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EXPERIMENTAL INVESTIGATIONS OF ²³⁸Pu BEHAVIOR IN SOIL COLUMNS

by

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ABSTRACT

Two series of experiments were conducted to study the transport of plutonium through soils. The first series involved deposition of small quantities (2.0 to 3.5 mg) of particulate ²³⁸Pu oxide on soil columns containing silt loam soil. When deionized water was allowed to percolate through the columns, plutonium was released into the drainage at the rate of 8 to 15 pg/day. During the 6.8-yr experiment, the total amount of plutonium released into the soil drainage amounted to less than 0.01% of the original source. Analysis of the soil as a function of depth at the end of the experiment revealed that more than 99% of the deposited source remained in the uppermost fraction (2.8 cm) of the column.

The second series of experiments was performed by pumping water containing plutonium through columns of soil and comparing the amount of plutonium in the column effluents to that in the feed. For a loamy sand soil, the plutonium content of the effluent reached a steady state of 5% of the feed after 500 days. Analysis of the soil at the end of the experiment (1200 days) showed the columns to be approximately 50% saturated. Saturation of the soil with plutonium would require 13 µg/g and 6.6 yr at the feed rate used (average of 1.2 µg/g into 300 g of soil). For a Florida soil, the plutonium content of the feed stabilized at 8% of the feed after only 80 days. Examination of the soil at the end of the experiment (220 days) showed the soil to be less than 20% saturated. Saturation of the soil would require a minimum of 9 µg/g and 3.0 yr at the feed rate employed (average of 1.4 µg/day into 130 g of soil). The loamy sand retained 93 to 95% of the plutonium in the feed, whereas the Florida soil retained 78 to 81%. Experimental limitations are discussed, and recommendations for future work are presented.

INTRODUCTION

In previously published reports we have described studies of the interactions of clad and unclad PuO₂ fuel material with terrestrial environments.¹⁻⁵ One important aspect of those studies was the transport of plutonium through soil. Particularly important are how such transport might depend on the nature of the soil and what other factors might affect the movement of plutonium

through soil. The studies that we reported in the past involved unsaturated conditions; that is, the soil sometimes had water flowing through it, while at other times the soil was allowed to partially dry out. Although such conditions are representative of what happens in nature, they are difficult to reproduce and to interpret experimentally. An additional complication caused by the use of environment simulation chambers is the large number of variables inherent in the experiment, so studying any one

aspect of the experiment is difficult. To examine the transport of plutonium through soils without these complications, we initiated some column experiments in which the transport of plutonium through various soils would be studied using soil-packed columns and saturated flow conditions.

Two sets of soil column experiments have been previously reported.^{6,7} The first included three 25-mm-diam columns packed to a depth of 100 mm with silt loam that had been sieved to remove particles larger than 0.8 mm in diameter. The soil was 60% silt, 25% sand, and 15% clay, with a bulk density of 1.70 g/cm³. Water at neutral pH containing small amounts of ²³⁸Pu chloride (approximately 1 µg/L) was allowed to flow through the soil. After 556 days, the soil had retained 99.8% of the plutonium in the feed. The retention was independent of the flow rate.⁶ The feed then was changed to plutonium-free 0.1M NaHCO₃. The flow rates decreased significantly and plutonium began to elute from the columns. After 550 days of bicarbonate feed, a maximum of 40% of the plutonium was eluted from the columns, with the removal rate being proportional to the bicarbonate flow rate.⁷ The second set of experiments involved three 25-mm-diam columns packed to a depth of 250 mm with silt loam that had been sieved to remove all particles less than 52 µm in diameter. Water containing plutonium was allowed to flow through the soils as in the first set of experiments. Retention of the plutonium after 1380 days ranged from 99.7 to 99.9%, with the lower retentions associated with the faster flow rates.⁷

This report describes the results of some further column experiments directed at studying additional soil types and different conditions.

EXPERIMENTAL SECTION

Three experiments were conducted. One involved deposition of PuO₂ particles on top of a column of soil. Water was allowed to flow down through the column, and the effluents were analyzed periodically for plutonium. The other two experiments involved passage of an aqueous medium containing plutonium through soil columns. The amounts of plutonium in the column effluents were then compared with the feed concentrations.

For the experiment involving plutonium oxide particles, soil was packed in 24-mm-diam glass columns to a depth of approximately 14 cm. The soil used was a silt loam whose characteristics are shown in Table I. Three columns were prepared, identified as columns 7, 8, and 9.

Column 7 had 3.5 mg of PuO₂ particles on its soil surface, with a particle size distribution mainly in the 40- to 60-µm range. Column 8 contained 2.2 mg of PuO₂ particles with an average diameter of 12 µm, and column 9 contained 2.6 mg of PuO₂ particles with an average diameter of 7 µm. The PuO₂ particles used were obtained by grinding and sieving plutonium oxide powder. The isotopic composition was 80% ²³⁸Pu, and the specific activity was 13.6 Ci/g. Eluent was passed through the columns for 2421 days. The eluent used for the early part of the experiment was deionized water. At approximately 1500 days the eluent was changed to tap water.

Two experiments were carried out by passing plutonium-containing water through soil columns. Both involved glass columns that were filled to a depth of approximately 13 cm with soil. The two experiments differed in the type of soil used to fill the columns. The first involved a coarse textured loamy sand (Table I) packed in 5-cm-diam columns, whereas the second used a composite soil from south Florida agricultural areas (Table I) packed in 3.2-cm-diam columns. Columns associated with the loamy sand soil are identified as columns 10, 11, and 12, and those associated with the Florida soil are identified as columns 13, 14, and 15. The feed solution to these columns was a dilute, neutral solution of plutonium chloride (15 µg/L), prepared by diluting a stock solution of ²³⁸Pu in 1M HCl (250 µL) to volume (8 L) with distilled water. The specific activity of the plutonium was 12.1 Ci/g. This mixture was known to be unstable when aged, but was thought to be a good simulation of contaminated rainwater. The feed solution was pumped up through the columns, using peristaltic pumps, at nominal flow rates of 1 to 2 µL/s.

In all experiments, samples of the effluents were collected and analyzed periodically for plutonium content. Aliquots from the last set of column effluent samples and the feed solutions at that time were filtered sequentially through 0.6- and 0.1-µm Nuclepore® filters. The filters and the filtrates then were analyzed for plutonium. The pH values of the column effluents and feed solutions also were measured at that time. The plutonium analyses were carried out by adding aliquots of the aqueous samples to a commercial scintillation cocktail and counting the resulting mixtures using a Packard Tri-Carb. At the conclusion of the experiments, the columns themselves were sectioned and the soil from each column was divided into five portions according to depth. These soil samples first were dissolved in nitric and hydrofluoric acids, and the plutonium was determined by liquid scintillation counting.

TABLE I. Soil Data^{a,b}

	Silt Loam	Loamy Sand	Florida Soil
Total sand	31.4	95.7	92.0
Total silt	58.3	2.6	4.9
Total clay	10.3	1.7	3.1
Total organic carbon	0.09	0.10	2.41
Particle size analysis			
>2 mm	tr	tr	2
>0.1 mm	2	89	88
1 mm < sand < 2 mm	0.2	0.2	0.3
0.5 mm < sand < 1.0 mm	0.2	1.3	4.8
0.25 mm < sand < 0.5 mm	0.2	30.1	16.5
0.1 mm < sand < 0.25 mm	1.1	57.1	64.1
0.05 mm < sand < 0.1 mm	29.7	7.0	4.5
0.02 mm < silt < 0.05 mm	42.2	1.2	1.7
0.002mm < silt < 0.02 mm	16.1	1.4	3.1
clay < 0.002 mm			
Free iron (dith-cit extractable)	0.5	0.3	0.2
Aluminum (dith-cit extractable)	0.1	tr	0.1
NH ₄ OAc extractable Mg (meq/100 g)	3.3	0.6	1.5
NH ₄ OAc extractable Na (meq/100 g)	2.8	—	—
NH ₄ OAc extractable K (meq/100 g)	0.4	0.1	0.4
Cation exchange capacity (pH 7)(meq/100 g)	12.7	3.5	8.1
Calcium carbonate equivalent	10	1	2
pH (1:2 0.01M CaCl ₂)	8.3	8.4	6.9
pH (1:1 H ₂ O)	8.3	8.4	6.9
Surface area (EGME)(m ² /g)	84	24	35
Moisture content at 15 bar	6.1	1.7	6.2

^aAll values are in weight percent unless otherwise noted.

^bAnalyses were performed by the US Department of Agriculture Soil Conservation Service Laboratory, Lincoln, NE 68508.

RESULTS AND DISCUSSION

A. Experiments with PuO₂ Particles

The effluent data for the particle experiment are listed in the Appendix and also are shown in Figs. 1 and 2. In both Figs. 1 and 2, the squares represent data from column 7, the circles represent data from column 8, and the triangles represent data from column 9. Figure 1 shows the cumulative plutonium release as a function of time. Very consistent behavior occurred during the first

1600 days, with the release rates (curve slopes) remaining virtually constant. For columns 7 and 8, the average release rate was 200 pCi/day (15 pg/day); the average release rate for column 9 was 110 pCi/day (8.2 pg/day). When compared with the amounts of plutonium put onto the columns, these releases are negligible, suggesting that essentially all the plutonium has remained in or on the soil.

Shortly after 1600 days, the behavior of all three columns changed simultaneously, with the release rates undergoing significant increases. The fact that these

Fig. 1. Cumulative release versus time for soil columns containing plutonium oxide particles. Square points represent column 7, circles column 8, and triangles column 9.

Fig. 2. Release rate versus time for soil columns containing plutonium oxide particles. Square points represent column 7, circles column 8, and triangles column 9.

changes correlate with time and not with effluent volume suggests that the cause is not associated with any property of the soil, but rather with some external factor. Because at about this time tap water began to be used for the feed, we believe that the changed eluent composition may have been the cause. If this is true, the eluent composition clearly is an important factor in determining the elution rate of plutonium from plutonium oxide particles through soil. Note, however, that even a 10-fold increase in the release rates would have a negligible impact on the bulk of the deposited plutonium. The total amounts of plutonium released over the course of the experiment (nearly 2500 days) were 0.11, 0.13, and 0.18 μg for columns 7, 8, and 9, respectively. In each case this represents less than 0.01% of the original source.

Another interesting phenomenon is shown in Fig. 2, where the release rates are plotted as functions of time. The plutonium releases observed in the initial samples were very high and, except for isolated cases from column 7, were never again matched. This has been observed before in terrestrial chamber experiments^{4,5} and has been attributed to rapid elution of exceedingly fine particulate matter accumulated on the surface of the plutonium oxide before deposition on the soil. Such fine particulate matter, possibly generated through recoil effects on the surface of the plutonia, could be rapidly released when first contacted by the eluent.

Table II shows the results of the soil analyses carried out after the completion of the experiment. In every case, greater than 99% of the plutonium found in the column was in the top section. This agrees with our expectations, because one would not expect the bulk of the deposited plutonium to move through the soil. The total plutonium

found in the columns ranged from 75 to 85% of the amount deposited on the columns at the beginning of the experiment. Because the amounts washed out of the columns were negligible in comparison, one must ascribe the discrepancies to errors in weighing the original samples, errors in the analysis of the soil samples, or impurities in the source materials. Because of the difficulties in weighing milligram quantities of highly radioactive plutonium oxide, we surmise that the first explanation probably made the largest contribution to the overall error.

B. Experiments Using an Aqueous Plutonium Feed

The remaining two experiments, involving six columns and two soil types, were conducted by passing a "solution" of plutonium through the columns and comparing the amount of plutonium leaving the column with that entering the column. The aqueous data are shown in the Appendix and in Figs. 3 and 4. Figure 3 shows the data for columns containing loamy sand, with the squares representing data for column 10, the circles data for column 11, and the triangles data for column 12. Similarly, Fig. 4 shows data for the columns with Florida soil, with the squares representing data for column 13, the circles data for column 14, and the triangles data for column 15. For columns 10, 11, and 12, the feed concentration decreased drastically after approximately 1050 days, and data after that time probably should be ignored. For columns 13, 14, and 15, the feed concentration decreased after 100 days, and data after that point probably have limited significance. These two experiments were started at different times, so the decreases in feed concentrations actually happened simultaneously and undoubtedly resulted from the same cause.

Figure 3 shows that some plutonium was released from the loamy sand soil within the first 50 days and that a plateau was reached shortly after 100 days. Note that in terms of the feed this release amounted to less than 0.5% of the input. At about 300 days, the release began to increase again and had increased by about 1.5 orders of magnitude by 500 days. The release remained at this approximate level until the feed concentration changed at about 1050 days. During this time, the output of plutonium from the column was approximately 5% of the input. There was no evidence of the column having approached saturation up through 1050 days. The apparent spike in the release data at about that time may be the result of changing feed composition. The decrease

TABLE II. Column Section Data for Columns 7, 8, and 9^{a,b}

Fraction	Column 7	Column 8	Column 9
1 (top)	2310	1550	1700
2	5.4	12.9	8.9
3	0.176	0.138	0.62
4	0.328	0.048	0.169
5	0.419	0.029	0.074
Total	2320	1560	1710

^aAll values are in micrograms.

^bEach column fraction was 28 mm high.

Fig. 3. Release rate versus time for soil columns containing loamy sand. Square points represent column 10, circles column 11, and triangles column 12.

Fig. 4. Release rate versus time for soil columns containing Florida soil. Square points represent column 13, circles column 14, and triangles column 15.

after 1050 days may reflect the lower feed concentration. The existence of two distinct waves in the release curve for this soil suggests that plutonium can be retained by the soil in more than one way. The more efficient retention mode was saturated early in the experiment, at about 300 days, after which plutonium retention was controlled by a less efficient mode until the end of the experiment. The mechanisms involved in these two modes cannot be identified with the information available.

Figure 4 shows that significant plutonium releases from the Florida soil occurred after only 30 days and that by 80 days the release rates had reached a plateau. At this time the release rates corresponded to about 8% of the feed rate. Shortly after 80 days, the feed composition changed significantly, so whether a true breakthrough might have been observed for that soil in a short period of time is pure conjecture. Although complete breakthrough was not observed for either of the two soils studied, the Florida soil showed significant releases (greater than 5% of the feed) much earlier in the experiment than did the loamy sand. This might indicate that the more efficient mode of retention noted above is simply absent in the Florida soil and that the two soils behave similarly otherwise, or that the two soils behave entirely differently. Because neither experiment was continued until breakthrough was observed, it is difficult to draw conclusions beyond this.

When column breakthrough is not observed, one can still determine the retention curve by dissecting the column and determining the distribution of the analyte within the column. This was done with the current soil columns; the data are shown in Tables III and IV. Under

TABLE III. Column Section Data for Columns 10, 11, and 12^{a,b}

Fraction	Column 10	Column 11	Column 12
1 (top)	830	970	670
2	730	777	930
3	380	293	240
4	55	54	31
5	17	20	23
Total	2012	2114	1894

^aAll values are in micrograms.

^bEach column fraction was 26 mm high.

TABLE IV. Column Section Data for Columns 13, 14, and 15^{a,b}

Fraction	Column 13	Column 14	Column 15
1 (top)	191	178	145
2	22	14.0	24.7
3	11.8	17.5	19.5
4	15.8	17.0	6.5
5	13	19	13
Total	254	246	209

^aAll values are in micrograms.

^bEach column fraction was 26 mm high.

conditions of constant feed concentration, the column will become saturated at the top first and then the analyte will be retained progressively farther down the column as time goes on. For both sets of columns this was the case. The top two fractions for columns 10, 11, and 12 have high concentrations of plutonium, the middle fractions have a little less than half the plutonium of the top fractions, and the bottom two fractions have only small amounts of plutonium. This suggests that these columns were nearly 50% saturated. Had the experiment been continued, breakthrough should have been observed at about 2400 days or 6.6 yr. It is a simple matter to deduce that approximately 4 mg of plutonium would have been required to saturate the columns. Because each column contained 300 g of soil, the capacity of the loamy sand soil for retaining plutonium is approximately 13 $\mu\text{g/g}$. Similar conclusions can be reached for columns 13, 14, and 15, which contained the Florida soil. Table IV shows that for these columns only the topmost fractions showed high levels of plutonium. Since there were five fractions for each column, these columns were at most 20% saturated. They may have been less saturated than this; there is no way to know how close the topmost fractions were to saturation. Conceivably these columns were much less than 20% saturated, so this should be considered an upper limit. With this in mind, one can calculate that a minimum of 1.2 mg of plutonium would be required to saturate each column, at a minimum time of 1100 days. With each column containing 130 g of soil, the minimum capacity of Florida soil for retaining plutonium is thus 9 $\mu\text{g/g}$. As noted above, the actual capacity may be many times this value; 9 $\mu\text{g/g}$ serves only as a lower limit to the retention capacity.

Table V shows the mass balance data for columns 10 through 15 and compares the total amount of plutonium fed into the columns to that found in the column effluents and in the soil analysis done at the end of the experiment. The most interesting aspect of Table V is the percent plutonium retained on the column, calculated by adding the plutonium found on the column to the amount found in the effluent and dividing this sum into the amount found on the column. This percentage ranged from 93 to 95 for columns 10 through 12 and from 78 to 81 for columns 13 through 15. The apparently lower retention for the Florida soil may reflect the much reduced feed rate during the latter half of this experiment. Clearly the majority of the plutonium was retained on the columns, with the loamy sand soil being somewhat more efficient than the Florida soil. The recoveries were determined by adding the total in effluent and the total in soil and dividing the sum by the total in feed. For columns 10 through 12, the recoveries ranged from 66 to 72%. More than 500 determinations are folded into each recovery, which speaks well for the precision of the analyses performed. Recoveries for columns 13 through 15 were better, ranging from 86 to 100%. Fewer measurements were involved for these columns, about 90 per column.

The final effluent samples were subjected to a brief series of filtrations in an attempt to learn something about the nature of the plutonium exiting the columns. The feed solutions also were filtered at this time. Two filter sizes were used, 0.6 and 0.1 μm . All filters were Nuclepore® polycarbonate membrane filters, characterized by a very narrow pore size distribution. The results of these filtrations are shown in Table VI. For the feed solutions, most of the activity passed through the finest filter, indicating that the majority of the plutonium probably exists as very

fine particulates. The intent of using the large pore size filter was to remove most of the suspended soil particles. Because the feed solutions were not exposed to any soil, large pore size filters were not used for the feed solutions. For the column effluents, significant amounts of plutonium were retained on both filters. That plutonium retained on the large pore size filters undoubtedly was associated with soil particles. That passing through the finest filter probably was not associated with soil particles, but may have been either in solution or as very fine suspended matter. Chemical principles suggest the latter. The material retained by the 0.1- μm filter probably represents a combination of particulate plutonium oxide and plutonium associated with fine soil particles. Note that the feed solutions showed some retention on this size filter but that the soil column effluent showed much larger retentions. The pH values for the feed solutions and the column effluents at the end of the experiment fell within the range of 7.7 to 8.4. Because the changes in pH were minimal, pH probably was not an important factor in this experiment.

CONCLUSIONS

In one set of experiments in which 2 to 3.5 mg of PuO_2 particles was deposited on 14 cm of silt loam soil, plutonium was released into the column drainages at rates of 8 to 15 pg/day. In terms of the original source, this release rate is negligible, amounting to less than 0.01% of the source over the entire 2500-day experiment. Analysis of the soil within the columns at the end of the experiment revealed that essentially all the plutonium remained at the top of the column and did not migrate

TABLE V. Mass Balances

Column	Total in Feed (mg)	Total in Effluent (mg)	Total in Soil (mg)	Recovery (%)	Fraction in Column (%)
10	2.99	0.128	2.01	71.5	93.9
11	3.24	0.153	2.11	69.8	93.4
12	2.99	0.140	1.89	66.7	95.0
13	0.314	0.060	0.254	100	80.9
14	0.311	0.063	0.246	99.4	79.6
15	0.311	0.058	0.209	85.6	78.3

TABLE VI. Final Effluent Filtering Data^a

Size	Column 10	Column 11	Column 12	Column 13	Column 14	Column 15	Feed 10-12	Feed 13-15
>0.6 μm	8.61	1.80	4.07	46.7	65.7	63.2	—	—
>0.1 μm <0.6 μm	6.05	2.61	2.39	3.35	9.96	3.80	52	63
<0.1 μm	3.92	4.80	1.44	10.1	8.42	9.79	259	206
Total	18.6	9.21	7.90	60.2	84.1	76.8	311	269

^aAll values are in nanograms. In each case a 50-mL aliquot was filtered sequentially through 0.6- and 0.1- μm Nuclepore® filters.

into the soil. In agreement with past observations, the first column effluents after the plutonium deposition showed relatively large releases. These have been ascribed to elution of very fine particulate matter accumulated on the surfaces of the plutonium oxide particles as the result of radiation damage during storage of the sources.

A second set of experiments was carried out using two soil types, a loamy sand and a Florida agricultural soil, and a constant feed of plutonium in water. Analysis of the column effluents over time showed that the amounts of plutonium in the effluents never exceeded a small fraction of the input, so breakthrough was not observed. For the Florida soil, the effluent release reached 8% of the feed within 80 days. For the loamy sand, nearly 500 days were required to reach a release equivalent to 5% of the feed. Between 50 and 300 days, the release for this experiment was stable at approximately 0.5% of the feed. This behavior suggests more than one retention mode for the sand soil. Although the Florida soil appeared to be less efficient at retaining small amounts of plutonium, neither soil exhibited any signs of saturation, and the vast majority of the plutonium fed into the soil columns was retained within the soil.

Analysis of the soil as a function of depth after completion of the experiments revealed that the loamy sand was approximately 50% saturated and the Florida soil was less than 20% saturated. From these data one can deduce that the loamy sand would have become saturated after about 2400 days (6.6 yr) at a soil loading of 13 $\mu\text{g/g}$. Similar calculations suggest that the Florida soil would have become saturated sometime after 1100 days (minimum value) at a minimum soil loading of 9 $\mu\text{g/g}$. These are lower limits—the actual values could be many times these. The loamy sand retained 93 to 95% of the plutonium feed, and the Florida soil retained 78 to 81%.

Most of the feed plutonium was able to pass through a 0.1- μm Nuclepore® filter, indicating that the feed probably was composed of very fine plutonium oxide particulates. Significant amounts of plutonium in the column effluents were retained on all the filters used. That retained on the largest pore size filters probably was associated with soil particles, whereas that passing through the finest filter may have been some unassociated plutonium oxide species.

RECOMMENDATIONS

During these investigations we identified some improvements that might be incorporated into future experiments to render the results more useful. The choice of feed solutions is of prime concern. This is an important aspect of any column experiment with plutonium because of the conflicting requirements of maintaining the pH in the neutral range and having enough acid present to forestall polymerization and precipitation of the plutonium during the dilution process. One way of circumventing this dilemma is to use a stock solution of a plutonium complex such as plutonium carbonate or plutonium DT₂PA at a neutral pH. Dilution of such a stock solution to volume with water may avoid the necessity of passing through conditions favoring uncontrolled precipitation and polymerization reactions.⁸ We suggest that such a feed solution be used in any future column experiments. In addition, one must ensure that the concentration of the feed does not change over the course of the experiment. Separating the effects of a variable feed composition from those of the soil after the fact is a nearly impossible task but is easily avoided if proper care is exercised during the experiment.

A second important consideration is the determination of the column pore volume and its dispersion curve.

Column data are best interpreted in terms of the effluent curve versus relative volume. The pore volume clearly is needed to calculate the relative volumes. If one wants to study the shapes of the breakthrough curves, then the dispersion curve is necessary to separate the hydrodynamic and chemical effects. Dispersion curves and the column pore volumes are easily determined by measuring the breakthrough curves for tritiated water.

Because of the extreme length of the experiments involved in this work, it might be more productive to study soil types using batch sorption experiments. This would allow one to examine the capacities of a large number of soils for retaining plutonium in a relatively short period of time. Column experiments then could be undertaken for the few interesting cases in which kinetic data seem important.

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APPENDIX. EXPERIMENTAL DATA

TABLE A-I. Experimental Data for Columns 7, 8, and 9

sample	date modyyr	column 7 volume (l)	column 7 pu conc (g/l)	column 8 volume (l)	column 8 pu conc (g/l)	column 9 volume (l)	column 9 pu conc (g/l)
p1001	110876	.2250e+00	.4580e-08	.2000e+00	.3370e-07	.1100e+00	.2580e-06
p1002	110976	.5400e-01	.5300e-09	.4700e-01	.7210e-08	.2300e-01	.3210e-07
p1003	111076	.5400e-01	.2700e-09	.4600e-01	.4160e-08	.2200e-01	.1760e-07
p1004	111176	.6500e-01	.1300e-09	.5500e-01	.1200e-08	.2500e-01	.8880e-08
p1005	111276	.6200e-01	.6250e-09	.5200e-01	.5300e-09	.2300e-01	.5900e-08
p1006	111976	.4000e+00	.5300e-10	.3500e+00	.1390e-09	.1750e+00	.3640e-08
p1007	120376	.8000e+00	.7640e-10	.7200e+00	.6040e-10	.2700e+00	.2930e-08
p1008	120776	.2250e+00	.6300e-10	.2000e+00	.1650e-09	.7500e-01	.7580e-09
p1009	122276	.6000e+00	.2800e-10	.5000e+00	.4500e-10	.1800e+00	.2000e-09
p1010	010477	.8500e+00	.2550e-10	.7000e+00	.3420e-10	.2750e+00	.1880e-09
p1011	012177	.1000e+01	.2630e-10	.8500e+00	.2400e-10	.3400e+00	.8230e-10
p1012	020977	.1100e+01	.3650e-10	.9500e+00	.2340e-10	.3900e+00	.7170e-10
p1013	022277	.7000e+00	.3580e-10	.6000e+00	.2300e-10	.2300e+00	.6700e-10
p1014	030777	.7500e+00	.5700e-10	.6600e+00	.2400e-10	.2600e+00	.6790e-10
p1015	032177	.8300e+00	.4100e-10	.7000e+00	.2300e-10	.2900e+00	.6120e-10
p1016	041477	.1400e+01	.3210e-09	.1180e+01	.2080e-10	.5000e+00	.5250e-10
p1017	050677	.1300e+01	.7850e-08	.1070e+01	.7070e-08	.4600e+00	.7390e-10
p1018	051777	.6400e+00	.5060e-08	.5400e+00	.6200e-10	.2500e+00	.6300e-10
p1019	060377	.9500e+00	.9380e-09	.7800e+00	.3490e-10	.3500e+00	.5200e-10
p1020	070177	.1600e+01	.4940e-09	.1400e+01	.1410e-09	.5600e+00	.6590e-10
p1021	072177	.1360e+01	.2410e-09	.1650e+01	.4240e-10	.5000e+00	.7300e-10
p1022	080977	.1640e+01	.5180e-10	.1460e+01	.6890e-10	.7000e+00	.6750e-10
p1023	083077	.1900e+01	.6340e-10	.1500e+01	.3970e-10	.8000e+00	.5110e-10
p1024	091377	.1300e+01	.4100e-10	.1000e+01	.4820e-10	.5000e+00	.1580e-08
p1025	092777	.1340e+01	.7630e-10	.1060e+01	.6590e-10	.5700e+00	.1890e-09
p1026	101777	.1850e+01	.1210e-09	.1480e+01	.9170e-10	.7800e+00	.8020e-10
p1027	110277	.1480e+01	.1330e-09	.1200e+01	.6800e-10	.6100e+00	.7400e-10
p1028	111677	.1250e+01	.1410e-09	.1000e+01	.1140e-09	.5500e+00	.8300e-10
p1029	120277	.1400e+01	.6900e-10	.1160e+01	.1070e-09	.6000e+00	.1550e-09
p1030	122077	.1530e+01	.2490e-09	.1250e+01	.1170e-09	.6500e+00	.6000e-10
p1031	010978	.1650e+01	.2330e-09	.1400e+01	.1290e-09	.7300e+00	.1330e-09
p1032	013078	.1750e+01	.2170e-09	.1500e+01	.1370e-09	.8000e+00	.8820e-10
p1033	021778	.1460e+01	.1700e-09	.1260e+01	.1150e-09	.7000e+00	.7100e-10
p1034	030978	.1600e+01	.1690e-09	.1360e+01	.1350e-09	.7500e+00	.7100e-10
p1035	032978	.1560e+01	.1870e-09	.1400e+01	.1420e-09	.7500e+00	.7020e-10
p1036	041378	.1200e+01	.1920e-09	.1050e+01	.1710e-09	.6000e+00	.2030e-09
p1037	042778	.1100e+01	.2030e-09	.1000e+01	.1620e-09	.5500e+00	.7200e-10
p1038	051278	.1170e+01	.2280e-09	.1120e+01	.1660e-09	.6000e+00	.8040e-10
p1039	052578	.1000e+01	.2110e-09	.9000e+00	.1720e-09	.5000e+00	.8620e-10
p1040	060978	.1150e+01	.1920e-09	.1040e+01	.1790e-09	.6000e+00	.8530e-10
p1041	062378	.1150e+01	.2100e-09	.1050e+01	.2280e-09	.6000e+00	.9280e-10
p1042	071078	.1260e+01	.2210e-09	.1125e+01	.1970e-09	.6500e+00	.9710e-10
p1043	072578	.1100e+01	.4270e-09	.1020e+01	.1820e-09	.5700e+00	.5440e-10
p1044	081078	.1150e+01	.2200e-09	.1050e+01	.2050e-09	.6000e+00	.9900e-10
p1045	082578	.1070e+01	.2160e-09	.9800e+00	.1980e-09	.5400e+00	.1000e-09
p1046	090878	.1000e+01	.5390e-10	.8800e+00	.2340e-09	.5000e+00	.4460e-09
p1047	092078	.8100e+00	.1820e-09	.7500e+00	.1940e-09	.4000e+00	.1110e-09
p1048	100678	.1170e+01	.2120e-09	.1050e+01	.2520e-09	.6000e+00	.1060e-09
p1049	102678	.1500e+01	.1940e-09	.1120e+01	.2780e-09	.7600e+00	.1080e-09
p1050	110978	.1000e+01	.2100e-09	.8800e+00	.3110e-09	.5100e+00	.9950e-10
p1051	112278	.9500e+00	.3400e-09	.8500e+00	.3250e-09	.5000e+00	.1210e-09
p1052	120878	.1250e+01	.3630e-09	.1050e+01	.3330e-09	.6000e+00	.1200e-09
p1053	122178	.1200e+01	.3260e-09	.8600e+00	.3130e-09	.5000e+00	.1240e-09
p1054	010379	.1000e+01	.3140e-09	.8500e+00	.2910e-09	.5000e+00	.1400e-09
p1055	011779	.1120e+01	.2520e-09	.9400e+00	.2630e-09	.5500e+00	.1240e-09
p1056	013179	.1050e+01	.4900e-09	.9000e+00	.5260e-09	.5600e+00	.2390e-10
p1057	021579	.1150e+01	.2700e-10	.1030e+01	.2770e-09	.6000e+00	.1420e-09
p1058	022879	.1000e+01	.2470e-09	.8600e+00	.2870e-09	.5000e+00	.1430e-09
p1059	031479	.1020e+01	.2300e-09	.9000e+00	.2710e-09	.5300e+00	.1460e-09
p1060	033079	.1150e+01	.5100e-09	.1025e+01	.2790e-09	.6000e+00	.2670e-09
p1061	041179	.9000e+00	.2100e-09	.8000e+00	.2950e-09	.4600e+00	.1350e-09
p1062	042579	.1000e+01	.2000e-09	.8600e+00	.2780e-09	.5200e+00	.1470e-09
p1063	050979	.8500e+00	.2210e-09	.8400e+00	.2480e-09	.4800e+00	.1590e-09
p1064	052379	.9500e+00	.1910e-09	.8300e+00	.2480e-09	.5000e+00	.1760e-09
p1065	060679	.9500e+00	.1840e-09	.8500e+00	.2330e-09	.5000e+00	.1850e-09

TABLE A-I. (cont)

p1066	062079	.9500e+00	.1960e-09	.8500e+00	.2650e-09	.5000e+00	.1790e-09
p1067	070379	.8500e+00	.1860e-09	.7500e+00	.2430e-09	.4500e+00	.1870e-09
p1068	071979	.1050e+01	.1790e-09	.9500e+00	.2490e-09	.6000e+00	.1890e-09
p1069	073179	.8000e+00	.1760e-09	.7300e+00	.2700e-09	.4100e+00	.2110e-09
p1070	081479	.9000e+00	.1590e-09	.8000e+00	.2240e-09	.5000e+00	.1840e-09
p1071	082879	.9200e+00	.1640e-09	.8500e+00	.2550e-09	.5000e+00	.2100e-09
p1072	091179	.1000e+01	.1640e-09	.9000e+00	.2830e-09	.5250e+00	.2350e-09
p1073	092679	.9500e+00	.2090e-09	.8700e+00	.3120e-09	.5000e+00	.2500e-09
p1074	101079	.9000e+00	.1740e-09	.8000e+00	.2900e-09	.5000e+00	.2210e-09
p1075	102479	.9250e+00	.1740e-09	.8500e+00	.1380e-09	.5000e+00	.4690e-09
p1076	110779	.9000e+00	.1830e-09	.8000e+00	.2900e-09	.5000e+00	.2420e-09
p1077	112179	.8800e+00	.1900e-09	.8200e+00	.2680e-09	.5000e+00	.2300e-09
p1078	120579	.9000e+00	.1740e-09	.8250e+00	.2590e-09	.5000e+00	.2350e-09
p1079	121979	.9500e+00	.2090e-09	.8500e+00	.2870e-09	.5000e+00	.2740e-09
p1080	010280	.9000e+00	.1950e-09	.8200e+00	.2770e-09	.5000e+00	.2780e-09
p1081	011680	.9200e+00	.2480e-09	.8500e+00	.1320e-09	.5000e+00	.3390e-09
p1082	013180	.1000e+01	.1670e-09	.9000e+00	.2740e-09	.5500e+00	.2490e-09
p1083	021380	.8500e+00	.1680e-09	.8000e+00	.2790e-09	.4700e+00	.2500e-09
p1084	022780	.9000e+00	.1720e-09	.8000e+00	.1040e-09	.5000e+00	.2490e-09
p1085	031480	.1000e+01	.1910e-09	.9250e+00	.3240e-09	.5750e+00	.2680e-09
p1086	040380	.1250e+01	.2310e-09	.1150e+01	.3520e-09	.7200e+00	.2770e-09
p1087	042480	.1350e+01	.2460e-09	.1250e+01	.3620e-09	.7200e+00	.3420e-09
p1088	050980	.9300e+00	.2300e-09	.8500e+00	.3770e-09	.5470e+00	.3580e-09
p1089	052380	.9000e+00	.1960e-09	.8000e+00	.3440e-09	.5000e+00	.3300e-09
p1090	060980	.1160e+01	.1860e-09	.1010e+01	.3550e-09	.6500e+00	.2980e-09
p1091	062780	.1270e+01	.1960e-09	.1100e+01	.3810e-09	.7000e+00	.3470e-09
p1092	071480	.1260e+01	.2270e-09	.1050e+01	.3960e-09	.7000e+00	.3000e-09
p1093	073180	.1220e+01	.2150e-09	.1020e+01	.4290e-09	.6600e+00	.4590e-09
p1094	081480	.1000e+01	.2000e-09	.8000e+00	.3930e-09	.5600e+00	.4940e-09
p1095	090380	.1380e+01	.1990e-09	.1220e+01	.3760e-09	.7500e+00	.9690e-09
p1096	092580	.1480e+01	.2560e-09	.1220e+01	.6020e-09	.8000e+00	.4070e-09
p1097	101080	.1000e+01	.3770e-09	.3500e+00	.4700e-09	.5300e+00	.3860e-09
p1098	102880	.1150e+01	.2900e-09	.9600e+00	.4450e-09	.6500e+00	.3730e-09
p1099	111880	.1360e+01	.2560e-09	.1160e+01	.4110e-09	.7600e+00	.3770e-09
p1100	120980	.1350e+01	.1930e-09	.1150e+01	.4100e-09	.7800e+00	.3810e-09
p1101	122980	.8500e+00	.2030e-09	.7800e+00	.3830e-09	.5000e+00	.3990e-09
p1102	010981	.1000e+01	.2760e-09	.9000e+00	.1030e-09	.6000e+00	.5030e-09
p1103	013081	.1300e+01	.1630e-09	.1130e+01	.1670e-09	.7500e+00	.2220e-09
p1104	022381	.1500e+01	.2940e-09	.1290e+00	.2470e-09	.8900e+00	.2440e-09
p1105	032381	.1775e+01	.4190e-09	.1550e+01	.3320e-09	.1050e+01	.3630e-09
p1106	041381	.1350e+01	.9780e-09	.1200e+01	.8370e-09	.9000e+00	.5070e-09
p1107	050781	.1450e+01	.9250e-09	.1400e+01	.1080e-08	.1100e+01	.7420e-09
p1108	052981	.1400e+01	.1420e-08	.1300e+01	.1440e-08	.1000e+01	.1770e-08
p1109	061881	.1200e+01	.3040e-08	.1170e+01	.3550e-08	.8000e+00	.4480e-08
p1110	071781	.1800e+01	.4020e-08	.1600e+01	.4810e-08	.1200e+01	.4400e-08
p1111	081281	.1550e+01	.2090e-08	.1400e+01	.4140e-08	.1000e+01	.2800e-08
p1112	091181	.1700e+01	.1950e-08	.1600e+01	.1630e-08	.1180e+01	.2350e-08
p1113	100881	.1480e+01	.1520e-08	.1400e+01	.1520e-08	.1000e+01	.2170e-08
p1114	110281	.1350e+01	.1370e-08	.1300e+01	.1390e-08	.9500e+00	.1960e-08
p1115	112381	.1200e+01	.8820e-09	.1200e+01	.8710e-09	.8500e+00	.1100e-08
p1116	121581	.1250e+01	.7690e-09	.1250e+01	.2190e-08	.9000e+00	.1150e-08
p1117	010782	.1350e+01	.9930e-09	.1350e+01	.6860e-09	.9500e+00	.8800e-09
p1118	021082	.1900e+01	.2690e-08	.1900e+01	.1920e-08	.1450e+01	.3220e-08
p1119	030882	.1550e+01	.1700e-08	.1600e+01	.2090e-08	.1150e+01	.3400e-08
p1120	032982	.1200e+01	.1980e-08	.1200e+01	.2770e-08	.9000e+00	.4010e-08
p1121	042282	.1320e+01	.1670e-08	.1320e+01	.3040e-08	.9900e+00	.5090e-08
p1122	051482	.1200e+01	.1430e-08	.1250e+01	.2390e-08	.9300e+00	.5530e-08
p1123	060782	.1280e+01	.3130e-08	.1350e+01	.1740e-08	.1000e+01	.6770e-08
p1124	070682	.1500e+01	.2000e-08	.1600e+01	.3000e-08	.1200e+01	.6040e-08
p1125	072782	.1150e+01	.1490e-08	.1250e+01	.2280e-08	.9000e+00	.4530e-08
p1126	082482	.1500e+01	.1270e-08	.1350e+01	.2020e-08	.1200e+01	.5110e-08
p1127	092082	.1400e+01	.1260e-08	.1470e+01	.1880e-08	.1080e+01	.5870e-08
p1128	101982	.1500e+01	.1410e-08	.1530e+01	.2090e-08	.1200e+01	.6170e-08
p1129	111682	.1380e+01	.1590e-08	.1400e+01	.1960e-08	.1100e+01	.5560e-08
p1130	122082	.1700e+01	.110e-08	.1700e+01	.2900e-08	.1350e+01	.9220e-08
p1131	011483	.1250e+01	.1660e-08	.1390e+01	.1380e-08	.9900e+00	.7150e-08
p1132	021683	.1590e+01	.8600e-09	.1680e+01	.9570e-09	.1250e+01	.3640e-08
p1133	031683	.1300e+01	.1300e-08	.1350e+01	.2330e-08	.1050e+01	.4670e-08
p1134	041383	.1250e+01	.1670e-08	.1300e+01	.1690e-08	.1000e+01	.4550e-08
p1135	051783	.1600e+01	.1280e-08	.1700e+01	.8890e-09	.1300e+01	.3250e-08
p1136	062283	.1350e+01	.1250e-08	.1450e+01	.1480e-08	.1150e+01	.4870e-08

TABLE A-II. Experimental Data for Columns 10, 11, and 12

sample	date modyr	column 10 volume (l)	column 10 pu conc (g/l)	column 11 volume (l)	column 11 pu conc (g/l)	column 12 volume (l)	column 12 pu conc (g/l)	feed pu conc (g/l)
r22001	021280	.1060e+01	.6160e-08	.1060e+01	.1540e-07	.1060e+01	.1190e-07	.8600e-05
r22002	021980	.1250e+01	.5160e-08	.1250e+01	.6320e-08	.1250e+01	.6930e-08	.1100e-04
r22003	022680	.1100e+01	.5820e-08	.1100e+01	.7470e-08	.1100e+01	.6600e-08	.1030e-04
r22004	030380	.1475e+01	.3800e-08	.1525e+01	.4370e-08	.1500e+01	.4120e-08	.1100e-04
r22005	031180	.1420e+01	.8870e-08	.1420e+01	.1150e-07	.1450e+01	.1140e-07	.1210e-04
r22006	031980	.1420e+01	.1040e-07	.1420e+01	.1470e-07	.1420e+01	.1740e-07	.1310e-04
r22007	032780	.1420e+01	.1170e-07	.1420e+01	.1650e-07	.1420e+01	.1730e-07	.1280e-04
r22008	040380	.1250e+01	.1350e-07	.1250e+01	.1900e-07	.1250e+01	.2060e-07	.1300e-04
r22009	041080	.1280e+01	.1300e-07	.1280e+01	.1950e-07	.1280e+01	.2150e-07	.1180e-04
r22010	041780	.1240e+01	.1500e-07	.1240e+01	.2110e-07	.1240e+01	.2250e-07	.1210e-04
r22011	042580	.1420e+01	.1570e-07	.1420e+01	.2250e-07	.1450e+01	.2410e-07	.1100e-04
r22012	050280	.1260e+01	.1750e-07	.1260e+01	.2460e-07	.1280e+01	.2700e-07	.1500e-04
r22013	050980	.1300e+01	.2010e-07	.2130e+02	.2860e-07	.1300e+01	.3070e-07	.1270e-04
r22014	051680	.1400e+01	.2100e-07	.1400e+01	.2780e-07	.1400e+01	.3230e-07	.1140e-04
r22015	052380	.1250e+01	.2060e-07	.1250e+01	.2860e-07	.1250e+01	.3160e-07	.1220e-04
r22016	053080	.1260e+01	.2090e-07	.1260e+01	.2800e-07	.1260e+01	.3250e-07	.1400e-04
r22017	060580	.1100e+01	.2290e-07	.1100e+01	.2990e-07	.1100e+01	.3560e-07	.1440e-04
r22018	061180	.1100e+01	.2260e-07	.1100e+01	.2870e-07	.1100e+01	.3460e-07	.1490e-04
r22019	062080	.1600e+01	.2350e-07	.1600e+01	.2820e-07	.1600e+01	.3510e-07	.1570e-04
r22020	062780	.1300e+01	.2510e-07	.1300e+01	.3050e-07	.1300e+01	.3740e-07	.1690e-04
r22021	070380	.1100e+01	.2210e-07	.1100e+01	.2690e-07	.1100e+01	.3460e-07	.1420e-04
r22022	071180	.1480e+01	.1660e-07	.1480e+01	.1920e-07	.1480e+01	.2930e-07	.1450e-04
r22023	071780	.1100e+01	.2480e-07	.1100e+01	.2830e-07	.1100e+01	.3840e-07	.1620e-04
r22024	072880	.1500e+01	.3010e-07	.1500e+01	.3710e-07	.1500e+01	.5250e-07	.1400e-04
r22025	080180	.1300e+01	.2640e-07	.1300e+01	.2870e-07	.1300e+01	.3660e-07	.1500e-04
r22026	080880	.1300e+01	.2700e-07	.1300e+01	.2750e-07	.1300e+01	.3770e-07	.1420e-04
r22027	081580	.1280e+01	.2590e-07	.1280e+01	.2780e-07	.1280e+01	.3840e-07	.1490e-04
r22028	082180	.1100e+01	.2580e-07	.1100e+01	.2480e-07	.1100e+01	.3620e-07	.1500e-04
r22029	082980	.1460e+01	.2570e-07	.1460e+01	.2720e-07	.1460e+01	.3570e-07	.1590e-04
r22030	090480	.1100e+01	.2580e-07	.1100e+01	.2480e-07	.1100e+01	.3620e-07	.1500e-04
r22031	091180	.1300e+01	.2800e-07	.1300e+01	.2700e-07	.1300e+01	.3920e-07	.1480e-04
r22032	091980	.1460e+01	.3050e-07	.1460e+01	.2950e-07	.1460e+01	.4300e-07	.1500e-04
r22033	092680	.1250e+01	.2900e-07	.1250e+01	.3940e-07	.1250e+01	.2610e-07	.1370e-04
r22034	100380	.1280e+01	.2930e-07	.1280e+01	.2850e-07	.1280e+01	.4110e-07	.1310e-04
r22035	101080	.1300e+01	.2940e-07	.1300e+01	.3060e-07	.1300e+01	.4210e-07	.1360e-04
r22036	101680	.1280e+01	.2830e-07	.1280e+01	.2970e-07	.1280e+01	.4240e-07	.1570e-04
r22037	102480	.1250e+01	.3550e-07	.1250e+01	.3710e-07	.1250e+01	.5500e-07	.1400e-04
r22038	103180	.1300e+01	.3770e-07	.1300e+01	.4070e-07	.1300e+01	.5940e-07	.1440e-04
r22039	110780	.1250e+01	.4000e-07	.1250e+01	.4330e-07	.1250e+01	.6240e-07	.1470e-04
r22040	111480	.1280e+01	.3610e-07	.1280e+01	.4430e-07	.1280e+01	.5650e-07	.1440e-04
r22041	112080	.1090e+01	.4150e-07	.1090e+01	.5130e-07	.1090e+01	.6840e-07	.1380e-04
r22042	112680	.1100e+01	.6590e-07	.1100e+01	.5670e-07	.1100e+01	.8080e-07	.1480e-04
r22043	120380	.1300e+01	.4690e-07	.1300e+01	.5800e-07	.1300e+01	.7250e-07	.1600e-04
r22044	121080	.1280e+01	.4890e-07	.1280e+01	.5660e-07	.1280e+01	.7690e-07	.1340e-04
r22045	121780	.1300e+01	.3970e-07	.1300e+01	.5390e-07	.1300e+01	.6570e-07	.1290e-04
r22046	122980	.1280e+01	.4290e-07	.1280e+01	.5310e-07	.1280e+01	.6620e-07	.1370e-04
r22047	123180	.1300e+01	.2880e-07	.1300e+01	.3750e-07	.1300e+01	.4300e-07	.1700e-04
r22048	010881	.1420e+01	.7040e-07	.1420e+01	.4230e-07	.1420e+01	.1070e-06	.1490e-04
r22049	011681	.1450e+01	.1830e-06	.1450e+01	.4420e-07	.1490e+01	.1800e-06	.1580e-04
r22050	012381	.1280e+01	.2690e-06	.1290e+01	.4380e-07	.1290e+01	.1440e-06	.1420e-04
r22051	013081	.1240e+01	.3610e-06	.1250e+01	.6170e-07	.1280e+01	.1640e-06	.1340e-04
r22052	020681	.1300e+01	.3890e-06	.1300e+01	.9540e-07	.1300e+01	.1320e-06	.1340e-04
r22053	021381	.1300e+01	.4690e-06	.1300e+01	.5520e-06	.1300e+01	.6500e-06	.1600e-04
r22054	022181	.1250e+01	.4610e-06	.1250e+01	.3870e-06	.1250e+01	.3730e-06	.1460e-04
r22055	022781	.1280e+01	.4630e-06	.1280e+01	.4000e-06	.1280e+01	.3560e-06	.1500e-04
r22056	030681	.1280e+01	.4620e-06	.1280e+01	.4420e-06	.1280e+01	.3620e-06	.1520e-04
r22057	031381	.1300e+01	.3530e-06	.1300e+01	.3650e-06	.1300e+01	.3110e-06	.1410e-04
r22058	032081	.1280e+01	.2890e-06	.1280e+01	.3030e-06	.1280e+01	.2910e-06	.1340e-04
r22059	032781	.1280e+01	.2080e-06	.1250e+01	.3540e-06	.1300e+01	.3870e-06	.1170e-04
r22060	040381	.1280e+01	.1740e-06	.1280e+01	.3620e-06	.1300e+01	.3270e-06	.1300e-04
r22061	041081	.1280e+01	.2190e-06	.1280e+01	.4290e-06	.1280e+01	.3200e-06	.1380e-04
r22062	041781	.1280e+01	.2040e-06	.1280e+01	.3710e-06	.1280e+01	.3310e-06	.1320e-04
r22063	042481	.1230e+01	.1740e-06	.1230e+01	.4050e-06	.1230e+01	.4640e-06	.1340e-04
r22064	050181	.1300e+01	.2130e-06	.1300e+01	.4310e-06	.1300e+01	.4760e-06	.1300e-04
r22065	050881	.1230e+01	.2140e-06	.1230e+01	.4120e-06	.1230e+01	.4620e-06	.1340e-04
r22066	051581	.1330e+01	.2420e-06	.1330e+01	.4860e-06	.1330e+01	.5500e-06	.1320e-04
r22067	052281	.1280e+01	.2800e-06	.1280e+01	.4720e-06	.1280e+01	.4950e-06	.1380e-04
r22068	052981	.1300e+01	.4700e-06	.1300e+01	.5640e-06	.1300e+01	.6730e-06	.1440e-04
r22069	060581	.1300e+01	.5000e-06	.1300e+01	.7100e-06	.1300e+01	.6210e-06	.1350e-04
r22070	061281	.1280e+01	.6290e-06	.1290e+01	.7670e-06	.1280e+01	.5410e-06	.1330e-04

TABLE A-II. (cont)

r22071	061981	.1300e+01	.2020e-06	.1300e+01	.2610e-06	.1300e+01	.2000e-06	.1420e-04
r22072	062981	.1300e+01	.2020e-06	.1300e+01	.2570e-06	.1300e+01	.2080e-06	.1370e-04
r22073	070281	.1060e+01	.4870e-06	.1060e+01	.5680e-06	.1060e+01	.5480e-06	.1390e-04
r22074	071081	.1450e+01	.6420e-06	.1450e+01	.6590e-06	.1450e+01	.6720e-06	.1360e-04
r22075	071781	.1300e+01	.1980e-05	.1300e+01	.1290e-05	.1300e+01	.1040e-05	.1380e-04
r22076	072481	.1300e+01	.2480e-05	.1300e+01	.1080e-05	.1300e+01	.8080e-06	.1450e-04
r22077	073181	.1300e+01	.1600e-06	.1300e+01	.7940e-06	.1300e+01	.5710e-06	.1440e-04
r22078	080781	.1300e+01	.1650e-06	.1300e+01	.1040e-06	.1300e+01	.1020e-06	.1060e-04
r22079	081481	.1280e+01	.1930e-06	.1280e+01	.1620e-06	.1280e+01	.1040e-06	.1340e-04
r22080	082181	.1280e+01	.2440e-06	.1280e+01	.1470e-06	.1280e+01	.2170e-06	.1450e-04
r22081	082881	.1300e+01	.3060e-06	.1300e+01	.2020e-06	.1300e+01	.2580e-06	.1650e-04
r22082	090481	.1300e+01	.1180e-05	.1300e+01	.6230e-06	.1300e+01	.6940e-06	.1530e-04
r22083	091181	.1230e+01	.1520e-05	.1230e+01	.9630e-06	.1230e+01	.9640e-06	.1570e-04
r22084	091881	.1280e+01	.3220e-06	.1280e+01	.1980e-05	.1280e+01	.1750e-05	.1560e-04
r22085	092581	.1280e+01	.2170e-05	.1280e+01	.2290e-05	.1280e+01	.2410e-05	.1650e-04
r22086	100281	.1250e+01	.5820e-06	.1250e+01	.1480e-05	.1250e+01	.6850e-06	.1060e-04
r22087	100981	.1300e+01	.4330e-06	.1300e+01	.3000e-06	.1300e+01	.2590e-06	.1370e-04
r22088	102081	.2000e+01	.7540e-06	.2000e+01	.5850e-06	.2000e+01	.1140e-05	.1470e-04
r22089	102781	.1300e+01	.3200e-06	.1300e+01	.3850e-06	.1300e+01	.3370e-06	.1220e-04
r22090	110381	.1250e+01	.4740e-06	.1250e+01	.4880e-06	.1250e+01	.1420e-06	.1300e-04
r22091	111081	.1300e+01	.1550e-06	.1300e+01	.2030e-06	.1300e+01	.2340e-06	.1240e-04
r22092	111881	.1300e+01	.1430e-06	.1300e+01	.3230e-06	.1300e+01	.4520e-06	.1280e-04
r22093	112481	.1250e+01	.1720e-06	.1250e+01	.4650e-06	.1250e+01	.5580e-06	.1390e-04
r22094	120181	.1300e+01	.2090e-06	.1300e+01	.3440e-06	.1300e+01	.8560e-06	.1260e-04
r22095	120881	.1250e+01	.1630e-06	.1250e+01	.3240e-06	.1250e+01	.5390e-06	.1270e-04
r22096	121581	.1300e+01	.3020e-06	.1300e+01	.4990e-06	.1300e+01	.1470e-05	.1460e-04
r22097	122281	.1100e+01	.4070e-06	.1100e+01	.4130e-06	.1100e+01	.1810e-05	.1480e-04
r22098	122981	.1300e+01	.5190e-06	.1300e+01	.6110e-06	.1300e+01	.2190e-05	.1600e-04
r22099	010582	.1300e+01	.5280e-06	.1300e+01	.6580e-06	.1300e+01	.2520e-05	.1300e-04
r22100	011282	.1250e+01	.5040e-05	.1250e+01	.6700e-06	.1250e+01	.1350e-05	.1570e-04
r22101	012082	.1450e+01	.5010e-06	.1450e+01	.6590e-06	.1450e+01	.1610e-05	.1570e-04
r22102	012782	.1300e+01	.4600e-06	.1300e+01	.8060e-06	.1300e+01	.1070e-05	.1620e-04
r22103	020382	.1250e+01	.7570e-06	.1250e+01	.8290e-06	.1250e+01	.2230e-05	.1150e-04
r22104	021082	.1250e+01	.5330e-06	.1250e+01	.7580e-06	.1250e+01	.1030e-05	.1230e-04
r22105	021782	.1250e+01	.5770e-06	.1250e+01	.7050e-06	.1250e+01	.1020e-05	.3980e-04
r22106	022482	.1250e+01	.4860e-06	.1250e+01	.7410e-06	.1250e+01	.8230e-06	.1830e-04
r22107	030382	.1300e+01	.4140e-06	.1300e+01	.7480e-06	.1300e+01	.8180e-06	.1570e-04
r22108	031082	.1250e+01	.6660e-06	.1250e+01	.6400e-06	.1250e+01	.7210e-06	.1600e-04
r22109	031782	.1300e+01	.7450e-06	.1300e+01	.6410e-06	.1300e+01	.6440e-06	.1380e-04
r22110	032482	.1300e+01	.1030e-05	.1300e+01	.8920e-06	.1300e+01	.5480e-06	.1290e-04
r22111	033182	.1250e+01	.1080e-05	.1250e+01	.7250e-06	.1250e+01	.5930e-06	.1440e-04
r22112	040782	.1300e+01	.1050e-05	.1300e+01	.8220e-06	.1300e+01	.6570e-06	.1590e-04
r22113	041582	.1400e+01	.1480e-05	.1400e+01	.7100e-06	.1400e+01	.5150e-06	.1560e-04
r22114	042282	.1280e+01	.1710e-05	.1280e+01	.8970e-06	.1280e+01	.6840e-06	.1320e-04
r22115	042982	.1280e+01	.1020e-05	.1280e+01	.7780e-06	.1280e+01	.7980e-06	.1500e-04
r22116	050682	.1300e+01	.1100e-05	.1300e+01	.8310e-06	.1300e+01	.6760e-06	.1270e-04
r22117	051382	.1250e+01	.1060e-05	.1250e+01	.9130e-06	.1250e+01	.7550e-06	.1730e-04
r22118	052082	.1280e+01	.8140e-06	.1280e+01	.7700e-06	.1280e+01	.6530e-06	.1400e-04
r22119	052782	.1280e+01	.7250e-06	.1280e+01	.6830e-06	.1280e+01	.5860e-06	.1500e-04
r22120	060282	.1500e+01	.4920e-06	.1500e+01	.5800e-06	.1500e+01	.4020e-06	.1400e-04
r22121	061082	.1490e+01	.6910e-06	.1490e+01	.7110e-06	.1490e+01	.5660e-06	.1370e-04
r22122	061682	.1100e+01	.7240e-06	.1100e+01	.8300e-06	.1100e+01	.6050e-06	.1420e-04
r22123	062282	.1280e+01	.5710e-06	.1280e+01	.7230e-06	.1280e+01	.4880e-06	.1490e-04
r22124	063082	.1280e+01	.3050e-06	.1280e+01	.5330e-06	.1280e+01	.3660e-06	.1590e-04
r22125	070782	.1200e+01	.3430e-06	.1200e+01	.4900e-06	.1250e+01	.3250e-06	.1380e-04
r22126	071482	.1250e+01	.3380e-06	.1250e+01	.5100e-06	.1250e+01	.3030e-06	.1420e-04
r22127	072482	.1220e+01	.2070e-05	.1220e+01	.2520e-05	.1220e+01	.2030e-05	.1550e-04
r22128	072882	.1300e+01	.1050e-05	.1300e+01	.1290e-05	.1300e+01	.1260e-05	.1450e-04
r22129	080482	.1280e+01	.3650e-06	.1280e+01	.8140e-06	.1280e+01	.3810e-06	.1500e-04
r22130	081182	.1280e+01	.4350e-06	.1280e+01	.1470e-05	.1280e+01	.5570e-06	.1530e-04
r22131	081882	.1300e+01	.4930e-06	.1300e+01	.9100e-06	.1300e+01	.4390e-06	.1750e-04
r22132	082682	.1400e+01	.5410e-06	.1400e+01	.8370e-06	.1400e+01	.5110e-06	.1490e-04
r22133	090182	.1100e+01	.5630e-06	.1100e+01	.8780e-06	.1100e+01	.4770e-06	.1480e-04
r22134	090882	.1280e+01	.5420e-06	.1280e+01	.1030e-05	.1280e+01	.5530e-06	.1560e-04
r22135	091582	.1300e+01	.3500e-06	.1300e+01	.1050e-05	.1300e+01	.6470e-06	.1600e-04
r22136	092382	.1300e+01	.5680e-06	.1300e+01	.1010e-05	.1300e+01	.3190e-06	.1490e-04
r22137	092982	.1220e+01	.7240e-06	.1220e+01	.1040e-05	.1220e+01	.5000e-06	.1440e-04
r22138	100682	.1270e+01	.1000e-05	.1270e+01	.1700e-05	.1270e+01	.8890e-06	.1730e-04
r22139	101482	.1230e+01	.1420e-05	.1230e+01	.2110e-05	.1290e+01	.1140e-05	.1960e-04
r22140	102082	.1270e+01	.1360e-05	.1250e+01	.1940e-05	.1260e+01	.1430e-05	.1800e-04
r22141	102782	.1200e+01	.1580e-05	.1220e+01	.1840e-05	.1240e+01	.1290e-05	.1810e-04
r22142	110382	.1300e+01	.4080e-05	.1300e+01	.5700e-05	.1310e+01	.4060e-05	.1850e-04
r22143	110982	.9800e+00	.3450e-05	.9800e+00	.6230e-05	.1000e+01	.3390e-05	.2600e-04
r22144	112382	.1500e+01	.1390e-05	.1500e+01	.4060e-05	.1500e+01	.2300e-05	.2080e-04
r22145	113082	.1300e+01	.1260e-05	.1300e+01	.3120e-05	.1300e+01	.2460e-05	.2880e-04
r22146	120682	.1100e+01	.7780e-05	.1100e+01	.9420e-05	.1100e+01	.9920e-05	.3290e-04
r22147	121582	.1600e+01	.9660e-05	.1500e+01	.9560e-05	.1600e+01	.8570e-05	.1010e-04
r22148	122182	.1080e+01	.1290e-05	.1080e+01	.1600e-05	.1080e+01	.1260e-05	.1260e-04
r22149	122982	.1500e+01	.1430e-05	.1500e+01	.2310e-05	.1550e+01	.1360e-05	.1140e-04
r22150	010583	.1300e+01	.7830e-06	.1300e+01	.6430e-06	.1300e+01	.6800e-06	.1570e-04
r22151	011183	.1500e+01	.4590e-06	.1500e+01	.6180e-06	.1500e+01	.5440e-06	.9800e-05
r22152	011983	.1500e+01	.7580e-06	.1500e+01	.7300e-06	.1500e+01	.6190e-06	.6400e-05
r22153	012583	.1100e+01	.6060e-06	.1100e+01	.5970e-06	.1100e+01	.4440e-06	.6800e-05
r22154	020283	.1580e+01	.4900e-06	.1580e+01	.4680e-06	.1580e+01	.3650e-06	.1150e-04
r22155	020983	.6800e+00	.9040e-06	.6000e+00	.1130e-05	.6800e+00	.9390e-06	.8200e-05

TABLE A-II. (cont)

r22156	021683	.1300e+01	.1450e-05	.1300e+01	.1190e-05	.1300e+01	.8400e-06	.5500e-05
r22157	022383	.1280e+01	.5820e-06	.1280e+01	.7840e-06	.1280e+01	.6200e-06	.7000e-05
r22158	030283	.1300e+01	.8260e-06	.1250e+01	.7580e-06	.1300e+01	.5120e-06	.6300e-05
r22159	030983	.1280e+01	.4890e-06	.1300e+01	.3810e-06	.1300e+01	.3680e-06	.6900e-05
r22160	031683	.1300e+01	.3870e-06	.1300e+01	.4180e-06	.1300e+01	.3370e-06	.8900e-05
r22161	032383	.1230e+01	.4060e-06	.1200e+01	.3110e-06	.1300e+01	.3000e-06	.9300e-05
r22162	032983	.1100e+01	.2810e-06	.1080e+01	.4350e-06	.1100e+01	.1790e-06	.9800e-05
r22163	040683	.1420e+01	.2640e-06	.1420e+01	.2020e-06	.1500e+01	.2260e-06	.8100e-05
r22164	041383	.1090e+01	.3190e-06	.1050e+01	.2540e-06	.1100e+01	.2690e-06	.6300e-05
r22165	042583	.1400e+01	.2490e-06	.1300e+01	.2760e-06	.1300e+01	.1810e-06	.7300e-05

TABLE A-III. Experimental Data for Columns 13, 14, and 15

sample	date modyyr	column 13 volume (l)	column 13 pu conc (g/l)	column 14 volume (l)	column 14 pu conc (g/l)	column 15 volume (l)	column 15 pu conc (g/l)	feed pu conc (g/l)
r2201	092982	.1100e+01	.3200e-09	.1100e+01	.3300e-09	.1000e+01	.9100e-09	.1970e-04
r2202	100682	.5600e+00	.2700e-09	.5600e+00	.2000e-09	.5600e+00	.2400e-09	.2110e-04
r2203	101482	.5800e+00	.2000e-10	.5800e+00	.9700e-09	.5800e+00	.4100e-09	.1800e-04
r2204	102082	.5600e+00	.2340e-07	.5700e+00	.1670e-07	.5500e+00	.2230e-06	.1970e-04
r2205	102782	.5800e+00	.5870e-07	.5900e+00	.8430e-07	.5800e+00	.3580e-06	.2000e-04
r2206	110382	.6000e+00	.2500e-06	.6000e+00	.2300e-06	.5800e+00	.7720e-06	.2040e-04
r2207	110982	.5000e+00	.3850e-06	.5000e+00	.3470e-05	.5000e+00	.9800e-06	.2620e-04
r2208	111682	.6000e+00	.4420e-06	.6000e+00	.4850e-06	.6000e+00	.1520e-05	.2550e-04
r2209	112382	.5900e+00	.9820e-06	.6000e+00	.1020e-05	.6000e+00	.2220e-05	.2410e-04
r2210	120182	.6500e+00	.2210e-05	.6500e+00	.2230e-05	.6300e+00	.3490e-05	.2520e-04
r2211	120982	.7000e+00	.3190e-05	.7000e+00	.3140e-05	.7000e+00	.3540e-05	.3980e-04
r2212	121582	.5000e+00	.3830e-05	.5000e+00	.3550e-05	.5000e+00	.4720e-05	.3680e-04
r2213	122182	.4900e+00	.4970e-05	.4000e+00	.4270e-05	.5000e+00	.4080e-05	.3850e-04
r2214	010383	.1100e+01	.1120e-04	.1100e+01	.1370e-04	.1100e+01	.1120e-04	.3850e-04
r2215	011383	.8700e+00	.1122e-04	.8700e+00	.1140e-04	.8700e+00	.1000e-04	.9600e-05
r2216	011983	.5000e+00	.9250e-05	.5000e+00	.7850e-05	.5000e+00	.6280e-05	.7700e-05
r2217	012783	.6800e+00	.5980e-05	.6800e+00	.6450e-05	.6800e+00	.5730e-05	.1030e-04
r2218	020283	.5000e+00	.4870e-05	.5000e+00	.5360e-05	.5000e+00	.5030e-05	.1050e-04
r2219	020983	.6000e+00	.5420e-05	.6000e+00	.5430e-05	.6000e+00	.4730e-05	.6300e-05
r2220	021683	.5800e+00	.3140e-05	.5800e+00	.4240e-05	.5800e+00	.3240e-05	.5000e-05
r2221	022483	.6800e+00	.3160e-05	.6800e+00	.2510e-05	.6800e+00	.2210e-05	.8200e-05
r2222	030383	.5000e+00	.3640e-05	.5000e+00	.3750e-05	.5000e+00	.2930e-05	.7600e-05
r2223	030983	.6000e+00	.3100e-05	.6000e+00	.2150e-05	.6000e+00	.2440e-05	.7900e-05
r2224	031783	.6500e+00	.2810e-05	.6500e+00	.2200e-05	.6500e+00	.2650e-05	.8200e-05
r2225	032383	.5000e+00	.2320e-05	.5000e+00	.2250e-05	.5000e+00	.2410e-05	.8400e-05
r2226	033183	.6500e+00	.2200e-05	.6500e+00	.3120e-05	.6200e+00	.2260e-05	.9800e-05
r2227	040683	.5000e+00	.2380e-05	.5000e+00	.2390e-05	.5000e+00	.1830e-05	.8100e-05
r2228	041383	.4800e+00	.1900e-05	.4800e+00	.2100e-05	.4800e+00	.1860e-05	.6800e-05