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Geothermal Reservoir Technology Research Program

Chemical Tracer Test at the Dixie Valley Geothermal Field, Nevada

October 1993

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Prepared for:
U.S. Department of Energy
Assistant Secretary for Energy Efficiency
and Renewable Energy
Geothermal Division
Washington, DC 20585

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October 1993

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INTRODUCTION

Operating results from geothermal fields around the world demonstrate that the injection of spent (cooled) geothermal water is necessary to maintain the pressure and productivity of a resource. Experience also indicates that it is essential to locate the water injection so that it enhances the energy production and does not prematurely cool the production wells through cold-water breakthrough. The Geothermal Division of the Department of Energy, as part of the Geothermal Reservoir Technology research program, is involved in research to improve methods for developers to site water injection wells in the most advantageous areas of the resource. Two supportive research efforts are discussed in this report, the development and testing of chemical tracers and the modeling of flow through reservoirs.

Organic-dye tracers have been used for several decades to follow the movement of surface and groundwaters. These tracers have been used with only limited success in geothermal systems, in part because their thermal stability was unknown. Tracer research at the University of Utah Research Institute (UURI) has quantified the rate of thermal decay of the tracer-dye fluorescein (Adams and Davis, 1991) and introduced several new organic tracers (Adams et al., 1986a; 1986b; 1992) with known thermal stability and compatibility with geothermal reservoir conditions. These geothermal tracers combine the advantages that they are compatible with the fluids moving through the geothermal reservoir, they do not occur naturally in the reservoir, they can be easily detected in minute concentrations, and they produce no damaging influence on the environment. Through the development and field testing of chemical tracers, there is the research potential to determine the temporal relationship between the arrival of a chemical tracer at a production well and the later arrival of cold water.

The Lawrence Berkeley Laboratory (LBL) has developed a progression of computer codes to simulate fluid flow in geothermal reservoirs and other subsurface systems. The flow simulator MULKOM (Pruess, 1983) was used to model the fracture-dominated hydrothermal system located in Dixie Valley, in north-central Nevada (Figure 1). The Dixie Valley geothermal field supports a 49.8-MW (net) power plant which began operations in the summer of 1988 using six production wells and four injection wells. Both the field and power plant are operated by Oxbow Geothermal Corporation. The MULKOM simulator (available from LBL) was used by Oxbow to create a numerical reservoir model for the Dixie Valley geothermal system (Oxbow, 1986; 1987; Doughty and Bodvarsson, 1988).

In a cooperative, cost-shared research project, Oxbow and the Department of Energy agreed to support a field test of three new tracer compounds, in combination with fluorescein, to identify possible fluid flow in the reservoir between the injection and production wells. A tracer test at Dixie Valley was jointly conducted by UURI and Oxbow during early 1989. This experiment was designed to test the application of organic tracers, to further refine the predictive capability of the reservoir model, and to improve the effectiveness of Oxbow's injection strategy.

Figure 1. Location map of the Dixie Valley geothermal field showing the locations of the injection (○) and production (●) wells. The arrow indicates the tracer breakthrough path.

In the injection test described in this report, chemical tracers established the fluid flow between one injection well and one production well. This report documents measured tracer concentrations, calculated flow rates, sampling schedules, and the daily events of the tracer test. A preliminary report of this tracer test was presented at the 1989 Annual Meeting of the Geothermal Resources Council (Adams et al., 1989).

TEST DESIGN AND TRACER SELECTION

The primary criteria for choosing tracers for geothermal injection test are: the maximum temperature in the field, the number of injection wells to be individually identified, the dominant pressure conducting medium (liquid- or vapor-dominated), and the analytical equipment available. At Dixie Valley, the maximum temperature in the exploited reservoir was approximately 250°C, four injection wells required individual identification, and the reservoir is liquid-dominated (requiring liquid-phase tracers). The availability of fluorometers and a liquid chromatograph made it possible to choose from 16 organic acids that had been laboratory-tested to 250°C (Adams and Davis, 1991; Adams et al., 1992). Fluid flow from the reservoir through six production wells averaged 592 kg/sec during the test period, and approximately 55 percent of the produced fluid was injected.

The final choice of injection wells and tracers to use for the test was based on cost, which in turn was dictated by estimates of the quantities needed to detect breakthrough in the production fluids. The quantities of tracers needed for the test were estimated in two ways. The first, based on numerical simulations of an injection test, was performed at Lawrence Berkeley Laboratory. In the second method, a simple analytical equation was used to estimate the swept volume of the reservoir between the injection and the production wells (Ramey and Nabor, 1954; Roland Horne, unpublished manuscript). Using the swept volume approach, the minimum tracer quantity required can be calculated from the equation:

$$C_{min} = \frac{V_{inj}}{1.076D^2h\phi}$$

Where:

C_{min} = Tracer Detection Limit (10^3 kg/m^3)

V_{inj} = Tracer Mass (10^3 kg)

D = Distance separating wells (m)

h = Reservoir thickness = $\sum$ producing zones (m)

ϕ = Porosity

In this way, the concentration C_{min} can be the intended concentration rather than the detection limit. The values used for the minimum tracer amount in Dixie Valley calculations were 30 parts per billion (ppb) for fluorescein and 60 ppb for the aromatic acids. The actual detection limits for these compounds are 3 and 10 ppb, respectively. The reservoir thickness,

Table 1. Tracer return curve characteristics predicted by two different methods for each possible well pair. Actual tracer-test data for breakthrough into well 76-7 from injection well 32-18 are shown in bold italics.

Injection Well	Production Well	Peak Conc. (ppb)	Time to Detection (days)	Time to Peak (days)	Tracer Mass (kg) predicted by Numerical Simulation	Tracer Mass (kg) predicted by Swept Volume
65-18	76-7	14800	11	102	382	80
	84-7	12300	15	148	460	115
	74-7	12900	12	125	439	168
	73-7	221	34	171	25600	213
	27-33	-	-	-	-	-
	45-33	-	-	-	-	-
45-5	76-7	-	-	-	-	-
	84-7	5780	49	216	1506	621
	74-7	6780	49	193	1284	784
	73-7	10400	49	273	837	635
	27-33	32200	19	171	270	1315
	45-33	32900	19	159	265	1982
32-18	76-7	69	8	30		100
32-18	76-7	229000	1	11	32	30
	84-7	12300	4	45	602	28
	74-7	1730	9	114	4283	66
	73-7	599	5	57	12370	119
	27-33	-	-	-	-	-
	45-33	-	-	-	-	-
52-18	76-7	26800	3	57	162	129
	84-7	17400	6	91	250	300
	74-7	20900	4	68	208	297
	73-7	209	9	91	20810	425
	27-33	-	-	-	-	-
	45-33	-	-	-	-	-

h, is difficult to realistically quantify in a fracture-dominated system. The technique used was to take an average of the sum of the thicknesses of production and injection zones in the well pairs of interest. This method will generally underestimate the amount of tracer needed to detect breakthrough, and the calculation should include a safety factor of two or three. The porosity is also difficult to quantify, and at Dixie Valley, a porosity of 5 percent was chosen.

These two methods were used to estimate the quantities of tracer required to detect breakthrough. The calculated tracer quantities and some of the characteristics of the return curve predicted by the numerical modeling are listed in Table 1. A comparison of these two methods shows the quantities calculated by the numerical methods are almost always higher than those calculated using the swept-volume method. Decisions regarding the quantity of tracer to inject and the selection of a tracer for each well, were based on a qualitative weighting of the tracer quantities predicted by each method and a consideration of the cost of each tracer. Tracer costs ranged from \$5 to \$35 per kg delivered to the site. It was decided that the amount inserted into each injection well should be sufficient to reach at least one production well, as calculated by both methods. In addition, it was decided that one of the injection wells, 65-18, did not have adequate hydrologic communication with any production wells, and the injection of a tracer was not useful.

The tracers chosen for identifying fluid from the three remaining injection wells were 1) benzoate, 2) benzenesulfonate, and 3) ethyl benzenesulfonate. Despite its relatively high cost, fluorescein was injected along with an aromatic acid in two of the wells because it can be easily and inexpensively analyzed in the field. The least expensive tracer, benzenesulfonate, was reserved for well 45-5 because of the higher quantity estimated for the test. The actual quantities of tracers used in the test are listed in Table 2.

Table 2. Actual test parameters: tracer species and quantities per injection well.

Injection Well	Production Well	Tracers	Quantity (kg)
32-18	76-7	Benzoate Fluorescein	100 150
52-18	None Detected	4-Ethyl benzenesulfonate Fluorescein	300 50
45-5	None Detected	Benzenesulfonate	900

DIXIE VALLEY GEOTHERMAL SYSTEM

The Dixie Valley geothermal system is located along permeable sections of the Stillwater fault zone that bounds Dixie Valley on the west. The geothermal wells produce primarily from the Humbolt ophiolite complex, which is able to sustain large, open fractures

(Waibel, 1987). Production depths in the ophiolite complex range from 2440 to 3050 m, in wells 45-33, 27-33, 73-7, 74-7, and 84-7. Water in the reservoir has an average temperature of 240°C and is a relatively dilute sodium-bicarbonate-chloride type solution thought to be in equilibrium with quartz, calcite, chlorite, and albite (Reed, 1989). Some tracers are unstable under oxidizing conditions, and it is important to note that the Dixie Valley reservoir represents a reduced environment with H_2S , CH_4 , and NH_3 in solution (Reed, 1989).

Wells 76-7 and 32-18, in the southern portion of the field, are completed in a fractured Miocene basalt at depths below 2270 m. Initial temperatures measured in the basalt intervals penetrated by these wells range from 213° to 221°C. Fluid produced from well 76-7 appears to be a mixture of water from the basalt aquifer with water from the hotter, deep reservoir. Measured temperatures in well 76-7 rose from a static temperature of 213°C to a flowing temperature of 239°C during the initial flow tests. Fluid produced by well 32-18 was typical of the lower-temperature, basalt aquifer, and this well was converted for use as an injection well.

Figure 1 shows the wide distribution of injection wells in the Dixie Valley field. Fluid injection is into different reservoir environments, but interference testing of all injection wells demonstrates good pressure communication with the production wells. Wells 52-18 and 65-18 inject fluid into the faulted and fractured ophiolite complex at approximately 2950 m depth. Reservoir analysis indicates that fluid injected into fractured Miocene basalt in well 45-5 at 1830 m is well connected to the permeable range-front fault, while fluid injection into well 32-18 at a depth of 2290 m is more limited by the fractured basalt horizon. Initial temperatures in the injection zones of these wells ranged from 200° to 232°C.

TEST SUMMARY

Different tracers, with measured thermal stabilities and decay rates, were used to uniquely define reservoir paths between injection and production wells and to determine the average temperatures along the flow paths. On January 4, 1989, benzenesulfonic acid was injected into well 45-5; on January 5, fluorescein and benzoic acid were injected into well 32-18; and, on February 3, fluorescein and 4-ethylbenzenesulfonic acid were injected into well 52-18. Tracers were delivered to the site as neutral-pH solutions with concentrations ranging from 10 to 30 weight percent.

Tracers were prepared for injection at each well site by pouring the tracer solutions into tanks containing 47.7 m³ (300 barrels) of hot, flashed geothermal brine. The tracers and brine were inserted as fluid slugs into the injection wells. Oxygen concentrations were monitored during mixing of the solutions because of the sensitivity of the tracers to molecular oxygen at elevated temperatures. Centrifugal pumps were used to inject the solutions into each well. The pumps could not overcome the flowing line pressure, so brine flow was interrupted during tracer injection. Tracer injection occurred under near-vacuum conditions. Tracer injection took approximately one hour, and normal flow of injection fluid was then reestablished.

Automatic samplers were used to monitor tracer return at the six production wells. Battery-powered samplers were built by UURI using commercial microprocessors and automatic valves. The tubing design of these samplers was modified from that of Jackson (1982). Hot brine was allowed to flow through the tubing every few seconds to avoid freezing of the sample lines. The use of automatic samplers allowed the experiment to be conducted by one technician. Samples for later analysis of the benzoic and benzenesulfonic acids were collected in two one-liter, high-density, polyethylene bottles and preserved with 0.5 parts per million (ppm) sodium azide to prevent biodegradation. Samples for analysis of the dye were collected in opaque bottles to avoid degradation by ultraviolet light. A total of 1,300 samples were taken during the test.

A Model 112 Turner digital-filter fluorometer provided frequent monitoring of the test progress through on-site analysis of fluorescein. The instrument was standardized daily, and samples were adjusted to a pH > 9 prior to analysis to stabilize the fluorescence. Detection limits for fluorescein were 3 ppb. Benzoic acid and the benzenesulfonic acids were analyzed by high-pressure liquid chromatography at the UURI laboratory in Salt Lake City, Utah. Detection limits for these compounds are approximately 7 ppb.

Both on-site monitoring and the predicted breakthrough times were used to determine the sampling frequencies. Since tracer return was expected within one day at well 76-7, samples were taken at two-hour intervals to insure detection of breakthrough. Subsequent sampling at well 76-7 was conducted at 4- to 24-hour intervals. Wells 73-7, 74-7, and 84-7 were expected to break through within 3 to 7 days, and were sampled every 6 to 8 hours. Because wells 27-33 and 45-33 were not expected to have tracer returns until the fourth week of the test, they were only sampled once every 12 hours. Sampling followed this schedule from January 4 to March 17, when the plant was shut down for routine maintenance. Samples were collected at least twice a month from all production wells throughout 1989, but no other tracer returns were detected.

MODELING STUDIES

An existing three-dimensional, porous-medium simulation model of the Dixie Valley geothermal field (Oxbow Geothermal Corporation, 1986, 1987) was used for mathematical modeling of the tracer test. This simulation was of enormous help in predicting tracer returns and in determining the quantities of tracer to inject. This mathematical model assumes that fluid flow in the reservoir is primarily through high-permeability channels associated with the northeast-southwest trending range-front fault that bounds Dixie Valley on the west. Integration of geological, geochemical, and seismological data, natural-state modeling of the system, and modeling of two extensive flow tests was used to develop the model. Application of this model is limited by the coarse spatial discretization, which is more appropriate for natural-state, flow-test, and production modeling, but the coarse grid reduces its accuracy for tracer-tests. The modeling results should be viewed as general estimates of future behavior rather than detailed predictions.

A simplified hybrid fractured and porous-medium model was derived from the porous-medium model through the following assumptions; fracture porosity is 1 percent, the volume of all elements was decreased by a factor of 100, total compressibility (rock plus water) was increased by a factor of 100, and rock heat capacity was increased by a factor of 100. This modification allows an approximate calculation of fracture flow, maintaining the appropriate pressure decline and movement of the thermal front. However, it is important to note that the assumption of 1 percent fracture porosity is only a preliminary estimate, which greatly affects the results obtained. Thus, all calculated results should also be considered as preliminary estimates.

To predict the outcome of this tracer test, the combined fractured/porous-medium model was used to simulate a six-month, 60-MW (gross) production period with 61 percent injection. After 31 days of steady-state production, 20 minutes of tracer flow was added to all injection wells. Initial tracer detection occurred in all production wells within 6 months, but well 73-7 had a very low tracer concentration. Wells 76-7, 84-7, and 74-7 had estimated initial tracer detection times of 1, 4, and 6 days after tracer injection, respectively. About 30 days after tracer injection, wells 45-33 and 27-33 show estimated tracer recovery. Well 73-7 had the slowest and lowest concentration for estimated initial tracer detection.

To better study the connectivity between individual injection and production wells, simulations were done in which tracer was injected into only one injection well at a time. These simulations were carried out for a one-year period. The wide range of values of injection mass for each injection well, listed in Table 1, shows that the amount of tracer required for 60 ppb detection depends strongly on which production well is being monitored. For example, the results obtained suggest that for tracer injected into well 45-5 to be detected at wells 84-7, 74-7, and 73-7, about 1500 kg of tracer should be injected. However, the same tracer may be detected in wells 27-33 and 45-33 with only 300 kg of tracer injected. Thus, one must weigh the cost of the tracer versus the number of wells in which it will be detected to obtain the best estimate for the amount of tracer that should be injected.

RESULTS AND DISCUSSION

Results

Intensive sampling continued through March 17, 1989, when the power plant was shut down for maintenance. At that time fluorescein and benzoic acid had been detected in fluid from well 76-7, demonstrating that breakthrough was from well 32-18. Measured concentrations are shown versus time in Figure 2. The maximum measured concentration of both fluorescein and benzoic acid was 69 ppb. The return curves, corrected for thermal decay, are shown in Figure 3. These corrections were made using kinetic data for fluorescein and benzoic acid (Adams and Davis, 1991; Adams et al., 1992). The average temperature of

Figure 2. Measured concentrations of fluorescein and benzoic acid in the production fluid from well 76-7. The tracers were injected at time = 0 hours.

Figure 3. Tracer return concentrations corrected for thermal decay. The average temperature indicated by the tracer ratios was used to correct the measured concentrations of the tracers.

decay used in the correction factor was derived from a comparison of theoretical and actual fluorescein/benzoic acid ratios (Figure 4). This comparison indicates an injection-production flow path temperature of approximately 230°C from the arrival time to the middle of the peak. Ratios in the fluid from the later portion of the test indicated temperatures increasing from 218°C just after the middle of the peak to 232°C at the tail. Breakthrough in 76-7 was detected 224 hours after injection, and the peak occurred approximately 570 hours later.

Comparison of Model Predictions With Field Data

The numerical simulation predicted that the first breakthrough would be from well 32-18 to well 76-7, in agreement with the tracer test results. Because the calculated breakthrough time is very sensitive to both the detection limit assumed and mesh discretization errors, it may be more useful to compare the arrival times of the peak concentration at a production well. For the 32-18 to 76-7 flow path, breakthrough = 800 hours (correcting for fluorescein decay), while the predicted value is 264 hours (~11 days).

Since the arrival of the concentration peaks will depend nearly linearly on fracture porosity, a correction factor of $3.4 = 800/264$ can be used to increase the assumed fracture porosity to 3.4 percent instead of 1 percent. Thus, all predicted values of peak arrival time would be increased by a factor of 3.4. Referring to Table 1, it is clear that for the well pairs for which breakthrough is expected, increasing peak arrival time by a factor of 3.4 would have the arrival of the peak concentration after the end of the tracer test. This seems consistent with the actual tracer test, in which tracer was not observed in any production well other than 76-7. Of course using the multiplier of 3.4, the model predicts breakthrough times that are short enough to have been observed, but this is not consistent with the extended observations of the actual tracer test. This discrepancy produced by the rough approximation of porosity points out the need for a much finer mesh and more sophisticated treatment of interactions between fractured and porous-medium models for accurate predictions of tracer tests.

Estimation of Flow Path Velocities and Temperatures

The results of the tracer test were used to calculate minimum velocities along the injection-production flow path. Velocities for the most direct path of the tracer slug were calculated using the time of breakthrough (Figure 3) and the distance between wells 32-18 and 76-7 of 1128 m. The minimum velocity for the tracer front was 5.0 m/hr and for the peak, 1.4 m/hr. Because both wells are completed in basalt at similar depths, the most probable path for the injected fluid was through the basalt aquifer.

Tracer ratios combined with kinetic data for thermal decay of the tracers can also be used to bracket the temperatures along the postulated injection-production flow path in the basalt. Calculations to match the tracer ratios measured in the production fluid of well 76-7 were performed by varying times and temperatures along the hypothetical flow-path. The models assumed that the initial temperature was the injection temperature, and that the final

Figure 4. Actual tracer ratios in produced fluid from well 76-7 compared to ratios calculated for three constant temperatures along the injection-production flow path.

temperature was the production temperature of well 76-7. Although the temperature distributions inferred from the model are not unique, they clearly indicate that the injected tracers would have had to spend at least 50 percent of the time at a temperature greater than or equal to 225°C. This temperature is higher than the pre-exploitation temperatures in the basalt, which ranged from 213° and 221°C in wells 32-18 and 76-7, respectively. However, there is evidence that well 76-7 produces fluid from the high-temperature reservoir through the fractured basalt as well as from the basalt aquifer. Thus, the difference between the calculated injection flow path temperatures and the pre-exploitation temperatures may imply that the basalt aquifer has heated up during exploitation due to movement of deeper reservoir fluid through the basalt.

CONCLUSIONS

Newly developed organic tracers and numerical reservoir modeling have been used in concert to design and test the existing injection strategies used in the Dixie Valley geothermal field. Connections between three injection and six production wells were tested using three sets of tracers. Several tracers were used in this test to uniquely identify connections between individual injection and production wells.

A numerical reservoir model was used in the design phase of the tracer test to predict which wells were likely to show breakthrough, and to calculate the mass of tracer required. This model predicted that the first breakthrough would be from injection well 32-18 to production well 76-7, which is in agreement with the test results. Actual arrival times were 3.4 times longer than those calculated from the model, possibly reflecting a low estimate of fracture porosity.

Benzoic acid and fluorescein were detected in the production fluid from well 76-7, demonstrating that breakthrough was from injection well 32-18. Concentrations of the tracers in the production fluid ranged from a few ppb to 69 ppb. Excellent resolution of the tracer return curve was obtained throughout the length of the test. The measured ratios of fluorescein to benzoic acid in the production fluid changed during the length of the test due to thermal decay. The rate of change that was measured agrees well with that predicted from experimental data on tracer stabilities and with temperatures measured in the Dixie Valley field.

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APPENDIX A

Daily log of the Dixie Valley tracer test.

The following is a chronological list of activities, problems, and solutions that occurred during the Dixie Valley tracer test. The log starts just prior to the first injection (1/4/89) and extends throughout the duration of the on-site sampling and analysis (3/5/89). All analyses discussed in the log are post-flash (steam fraction = 0.14).

12/31/88 Activities

Twenty-six barrels of tracers in liquid solution arrived in a tractor trailer at Dixie Valley. The trailer came equipped with a catalytic propane heater. The driver demonstrated the use of the heater and left it running. The trailer was positioned at well 32-18 and the driver left with the cab. The automatic samplers were kept running to avoid freezing and to evaluate their performance. Daily maintenance of the automatic samplers was performed. The routine maintenance, performed each day throughout the test, consisted of cleaning the in-line sample filters, checking the sample times, measuring the voltage of the batteries, examining the fluid level of the cooling barrels, and checking the lines for clogs or freezing.

Problems and Solutions

As soon as the driver of the truck that delivered the tracers left the site, the heater in the trailer containing the tracer solutions went out and subsequent attempts to keep it running failed. We went to Battle Mountain to fill the propane bottles for the trailer heater, in case the heater had run out of propane. The heater still would not function, so the pilot light was wired on to provide some heat to the trailer. Electric heaters could not be used because there was no electricity at the site, and no portable generator of sufficient wattage was available.

01/1/89 Activities

Routine maintenance was performed on the automatic samplers and their performance was monitored.

Problems and Solutions

The automatic samplers were reinitializing the sampling times whenever alterations were made to the sampling schedule and when the power was turned off while changing the batteries. Also, the ambient temperature was dropping and the lines were beginning to freeze. The program stored in the automatic samplers was changed to avoid resetting the sampling times when the units were turned off. The "antifreeze" flow cycle of the automatic samplers was adjusted to compensate for colder temperatures by flowing hot geothermal water from the sample port for 5 seconds out of every 15 seconds.

1/2/89 Activities

Routine maintenance was performed on the automatic samplers and their performance was monitored. Bottles, labels, and preservative solutions of 200 ppm sodium azide were prepared for the first tracer injection. Final background samples were taken and background

fluorescence was analyzed.

1/3/89 Activities

The tanks and associated hoses, clamps, and pumps were set up at well 45-5. The injection well was taken off line and a pressure-measuring device inserted into the well on a wireline. Pressure was measured until the next morning. Routine maintenance was performed on the automatic samplers and their performance was monitored. The sampling times were set for each well. We decided that wiring the pilot light of the trailer heater on was too dangerous and it was turned off. The heat output from this method was minimal anyway.

1/4/89 Activities

Injection day for well 45-5. Twelve barrels of 30 percent benzenesulfonic acid (neutralized) were transported on a flatbed truck to well 45-5. The wireline pressure-monitoring device was withdrawn from the well. The pressure-monitoring device was inserted into well 32-18 to evaluate the pressure drop in that well prior to injection. The wellhead valve was closed and the line pressurized. The tank was filled with 300 barrels of geothermal fluid. The fluid flashed at atmospheric pressure. Safety equipment was put on and UURI personnel (Mike Adams and John Christensen) mounted the tank. The barrels, which weighed about 600 pounds each, were lifted to the top of the tank by a boom truck.

The tracer solution was then recirculated for 30 min. We discovered that little recirculation had been accomplished because the valves on the tank were clogged. At this point, it was late in the day and we decided not to recirculate, but to take the fluid from a valve at the lowest point of the tank and continue with the injection. This was accomplished by turning off the brine injection line and opening the wellhead valve, which provided a negative pressure in the injection line, and pumping the contents of the tank into the well. The tracer injection began at 15:45 and was finished at 16:10. Flow in the brine injection line was reestablished at 16:36. At 16:00, all of the plant personnel went home so UURI and Oxbow personnel disconnected the hoses and drained them. The sample bottles for the actual test were then put in place in the automatic samplers and the timing mechanisms reset.

Problems and Solutions

During tracer injection, it was discovered that about half of each barrel was frozen solid, that the pump would not start, and that the valves connected to the pump were clogged. The liquid from each barrel was poured off, the tops were taken off, and the frozen solution was pounded with a piece of drill pipe while the outside of the barrel was heated with large propane blowers. The resulting tracer slurry was then poured into the tank. A small electric generator and heater were found and placed in the trailer to try and thaw the remaining barrels. The pump was jump-started by the forklift, and the inlet to the pump was reconnected to an unplugged valve under the axle of the tank.

1/5/89 Activities

Injection day for well 32-18. By 10:00 the pump, hoses, and clamps were transported to

the injection site at well 32-18, and the pressure device had been removed from the well and pressure restored to the line. The tank was filled with 320 barrels of geothermal brine. The barrels of tracer were hoisted to the top of the tank, and the same procedure was followed as the day before. Two barrels of benzoic acid and eight barrels of fluorescein were poured into the tank. The brine injection line was closed to provide negative pressure to the pump, and the tracer fluid pumped into the well. The tracer injection began at 15:58 and continued to 16:30. Flow was restored to the brine injection line at 17:15. The hoses were disconnected and drained. Routine maintenance was performed on the automatic samplers and their performance was monitored. The sample bottles were collected and new bottles set out.

It was originally planned to inject only 2.5 barrels of fluorescein into well 32-18. We decided to inject eight barrels because well 32-18 was the most likely to break through to the producing wells and because the availability of chemicals for the last injection (into well 52-18) was in doubt.

Problems and Solutions

At 05:00 it was decided that the Oxbow heater in the trailer was not going to heat up the barrels because of insufficient wattage. As the apparatus for the test was set up, it was discovered that one hose had been ripped and that three clamps did not fit the new injection well fittings. At this point a blizzard hit, with high winds and snowfall. The barrels were still frozen, and the connections on the pump leaked.

UURI personnel set up large propane torches in the trailer. This provided substantial heat to the trailer, but had to be watched continually because of the fire danger. After several hours of heating the trailer, the barrels were turned upside down to heat the frozen bottoms. In order to perform the injection of the tracers, one clamp was ground down to accommodate the configuration of the injection well fitting, one was manufactured, and a pipe chain was used to clamp the final fitting to the pump. No solution to the blizzard was found. The freezing of the barrels was not as severe as the day before, thanks to the propane blowers, so the barrels could be cut open and immediately poured into the tank. It was decided not to recirculate the tanks because the pump was leaking at several connections and tracer would have been lost to the surface.

1/6/89 Activities

Mike Adams left Dixie Valley to return to UURI. John Christensen remained at Dixie Valley to collect samples, analyze the samples for fluorescein, and keep the automatic samplers running.

1/8/89 Activities

Well 27-33 was taken off line because the workover rig had to ream out the scale inhibitor cap tubing that had parted and dropped down the well. The workover of 73-7 was completed and our sampler was connected to the well.

1/9/89 Activities
Continued Sampling.

Problems and Solutions

We discovered that car batteries for the automatic samplers must be charged to 12.0 volts or above or communication errors will occur within the microprocessor. Two valves failed on the automatic samplers due to a silica buildup. The valves were cleaned and restored to the samplers. The batteries were charged.

1/11/89 Activities
Continued Sampling.

Problems and Solutions

Several of the valves jammed. We attribute this to silica deposition, although the "particles" are too small to be seen. Cleaning the valves has thus far been sufficient to restore function.

1/12/89 Activities

Temperatures dropped and one automatic sampler froze up. Function was restored and no samples were lost. Aldrich chemical requested that they be able to lower the concentration of the next tracer (4-ethylbenzenesulfonate) to be injected from 40 percent to 25 percent. We agreed to this change. Estimated shipping date for this tracer is January 18. A tentative injection date has been set for Jan. 30.

1/13/89 Activities

Continued sampling. We have received permission from Oxbow to store the barrels of tracer intended for injection into well 52-18 in the heated maintenance shed. The fluorescein concentrations in fluid from well 76-7 are now at twice the background level, which is 0.8 ppb for this well.

Problems and Solution

Some diodes on the automatic samplers have broken and fuses have blown from the silica scale jamming the valves. Mike Adams will bring spare parts out to Dixie Valley on 1/16/89. Oxbow has reported that the rate of injection is 3900 gpm rather than the 6000 gpm used for the injection breakthrough calculations.

1/14/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 2.8 ppb.

Problems and solutions

An inexpensive tool used to disassemble the automatic valves broke. Replacements have been purchased and will be brought to Dixie Valley by Mike Adams. The valves are now being cleaned with a dilute solution of hydrofluoric acid because of the silica buildup.

1/15/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 5.0 ppb.

Problems and Solutions

The water level in the 55 gallon drums that hold the cooling coils of the sampling line has dropped to a point where we risk overheating the valves on the automatic samplers. To avoid transporting water in buckets to fill the barrels, float valves used for swamp coolers were obtained from the hardware store in Fallon and adapted to automatically fill the drums from the sample line when the fluid level gets low.

1/16/89 Activities

Continued sampling. Mike Adams traveled to Dixie Valley to retrieve samples and bring supplies. The fluorescein concentrations in fluid from well 76-7 have reached 8.1 ppb.

1/17/89 Activities

Continued sampling. The drilling camp that we were staying in was closed. We will now stay in the plant operators' trailer. The fluorescein concentrations in fluid from well 76-7 have reached 14.1 ppb.

Problems and Solutions

Several diodes were found to have broken on the automatic samplers, and were replaced. They were connected to inactive valves, so no samples were lost.

1/18/89 Activities

Continued sampling. Mike Adams returned to Salt Lake City with 1300 lbs of samples. The fluorescein concentrations in fluid from well 76-7 have reached 21.1 ppb.

1/19/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 29.5 ppb.

1/20/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 37.3 ppb.

1/21/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 46.7 ppb.

1/22/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 51.4 ppb.

1/23/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 55.7 ppb.

1/24/89 Activities

Continued sampling. Chemicals for the next injection (well 52-18) were shipped from the supplier.

Problems and Solutions

The automatic sampler on well 76-7 froze up and several valves had to be rebuilt. One day of samples lost. The antifreeze cycle was changed to 15 seconds on, 60 seconds off.

1/25/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 67.9 ppb.

1/26/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 69.9 ppb. The concentration versus time curve appears to be leveling off.

1/27/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 72.6. The automatic sampler at well 76-7 froze up. No samples were lost.

1/28/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have

reached 73.9.

1/29/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 74.3.

1/30/89 Activities

Continued sampling. The fluorescein concentrations in fluid from well 76-7 have reached 75.8.

1/31/89 Activities

Continued sampling. The fluorescein concentration in fluid from well 76-7 at the end of this day was 75.6.

2/1/89 Activities

Continued sampling. The fluorescein concentration in fluid from well 76-7 at the end of this day was 77.6. Mike Adams arrived for the injection planned for well 52-18.

2/2/89 Activities

Continued sampling. The fluorescein concentration in fluid from well 76-7 at the end of this day was 76.4. The weather was good, so the tracers did not arrive in time to be injected.

2/3/89 Activities

Injection into well 52-18. Temperatures dropped below zero and visibility was reduced by snowfall. Three hundred kg of 4-ethylbenzenesulfonate and 51.5 kg of fluorescein were injected with 300 barrels of geothermal fluid. The tracers were in the well by 11:00 and the injection flow from the plant was resumed by 12:00. Continued sampling. The fluorescein concentration in fluid from well 76-7 at the end of this day was 75.6.

2/4/89 Activities

Continued sampling. The fluorescein concentration in fluid from well 76-7 at the end of this day dipped to 42.3. Several standards were run with these samples, so the low concentration does not appear to be an analytic problem.

2/5/89 Activities

Continued sampling. The fluorescein concentration at the end of the day was 72.9.

2/6/89 Activities

Continued sampling. No fluorescein analysis done on this date. During the night the temperature dropped to -27°F in the nearby town of Fallon.

2/7/89 Activities

Continued sampling wells 27-33, 45-33, and 73-7 with the automatic samplers.

Problems and solutions

The automatic samplers on wells 76-7, 74-7, and 84-7 were frozen during the night. Two samples were taken by hand from well 76-7 while the samplers were unfrozen and the valves replaced or rebuilt. The power plant tripped (shut down automatically) during the day for reasons unknown. During the time that the plant was down, the fluid from well 76-7 was sent to the pit. Our samples from this well during this time may be from a stagnant pipe. Pit times will be checked and correlated with sample times to determine the samples validity.

2/8/89 Activities

Continued sampling.

Problems and solutions

The automatic sampler valves on well 76-7 continued to leak despite the standard reconditioning with HF cleaning solution. The valves involved in active sampling were replaced, and the valves not used were capped off. A buildup of black material in addition to silica was noted in the valves for the first time. The identity of this substance is not known. The plant tripped twice during the day. The reasons for the magical mystery trips are unknown.

2/9/89 Activities

Continued sampling. No analyses were conducted on this day due to time being devoted to valve rebuilding.

Problems and solutions

Many of the valves are still leaking or jamming. To prevent further degradation of valves not actively involved in sampling, the inactive valves were either capped off or removed from the fluid flow. These inactive valves will be used as backups for the active valves. Hand samples are being obtained while the automatic valves are not functioning.

2/10/89 Activities

Continued sampling. No analyses were conducted on this day due to time being devoted to valve rebuilding.

2/11/89 Activities

Continued sampling. No analyses were conducted on this day due to time being devoted to valve rebuilding.

2/12/89 Activities

Continued sampling. All of the samplers are working. Analyses of the past few days samples were performed. The fluorescein concentration at 05:30 was 69.9 ppm. This does not imply that we are past the peak because fluorescein decay in the reservoir has lowered the dye concentration. Calculations using the kinetic parameters from our experiments and assuming an average temperature of 240°C indicate that the curve is still slowly rising or is flat.

2/13/89 Activities

Continued sampling. All samplers are working.

2/14/89 Activities

Continued sampling. All samplers are working. The fluorescein concentration from well 76-7 at the end of the day was 59.5.

Problems and Solutions

A sample was lost at 13:30 due to maintenance on one of Oxbow's inline pumps. The plant tripped due to electrical problems. The wells will continue to produce during the down time but the flow into the injection wells will be cut in half. The scale inhibitor tubing in wells 84-7 and 74-7 parted.

2/15/89 Activities

Continued sampling. The fluorescein concentration in fluid from well 76-7 at the end of the day was 60.5.

Problems and Solutions

Well 74-7 was shut in. A workover rig will remove the parted cap tubing. This will take about a week. The plant is still shut down.

2/16/89 Activities

Continued sampling. The fluorescein concentration from well 76-7 at 05:30 was 59.9. Kinetic analysis of the data indicates that we may be past the peak of the return curve.

2/17/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 58.2 ppb.

2/18/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 52.9 ppb.

2/19/89 Activities

Continued sampling. The workover rig is now on well 74-7. The fluorescein concentration in well 76-7 fluid at the end of the day was 49.7 ppb.

2/20/89 Activities

Continued sampling. 74-7 is back on line, the workover rig moved to well 84-7. The fluorescein concentration in well 76-7 fluid at the end of the day was 47.5.

2/21/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 49.8 ppb.

2/22/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 45.7 ppb.

2/23/89 Activities

Continued sampling. Well 84-7 is back on line. The fluorescein concentration in well 76-7 fluid at the end of the day was 42.1 ppb.

2/24/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 40.3 ppb.

2/25/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 38.3.

2/26/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 37.2.

2/27/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at the end of the day was 36.0.

2/28/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at 05:30 was 34.3.

Problems and Solutions

Several samples were not taken due to a malfunction in the microprocessor. The problem was corrected using software manipulation.

3/1/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at 13:30 was 34.3.

3/2/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at 13:30 was 34.2.

3/3/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at 13:30 was 32.3.

3/4/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at 13:30 was 32.6.

3/5/89 Activities

Continued sampling. The fluorescein concentration in well 76-7 fluid at 13:30 was 30.1.

APPENDIX B

Tracer concentrations and sampling schedule for well 76-7.

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
17	05-Jan-89	18:30	1.2	0.4	0.4
23	06-Jan-89	06:30	1.4		
29	06-Jan-89	18:30	1.2		
35	07-Jan-89	06:30	1.2		
42	07-Jan-89	19:19	0.8		
47	08-Jan-89	05:19		0.3	6.7
48	08-Jan-89	07:19	1.4		
54	08-Jan-89	19:19	0.9		
60	09-Jan-89	07:19	1.2		
66	09-Jan-89	19:19	1.0		
72	10-Jan-89	07:19	0.5		
78	10-Jan-89	19:19	0.7		
83	11-Jan-89	05:19			6.5
84	11-Jan-89	07:19	0.8		
90	11-Jan-89	19:25	1.0		
96	12-Jan-89	07:25	0.6	0.3	
97	12-Jan-89	09:25		0.4	6.4
98	13-Jan-89	11:40	1.2	0.4	
99	13-Jan-89	13:30	1.6	0.6	
100	13-Jan-89	17:30	1.7	0.7	
101	13-Jan-89	21:30	1.6	0.7	
102	14-Jan-89	01:30	1.6	0.8	9.2
103	14-Jan-89	05:30	2.0	1.0	
104	14-Jan-89	09:30	2.1	0.9	
105	14-Jan-89	13:30	2.3	1.1	

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
106	14-Jan-89	17:30	2.7	1.3	
107	14-Jan-89	21:30	2.8	1.6	7.9
108	15-Jan-89	01:30	3.3	1.8	
109	15-Jan-89	05:30	3.5	2.0	
110	15-Jan-89	09:30	4.1	2.4	
111	15-Jan-89	13:30	4.3	2.8	
112	15-Jan-89	17:30	4.9	3.4	12.1
113	15-Jan-89	21:30	5.0	3.8	
114	16-Jan-89	01:30	5.3	4.2	
115	16-Jan-89	05:30	5.9	4.8	
116	16-Jan-89	09:30	6.2	5.3	
117	16-Jan-89	13:30	6.9	6.0	11.2
118	16-Jan-89	17:30	7.5	6.7	
119	16-Jan-89	19:30	7.1	7.1	
120	16-Jan-89	21:30	7.8	7.7	
121	16-Jan-89	23:30	8.1	8.1	
122	17-Jan-89	01:30	8.5	8.5	15.5
123	17-Jan-89	03:30	9.2	8.9	
124	17-Jan-89	05:30	9.5	9.2	
125	17-Jan-89	07:30	9.7	9.9	
126	17-Jan-89	09:30	10.5	10.2	
127	17-Jan-89	11:30	10.8	10.7	15.0
128	17-Jan-89	13:30	11.8	11.3	
129	17-Jan-89	15:30	12.8	12.5	
130	17-Jan-89	17:30	12.4	12.5	
131	17-Jan-89	19:30	12.4	12.1	
132	17-Jan-89	21:30	13.6	12.6	18.1
133	17-Jan-89	23:30	14.1	13.0	

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
134	18-Jan-89	01:30	14.7	13.3	
135	18-Jan-89	03:30	14.8	13.7	
136	18-Jan-89	05:30	15.5		15.4
137	18-Jan-89	07:30	16.5	16.3	
138	18-Jan-89	09:30	16.9		
139	18-Jan-89	11:30	17.1		
140	18-Jan-89	13:30	18.0		
141	18-Jan-89	15:30	20.2	20.2	
142	18-Jan-89	17:30	19.5		
143	18-Jan-89	19:30	19.2		23.7
144	18-Jan-89	21:30	20.6		
145	18-Jan-89	23:30	21.1	21.1	
146	19-Jan-89	01:30	22.0		
147	19-Jan-89	03:30	22.3		
148	19-Jan-89	05:30	23.1		
149	19-Jan-89	07:30	23.8	23.7	
150	19-Jan-89	09:30	24.8		
151	19-Jan-89	11:30	25.6		
152	19-Jan-89	13:30	26.8		
153	19-Jan-89	15:30	27.6	27.0	29.2
154	19-Jan-89	17:30	27.5		
155	19-Jan-89	19:30	28.5		
156	19-Jan-89	21:30	29.4		
157	19-Jan-89	23:30	29.5	28.3	
158	20-Jan-89	01:30	30.5		
159	20-Jan-89	03:30	31.3		
160	20-Jan-89	05:30	31.9		
161	20-Jan-89	07:30	32.7	31.1	32.8

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
162	20-Jan-89	09:30	32.7		
163	20-Jan-89	11:30	33.4		
164	20-Jan-89	13:30	34.0		
165	20-Jan-89	15:30	35.4	35.6	
166	20-Jan-89	17:30	35.7		
167	20-Jan-89	19:30	36.0		35.6
168	20-Jan-89	21:30	36.5		
169	20-Jan-89	23:30	37.3	37.4	
170	21-Jan-89	01:30	37.6		
171	21-Jan-89	03:30	38.6		
172	21-Jan-89	05:30	39.1		
173	21-Jan-89	07:30	41.1	41.3	
174	21-Jan-89	09:30	42.4		
175	21-Jan-89	13:30	44.4		36.5
176	21-Jan-89	17:30	45.2		
177	21-Jan-89	21:30	46.7	43.8	
178	22-Jan-89	01:30	47.9		
179	22-Jan-89	05:30	49.3		
181	22-Jan-89	13:30	49.0	48.3	45.8
182	22-Jan-89	17:30	50.2		
183	22-Jan-89	21:30	51.4		
184	23-Jan-89	01:30	52.1		
185	23-Jan-89	05:30	53.6	52.1	
186	23-Jan-89	09:30	53.0		
187	23-Jan-89	13:30	53.5		
188	23-Jan-89	17:30	54.7		
189	23-Jan-89	21:30	55.7	55.3	53.0
190	24-Jan-89	01:30	57.8		

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
191	24-Jan-89	05:30	57.7		
192	24-Jan-89	09:30	58.4		
198	25-Jan-89	11:45	66.6		
193	25-Jan-89	15:45	66.4	64.4	
194	25-Jan-89	19:45	67.4		
195	25-Jan-89	23:45	67.9		62.4
196	26-Jan-89	03:45	68.1		
197	26-Jan-89	07:45	69.2	66.5	
199	26-Jan-89	09:30	69.0		
200	26-Jan-89	13:30	69.3		
201	26-Jan-89	17:30	70.1	68.5	
202	26-Jan-89	21:30	69.9		
203	27-Jan-89	01:30	70.0		65.2
204	27-Jan-89	05:30	70.2		
205	27-Jan-89	09:30	70.2	69.2	
206	27-Jan-89	13:30	72.0		
207	27-Jan-89	17:30	72.5		
208	27-Jan-89	21:30	72.6		
209	28-Jan-89	01:30	72.8	70.9	67.7
210	28-Jan-89	05:30	73.5		
211	28-Jan-89	09:30	72.1		
212	28-Jan-89	13:30	72.9		
213	28-Jan-89	17:30	73.1	74.1	
214	28-Jan-89	21:30	73.9		
215	29-Jan-89	01:30	73.7		74.2
216	29-Jan-89	05:30	73.6		
217	29-Jan-89	09:30	74.0	74.5	
218	29-Jan-89	13:30	73.9		

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
219	29-Jan-89	17:30	73.6		
220	29-Jan-89	21:30	74.3		
221	30-Jan-89	01:30	74.5	75.0	
222	30-Jan-89	05:30	74.5		
223	30-Jan-89	09:30	73.8		
224	30-Jan-89	13:30	75.2		
225	30-Jan-89	17:30	75.7		69.6
226	30-Jan-89	21:30	75.8		
227	31-Jan-89	01:30	75.5	76.4	
228	31-Jan-89	05:30	75.5		
229	31-Jan-89	09:30	75.5		
230	31-Jan-89	13:30	76.5		
231	31-Jan-89	17:30	75.6	77.1	
232	31-Jan-89	21:30	75.6		
233	01-Feb-89	01:30	76.0		72.7
234	01-Feb-89	05:30	74.9		
235	01-Feb-89	09:30	75.5	76.1	
236	01-Feb-89	13:30	76.5		
237	01-Feb-89	17:30	77.9		
238	01-Feb-89	21:30	77.6		
239	02-Feb-89	01:30	77.1	75.2	
240	02-Feb-89	05:30	76.0		
241	02-Feb-89	09:30	76.6		
242	02-Feb-89	13:30	76.4		
243	02-Feb-89	17:30	76.4	77.2	73.1
244	02-Feb-89	21:30	76.4		
245	03-Feb-89	01:30	76.2		
246	03-Feb-89	05:30	75.9		

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
247	03-Feb-89	09:30	74.8	77.0	
248	03-Feb-89	13:30	75.1		
249	03-Feb-89	17:30	77.4		
250	03-Feb-89	21:30	75.2		
251	04-Feb-89	01:30	74.9	76.0	
252	04-Feb-89	05:30	75.0		
253	04-Feb-89	09:30	75.0		
255	04-Feb-89	17:30	47.9	74.5	75.2
256	04-Feb-89	21:30	42.3	75.7	
257	05-Feb-89	01:30	56.3	75.1	
258	05-Feb-89	05:30	72.8		
259	05-Feb-89	09:30	68.7	74.2	
260	05-Feb-89	13:30	69.5		
261	05-Feb-89	17:30	73.6		
262	05-Feb-89	21:30	72.9	73.5	
263	06-Feb-89	01:30	72.5		
264	06-Feb-89	05:30	71.6	73.8	78.8
271	07-Feb-89	13:00	75.5	71.8	
272	07-Feb-89	18:00	74.7		
273	07-Feb-89	21:30	75.7		
275	08-Feb-89	05:30	76.3	79.2	67.9
276	08-Feb-89	09:30	76.0		
277	08-Feb-89	09:30	77.0		
279	08-Feb-89	17:30	75.3	73.8	76.6
280	08-Feb-89	21:30	74.6		
281	09-Feb-89	01:30	74.9		
282	09-Feb-89	05:30	55.5		
284	09-Feb-89	09:30	73.0	70.9	

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
285	09-Feb-89	13:00	73.9		
286	09-Feb-89	17:30	72.5		
287	09-Feb-89	21:30	71.8		
288	10-Feb-89	01:30	70.8	71.8	64.1
290	10-Feb-89	09:45	70.1		
291	10-Feb-89	14:24	69.9	71.3	68.7
296	11-Feb-89	11:00	65.5	67.6	64.1
297	11-Feb-89	13:30	67.5		
298	11-Feb-89	17:30	67.5		
299	11-Feb-89	21:30	67.2		
300	12-Feb-89	01:30	66.8	68.4	67.1
301	12-Feb-89	05:30	66.9		
302	12-Feb-89	09:30	64.8		
303	12-Feb-89	13:30	66.2		
304	12-Feb-89	17:30	65.6	67.9	67.9
305	12-Feb-89	21:30	65.6		
306	13-Feb-89	01:30	65.0		
307	13-Feb-89	05:30	64.7		
308	13-Feb-89	09:30	63.2	63.3	63.0
309	13-Feb-89	13:30	64.0		
310	13-Feb-89	17:30	63.3		
311	13-Feb-89	21:30	62.8		
312	14-Feb-89	01:30	62.1	63.4	64.8
313	14-Feb-89	05:30	61.7		
314	14-Feb-89	09:30	56.6		
316	14-Feb-89	17:30	59.9	63.4	63.2
317	14-Feb-89	21:30	59.5		
318	15-Feb-89	01:30	58.5		

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
319	15-Feb-89	05:30	57.8		59.5
320	15-Feb-89	09:30	62.5	66.7	29.7
321	15-Feb-89	13:30	58.7		58.7
322	15-Feb-89	17:30	60.9		
323	15-Feb-89	21:30	60.5		
324	16-Feb-89	01:30	59.9	62.0	66.1
325	16-Feb-89	05:30	59.9		
326	16-Feb-89	09:30	61.2		
327	16-Feb-89	13:30	61.8		
328	16-Feb-89	17:30	61.1	60.6	63.7
329	16-Feb-89	21:30	61.1		
330	17-Feb-89	01:30	60.4		
331	17-Feb-89	05:30	59.8		
332	17-Feb-89	09:30	59.8	59.5	64.7
333	17-Feb-89	13:30	60.1		
334	17-Feb-89	17:30	59.0		
335	17-Feb-89	21:30	58.2		
336	18-Feb-89	01:30	58.0	58.1	60.8
337	18-Feb-89	05:30	57.8		
338	18-Feb-89	09:30	55.4		
339	18-Feb-89	13:30	54.5		
340	18-Feb-89	17:30	53.7	55.1	60.8
341	18-Feb-89	21:30	52.9		
342	19-Feb-89	01:30	52.5		
343	19-Feb-89	05:30	51.5		
344	19-Feb-89	09:30	51.0	50.8	53.0
345	19-Feb-89	13:30	50.5		
346	19-Feb-89	17:30	49.6		

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
347	19-Feb-89	21:30	49.7		
348	20-Feb-89	01:30	49.6	51.4	53.0
349	20-Feb-89	05:30	49.1		
350	20-Feb-89	09:30	50.1		
351	20-Feb-89	13:30	48.3		
352	20-Feb-89	17:30	47.8	49.8	51.0
353	20-Feb-89	21:30	47.5		
354	21-Feb-89	01:30	46.8		
355	21-Feb-89	05:30	45.8		
356	21-Feb-89	09:30		47.8	53.5
357	21-Feb-89	13:30	50.6		
359	21-Feb-89	21:30	49.8		
360	22-Feb-89	01:30		46.5	49.7
361	22-Feb-89	05:30	49.3		
363	22-Feb-89	13:30	47.3		
364	22-Feb-89	17:30		45.3	49.2
365	22-Feb-89	21:30	45.7		
367	23-Feb-89	05:30	45.6		
368	23-Feb-89	09:30		44.0	51.7
369	23-Feb-89	13:30	42.6		
371	23-Feb-89	21:30	42.1		
372	24-Feb-89	01:30		41.3	48.7
373	24-Feb-89	05:30	41.0		
375	24-Feb-89	13:30	40.7		
376	24-Feb-89	17:30		41.1	50.2
377	24-Feb-89	21:30	40.3		
379	25-Feb-89	05:30	39.7		
380	25-Feb-89	09:30		40.7	48.4

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
381	25-Feb-89	13:30	39.1		
383	25-Feb-89	21:30	38.3		
384	26-Feb-89	01:30		39.0	49.3
385	26-Feb-89	05:30	37.8		
387	26-Feb-89	13:30	38.2		
388	26-Feb-89	17:30		38.5	48.0
389	26-Feb-89	21:30	37.2		
391	27-Feb-89	05:30	37.1		
392	27-Feb-89	09:30		37.0	42.2
393	27-Feb-89	13:30	36.3		
395	27-Feb-89	21:30	36.0		
396	28-Feb-89	01:30		35.9	45.7
397	28-Feb-89	05:30	35.3	35.7	48.2
404	01-Mar-89	09:30		34.1	41.5
405	01-Mar-89	13:30	34.3		
408	02-Mar-89	01:30	34.2	35.4	45.0
412	02-Mar-89	17:30		34.4	43.1
414	03-Mar-89	01:30	32.3		
416	03-Mar-89	09:30		35.4	43.6
420	04-Mar-89	01:30	32.6	34.6	42.9
424	05-Mar-89	01:30	30.1	32.6	42.8
427	06-Mar-89	01:30	29.5		
428	06-Mar-89	09:30		30.5	40.7
430	07-Mar-89	01:30	28.9		
432	07-Mar-89	17:30		29.2	41.6
433	08-Mar-89	01:30	28.0		
436	09-Mar-89	01:30	26.6	28.3	41.6
439	10-Mar-89	01:30	26.2		

Sample	Date	Time	Fluorescein		Benzoate
			Field Analysis (ppb)	Laboratory Analysis (ppb)	Laboratory Analysis (ppb)
440	10-Mar-89	09:30		26.7	40.1
442	11-Mar-89	01:30	24.9		
444	11-Mar-89	17:30		25.2	39.2
445	12-Mar-89	01:30	24.4		
448	13-Mar-89	01:30	23.4	24.0	39.7
451	14-Mar-89	01:30	22.8		
452	14-Mar-89	09:30	22.7	23.1	37.0
456	15-Mar-89	17:30		23.1	35.4
460	17-Mar-89	01:30		22.6	36.3
462	17-Mar-89	10:30			34.7
464	03-Apr-89	17:40		17.4	
465	04-Apr-89	13:09		16.3	33.0
466	11-Apr-89	10:18		11.8	31.0
467	12-Apr-89	11:40		11.2	31.7
468	25-Apr-89	09:28		10.1	27.2
469	01-May-89	10:15		10.2	29.7