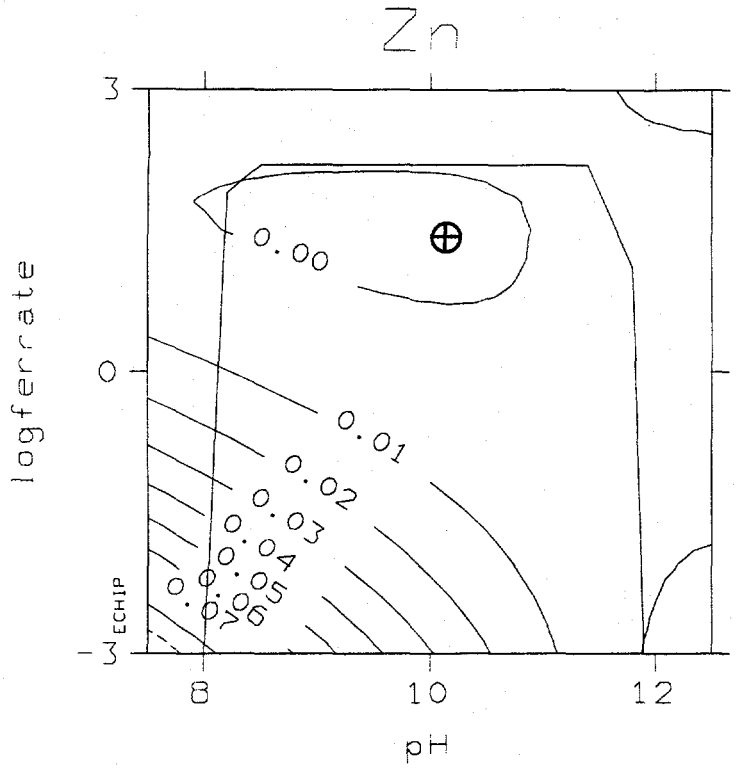


pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
0.0605	**0.0534**	**0.0676**



Lack Of Fit

pH=10.20		logferra= 1.36
Value	Low Limit	High Limit
0.0048	-0.0031	0.0127



pH=10.20		logferra= 1.36
Value	**Low Limit**	**High Limit**
-0.0007	**-0.0044**	**0.0031**

APPENDIX G

ACRONYM LIST

%	Percent
<	Less Than
>	Greater Than
ADL	Analytical Detection Limits
Ag	Silver
Al	Aluminum
Al_2SO_4	Alum
Am	Americium
B-Ker^2 ™	Beaker Used in Water Treatment Tests (registered Trade Mark)
Ba	Barium
CDPHE	Colorado Department of Public Health and Environment
Co	Cobalt
COCs	Contaminants of Concern
Cr	Chromium
Cu	Copper
CWQCC	Colorado Water Quality Control Commision
DE	Deleware
DOE	Department of Energy
ECHIP	Computer Software Used in This Study
EPA	U. S. Environmental Protection Agency
ERPD	Environmeental Restoration Program Division
Fe	Iron
$Fe(OH)_3$	Iron (III) Hydroxide
Fe_2O_3	Iron Oxide or Ferric Oxide
gal	Gallon
GFAA	Graphite Furnace Atomic Adsorption, an Analytical Method
gm	Gram
H_2O	Water
ICP	Inductive Coupled Plasma, an Analytical Method
K_2FeO_4	Potassium Ferrate
Kacl	Weathered Claystone
Kass	Unweathered Sandstone
KOH	Potassium Hydroxide
lb	Pound
log	Logarithm base 10
Mb	Megabyte

mg	Milligram
mg/l	Milligram per Liter
ml	Milliter
N	Normal, Chemical Equivelents per Liter of Water
$Na_2S_2O_3$	Sodium Thiosulfate
NaOH	Sodium Hydroxide
pCi/l	Picocuries per Liter
pH	Measure of Water Acidity
Pu	Plutonium
QA/QC	Quality Assurance / Quality Control
RAM	Random Access Memory
RFETS	Rocky Flats Environmental Technology Site
rpm	Revolutions per Minute
S. D.	Standard Deviation
Se	Selenium
SEPs	Solar Evaporation Ponds
STSP	Sitewide Treatability Studies Program
TRU/Clear™	Potassium Ferrate Based Water Treatment Chemical (Registered Trade Mark)
TSS	Total Suspended Solids
U	Uranium
ug/Kg	Microgram per Kilogram
V	Vanadium
VGA	Visual Graphic Ability
Zn	Zinc