

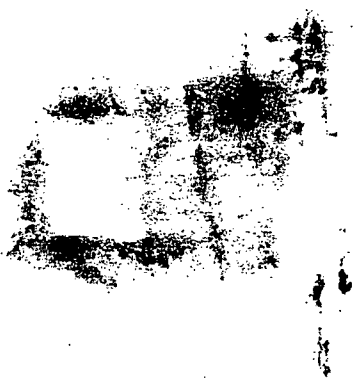
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Appendix H

PARTICLE METER TESTING
(Battelle Pacific Northwest Laboratories)

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Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509) 376-3139
Telex 15-2874

August 18, 1988

Mr. Chuck Snyder
Bechtel Corporation
P.O. Box 3965
San Francisco, California 94119

Dear Chuck:

SALTON SEA SCIENTIFIC DRILLING PROJECT JUNE FLOW TEST -
SUMMARY OF PACIFIC NORTHWEST LABORATORY (PNL) PARTICLE METER TESTING

As you requested, I have prepared a short summary description of our field test work during the June flow test. We have completed part of the data analysis, but a detailed report will not be done until next fiscal year after we are able to finish the particle analyses. The PNL field team was Bob Sullivan (mechanical equipment), Bob Robertus (solids identification), and Cecil Kindle (particle meter).

TEST OBJECTIVES

The objectives of the Pacific Northwest Laboratory field test were:

- Establish the suspended solids content of the brine from the bottom of the separator immediately after flashing and after a 2-hour hold time.
- Characterize the chemical and size characteristics of the suspended solids.
- Evaluate an on-line computerized ultrasonic particle counter in a high-solids brine.
- Evaluate the effects of scale deposits on the optical window of a laser particle counter.

EXPERIMENTAL APPROACH

A schematic diagram of the experimental equipment is given in Figure 1. Brine from the bottom of the main steam separator was run through a 1/2 NPT line about 125 ft to the PNL test stand. A brine flow of 5 to 10 gpm was maintained in this line to reduce the residence time before measurements in the test stand to about 30 seconds.

Brine entered the test stand and was split into two streams. One stream was available for immediate flow through the laser optical window, an ultrasonic



detector (U cell, Figure-1), and also could be run through a weighed filter for measurement of the suspended solids content. Samples of both brine and solids were also collected for later analyses. The second stream was directed into a heated 6-gallon vessel to hold the brine at temperature for 90 to 160 minutes to allow precipitation, and then either filter the brine for weighed samples or direct the brine through a second ultrasonic cell.

Because of the short time available to build the test stand, an existing piece of equipment used at the Heber Binary Plant was reworked. This system was sized for 1/4 inch tubing and valves. This small diameter caused plugging difficulties in the test stand. It would have been better to use larger valves and tubing for the test stand, but this was not possible within the time and cost constraints.

During May and early June, two visits were made to the site. In June, after set up and check-outs of the system, the test was started on June 8 and continued until June 15.

This geothermal well has one of the highest solids contents in the world. Thus it was anticipated that some scaling and plugging problems would be encountered during the test. The 10 micron filter (shown in Figure 1) was intended to remove large particles, but this filter plugged in the first 20 minutes of flow and was removed for the balance of the test. With the coarse filter out, larger particles were able to get into the rest of the test system and produced a number of flow interruptions. It was originally planned to run a series of precipitation tests at four different temperatures. However, plugging problems required running the lag time tests at just the test stand inlet temperature. It was possible to run the test stand for several hours before cleaning was required.

RESULTS

Only preliminary results are available at this time. It was found that the solids content of the brine at the test stand inlet varied over a wide range of 166 to 670 mg/l. On June 10, the inlet solids content was 314 mg/l, increasing to 421 mg/l after 159 minutes of holding time. On June 13, the inlet solids content was 166 mg/l, increasing to 484 mg/l after 120 minutes holding time. The high inlet solids content of the brine indicates that even after just 30 seconds after flashing in the separator a substantial solids content has already formed in the brine. The data probably have a fairly wide scatter due to both varying solids content and difficulties in washing residual soluble salts out of the salt cake on the filter media.

Solids have been analyzed using X-ray diffraction, a scanning electron microprobe, and X-ray fluorescence. As expected, silica was the major constituent of the solids. Barium sulfate was identified, and compounds of lead, arsenic, strontium, zinc, calcium, antimony, zinc, and silver were detected. No quantitative work has been completed on the sample compositions or particle sizes.

Mr. Chuck Snyder
August 18, 1988
Page 3



The ultrasonic particle counter operated successfully under severe scaling conditions and is usable in its current form. A lot of particle counts versus time data were obtained. The transducer was successful in detecting increases in particle loading when flow stopped and particle nucleation and growth occurred. In general it was much easier to get particle data using the ultrasonic instrument than it was to use the manual sampling and weighing procedures. There is a temperature limit of 180°F on the current ultrasonic transducer which was operated in the 100-125°F region for this test. PNL plans further work to increase the temperature limit of the transducer.

The window of the laser particle counter quickly became coated with solids and was totally obscured in two days of operation. Since window clarity was also a problem when the laser particle counter was operated on a binary plant at Heber due to oil film, it appears that the laser counter approach would require almost continuous maintenance and would not be suitable for geothermal plant use until a solution is found to keep windows transparent.

We plan to complete the data analysis next fiscal year and write a complete report then. The scope of the report will depend on final FY89 budgets.

If you have any questions, please call.

Very truly yours,

DWS

D. W. Shannon
Chief Scientist
Corrosion and Metallurgy Section

DWS:pl

xc: Gladys Hooper

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Appendix I

GEOHERMAL WASTE TREATMENT BIOTECHNOLOGY
(Brookhaven National Laboratory)

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BROOKHAVEN NATIONAL LABORATORY (BNL) INVOLVEMENT IN THE
SALTON SEA SCIENTIFIC DRILLING PROJECT

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OBJECTIVE:

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o Obtain a large geothermal waste sample from the SSSDF site to conduct scaled-up research studies, in which BNL uses biochemical techniques to remove toxic elements that exceed environmental regulations.

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BACKGROUND:

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Disposal of toxic leachable solid waste in an environmentally and economically acceptable way may be a major impediment to large-scale geothermal development.

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For example, in the Imperial Valley of Southern California, there are nine known geothermal resource areas (KGRA). Brines from the Salton Sea KGRA in the Imperial Valley may contain total dissolved solids up to 350,000 ppm. These hypersaline brines lead to the generation of geothermal solid wastes in power plants. All of the solid waste produced must be analyzed for regulated metals using the California Department of Health Services (DOHS) analytical techniques, and if found hazardous, the solid waste must be disposed of off-site in an approved waste management facility.

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Currently, the disposal of these wastes can cost over \$1 million per year for a 50-MW geothermal power plant operating in the Salton Sea KGRA. High disposal costs and the long-term liability associated with hazardous-waste disposal provide the incentive for this study.

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It is known that microorganisms can interact with metals specifically by several mechanisms such as surface adsorption, oxidation, reduction, and solubilization and/or precipitation. These mechanisms serve as a basis for the development of biotechnology which allows use of biochemical processes for removal and concentration of toxic metals present in the waste or makes possible solubilization of the waste.

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Such biotechnology is particularly useful when large quantities of wastes are present which contain low, but nevertheless environmentally significant, concentrations of toxic metals, disposal of which is regulated. Another advantage of the biochemical processes considered in this program is due to the type of microorganism used. These microorganisms are acidophilic and thermophilic capable of living under very harsh conditions such as extreme acidic pH, high salt concentrations, and elevated temperatures. Such conditions are unsuitable to most other microorganisms which require mild conditions for their growth. This means that the new biotechnology developed at BNL does not require sterile conditions.

STRATEGY:

- o The BNL experimental strategy is based on the use of biochemical methods (i.e. selected microorganisms) for dissolution of toxic elements found in geothermal residues. Thus, the produced solution, which contains toxic metals can be reinjected or the metals can be concentrated and recovered. The efficiency of the metal solubilization (i.e., removal from the waste) is determined by experimental conditions which enable removal of toxic metal (to at least below the regulatory level) in the shortest possible time. To optimize the process, compatible microorganisms must be identified, plus other variables, such as biomass to residual sludge ratio, different residence times, mixed cultures, ambient and elevated temperatures, must be considered.

EXPERIMENTAL APPROACH:

- o Using sludge samples obtained from the SSBDP site, BNL will conduct scaled-up biochemical activities, some of which are covered below:
 - Kinetic studies will be conducted using mixed cultures of different strains of acidophilic and thermophilic microorganisms. The studies will be performed in the five to ten gallon range. Earlier BNL studies have been performed at the 250 to 500 milliliter range. During the kinetic studies, sampling will be carried out over extended periods of time. Timing will vary from hours to days, with 10 days being the common residence time. Aqueous and solid phase sample analyses will be carried out, using various analytical tools, such as atomic adsorption to determine the relative solubilization (i.e., removal) of toxic metals from solid brine, as seen in the culture media after microbiological treatment.
 - The solids will be examined after treatment to determine the efficiency data. In this process, the solid material is subjected to chemical treatment, such as acid solubilization or boron fission and then analyzed by atomic adsorption. Sampling is carried out at $t = 0$ and $t = 10$ days to evaluate the maximum concentration of solids vs. the viability of cycled biomass and nutrients. Since the residual sludges from geothermal plants are site specific, samples containing metal concentrations exceeding the environmentally allowable threshold limits are analyzed.
 - Three types of bioreactors will be considered during the upscaled experiments: column, flat bed, and fluidized bed reactors for the purpose of evaluating the process design efficiencies of each. Initially, the flat bed and fluidized bed reactors will be evaluated.

RESEARCH RESULTS:

- o Preliminary research results using the SSBDP sludges will be presented later this year.

SOME ASPECTS OF GEOTHERMAL WASTE TREATMENT BIOTECHNOLOGY

Eugene T. Premuzic and Mow Lin

Department of Applied Science, Brookhaven National Laboratory,
Upton, New York 11973P
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Recent studies have indicated that biotechnological processes for detoxification of geothermal residual brine sludges are feasible. Preliminary studies have also shown that such processes are controlled by several factors which include the concentration of the residual sludge in the bioreactor, the type of bioreactor and the strain of acidophilic microorganisms used. A brief discussion of these factors follows.

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Production of electricity by extraction of energy from underground geothermal reservoirs is highly promising and growing industry. Large scale production of electricity from geothermal sources produces considerable wastes, which accumulate in the form of residual brine sludges containing different concentrations of toxic metals which makes it necessary to ship these residues to hazardous waste disposal sites at a considerable cost. Typically, a 50 MW liquid-dominated hydrothermal power plant in Southern California produces about 70,000 lb/day of solid residues containing in addition to silica and soluble salts, heavy metals, whose concentrations at times exceed the state regulation limits (Royce, 1985).

Work at the Brookhaven National Laboratory (BNL) has shown that acidophilic microorganisms can be used as the "active agents" in the detoxification of geothermal brine residues (Lin et al., 1987; Premuzic et al., 1988). A preliminary design for a process has been suggested (Premuzic et al., 1988). A technical and feasibility study of this process has been described elsewhere (Premuzic et al., 1988) and will only be mentioned here briefly. Thus a bioprocess for a plant producing 123,000 lb/day of a 65% wt. filter process cake was based on 5% sludge-to-liquid ratio and a 10 day residence time. Such a process represents about a one million dollar per year savings, or the equivalent of the 1986 regulated waste disposal cost. This estimate does not take into consideration the long-term liability associated with hazardous waste disposal, increases in the cost of shipping, dumping and the possibility of the dump-sites being closed. Earlier studies have also indicated that

the efficiency of the bioprocess depends on the concentration of the sludge, the type of bioreactor and the type of single and/or mixed cultures of bacterial strains used. Some results of recent studies will be discussed in this paper.

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Three types of bioreactor systems are being considered as possible candidates to be included in the design of a biosystem for detoxification of geothermal residual sludges. These include a fluidized bed type, diagrammatically shown in Fig. 1., a column type batch bioreactor, Fig. 2, and a flat bed-type bioreactor, Fig. 3. In each case flow rates and air supply to the system have to be balanced in order to maintain a steady and active microbial culture supplied with nutrients as needed throughout the cycle. This is verified in all cases by routine sampling and monitoring for viable microbial growth and the metal concentration. The efficiency of metal solubilization by several strains of Thiobacillus thiooxidans and Thiobacillus ferrooxidans from the Brookhaven National Laboratory (BNL) collection have been studied. Different samples of residual brine sludge from proprietary sources, kindly supplied by the geothermal electrical power industry have been used in detoxification processes. The different sludges are site specific, with some containing more than ten toxic metals (Premuzic et al., 1988). In the work presented in this paper for sake of brevity, only a few representative metals have been used as process indicators.

In Table 1, the effect of eight strains of Thiobacillus ferrooxidans on a single residual brine sludge is shown. In this series of experiments a batch bioreactor with a 2-6% loading with stirring has been used. The most efficient metal solubilizing (removing) microorganisms for the metal are identified in Table 1 (square boxes). Results of similar experiments using strains of Thiobacillus thiooxidans and mixed cultures of T. thiooxidans (T.T.) and T. ferrooxidans (T.F.) are shown in Table 2. Tables 1 and 2 indicate that different strains solubilize metals, i.e., remove them from sludges in varying degrees (see square boxes) with a high efficiency for all the metals tested being exhibited by mixed cultures.

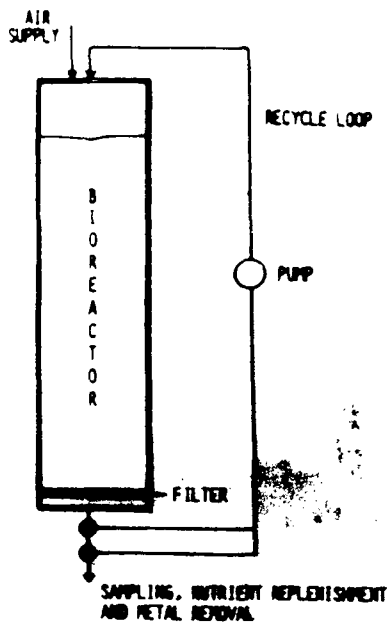
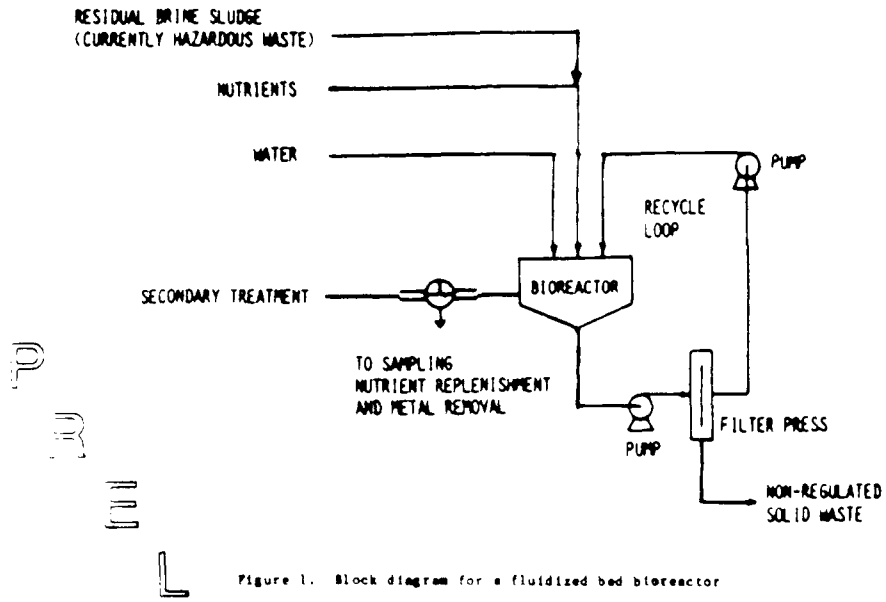


Figure 2. Block diagram for a column type batch bioreactor

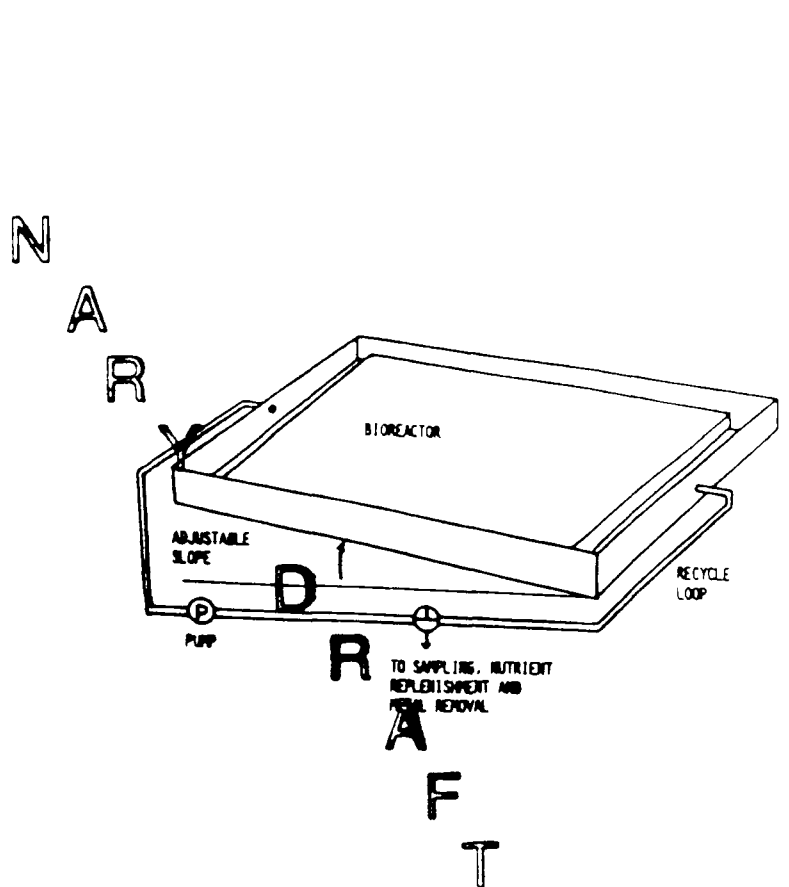


Figure 3. Block diagram for a flat bed type batch bioreactor

Table 1. % Removal of chromium, copper, manganese and zinc from residual brine sludge (BR-1) by the action of different strains of Thiobacillus ferrooxidans.

Strain	% Metal removed			
	Cr	Cu	Mn	Zn
BNL-2-45	30	55	77	90
BNL-2-49	26	58	77	90
BNL-2-44	35	53	58	68
BNL-2-45	26	84	35	88
BNL-2-46	25	88	40	85
BNL-2-47	48	31	57	89
BNL-2-48	22	85	33	85
BNL-2-49	32	91	41	85

Table 2. % Removal of chromium, copper, manganese and zinc from residual sludges BR-1, BR-3, and BR-5 by Thiobacillus thiooxidans (T.T.) and mixed cultures of T. thiooxidans and T. ferrooxidans (T.F.).

Strain	Brine	% Metal removed			
		Cr	Cu	Mn	Zn
T.T.					
BNL-3-23	BR-1	2	50	30	77
BNL-3-23	BR-3	6	65	34	77
T.T. + T.F.					
BNL-2-49	BR-1	65	90	80	85
+	BR-5	20	90	78	60
BNL-3-24					
BNL-3-25	BR-5	85	88	85	72
+	BR-5				
BNL-2-46					

Various concentration of residual brine sludge in the bioreactor also influence the extent of metal solubilization as shown in Tables 3 and 4.

CONCLUSIONS

Based on the current results the following conclusion may be drawn:

Table 3. The influence of different concentration of residual brine sludge (BR-2) on the extent of metal solubilization.

Strain	% BR-2 (w/v)	% Metal removed			
		Cr	Cu	Mn	Zn
T.T. + T.F.					
	1	56	40	62	69
BNL-3-26	2	51	42	61	65
+	4	53	48	67	72
BNL-2-45	6	58	52	74	67
	8	64	50	75	*
	10	56	46	66	*

*not determined.

Table 4. The influence of different concentration of residual brine sludge (BR-5) on the extent of metal solubilization.

Strain	% BR-5 (w/v)	% Metal removed			
		Cr	Cu	Mn	Zn
T.T. + T.F.					
	1	91	40	88	73
BNL-3-25	2	83	46	90	75
+	4	80	57	86	79
BNL-2-46	8	75	51	76	72
	12	79	55	71	47

1. Choice of microorganisms may well be predetermined by the composition of a particular residual sludge. Thus a sludge which, for example, is predominately rich in chromium may require a concentration of microorganisms most efficient for chromium and not necessarily efficient for other toxic metals, which may be present in trace amounts at concentrations well below the threshold limits;

2. The treatment cycle may also be shortened from say six to three days if only few metals are to be considered;

3. In terms of bioreactor design, efficient cycling, supply of nutrients and air will dictate a particular basic design concept, i.e., batch or continuous.

Preliminary results discussed above indicate that mixed cultures of different strains of microorganisms, the relative concentration of the residual brine sludges in a bioreactor and the number of toxic metals present in concentrations exceeding the threshold limits play critical roles

in scaled up processes and require further research and development studies. The results of these studies will generate information essential to the design of efficient biotechnology for detoxification of residual brine sludges.

ACKNOWLEDGMENTS

This work has been sponsored by the U.S. Department of Energy, under Contract No. AM-35-10 and by Brookhaven National Laboratory and the U.S. Department of Energy under Contract No. DE-AC02-76CH00016. We wish to acknowledge L. Kukacka of BNL for valuable discussion and advice. We also wish to acknowledge M. Moseley, a BNL semester student for technical assistance.

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SOME ASPECTS OF GEOTHERMAL WASTE
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Eugene T. Premuzic and Mow Lin

June 1988

For presentation at
the Geothermal Resources Council
1988 Annual Meeting
San Diego, CA
October 9-12, 1988

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To be published in the TRANSACTIONS, Volume 12

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SOME ASPECTS OF GEOTHERMAL WASTE TREATMENT BIOTECHNOLOGY

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Department of Applied Science, Brookhaven National Laboratory,
Upton, New York 11973

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ABSTRACT

Recent studies have indicated that biotechnological processes for detoxification of geothermal residual brine sludges are feasible. Preliminary studies have also shown that such processes are controlled by several factors which include the concentration of the residual sludge in the bioreactor, the type of bioreactor and the strain of acidophilic microorganisms used. A brief discussion of these factors follows.

INTRODUCTION

Production of electricity by extraction of energy from underground geothermal reservoirs is a highly promising and growing industry. Large scale production of electricity from geothermal sources produces considerable wastes, which accumulate in the form of residual brine sludges containing different concentrations of toxic metals which makes it necessary to ship these residues to hazardous waste disposal sites at a considerable cost. Typically, a 50 MW liquid-dominated hydrothermal power plant in Southern California produces about 70,000 lb/day of solid residues containing in addition to silica and soluble salts, heavy metals, whose concentrations at times exceed the state regulation limits (Royce, 1985).

Work at the Brookhaven National Laboratory (BNL) has shown that acidophilic microorganisms can be used as the "active agents" in the detoxification of geothermal brine residues (Lin et al., 1987; Frenoux et al., 1988). A preliminary design for a process has been suggested (Frenoux et al., 1988). A technical and feasibility study of this process has been described elsewhere (Frenoux et al., 1988) and will only be summarized here briefly. This bioprocess is designed to produce 123,000 lb/day of a 65% wt. sludge process cake was based on 30 sludge-to-liquid ratio and a 10 day residence time. Such a process represents about a one million dollar per year savings, or the equivalent of the 1985 regulated waste disposal cost. This estimate does not take into consideration the long-term liability associated with hazardous waste disposal, increases in the cost of shipping, dumping and the possibility of the dump sites being closed. Earlier studies have also indicated that

the efficiency of the bioprocess depends on the concentration of the sludge, the type of bioreactor and the type of single and/or mixed cultures of bacterial strains used. Some results of recent studies will be discussed in this paper.

RESULTS AND DISCUSSION

Three types of bioreactor systems are being considered as possible candidates to be included in the design of a biosystem for detoxification of geothermal residual sludges. These include a fluidized bed type, diagrammatically shown in Fig. 1, a column type batch bioreactor, Fig. 2, and a flat bed-type bioreactor, Fig. 3. In each case flow rates and air supply to the system have to be balanced in order to maintain a steady and active microbial culture supplied with nutrients as needed throughout the cycle. This is verified in all cases by routine sampling and monitoring for viable microbial growth and the metal concentration. The efficiency of metal solubilization by several strains of *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* from the Brookhaven National Laboratory (BNL) collection have been studied. Different samples of residual brine sludge from proprietary sources, kindly supplied by the geothermal electrical power industry have been used in detoxification processes. The different sludges are site specific, with some containing more than ten toxic metals (Frenoux et al., 1988). In the work presented in this paper for sake of brevity, only a few representative metals have been used as process indicators.

In Table 1, the effect of eight strains of *Thiobacillus ferrooxidans* on a single residual brine sludge is shown. In this series of experiments a batch bioreactor with a 2-6% loading with stirring has been used. The most efficient metal solubilizing (removing) microorganisms for the metal are identified in Table 1 (square boxes). Results of similar experiments using strains of *Thiobacillus thiooxidans* and mixed cultures of *T. thiooxidans* (T.T.) and *T. ferrooxidans* (T.F.) are shown in Table 2. Tables 1 and 2 indicate that different strains solubilize metals, i.e., remove them from sludges in varying degrees (see square boxes) with a high efficiency for all the metals tested being exhibited by mixed cultures.

Table 1. % Removal of chromium, copper, manganese and zinc from residual brine sludge (BR-1) by the action of different strains of Thiobacillus ferrooxidans.

Strain	% Metal removed			
	Cr	Cu	Mn	Zn
BNL-2-43	30	55	77	90
BNL-2-49	26	58	77	90
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BNL-2-45	26	84	35	88
BNL-2-46	25	88	40	85
BNL-2-47	48	31	57	89
BNL-2-48	22	85	35	85
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Table 2. % Removal of chromium, copper, manganese and zinc from residual sludges BR-1, BR-3 and BR-5 by Thiobacillus thiooxidans (T.T.) and mixed cultures of T. thiooxidans and T. ferrooxidans (T.F.).

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BNL-2-49	BR-1	65	90	80	85
+	BR-5	20	90	78	60
BNL-3-24					
BNL-3-25	BR-5	85		85	72
+					
BNL-2-46					

Various concentration of residual brine sludge in the bioreactor also influences the extent of metal solubilization as shown in Tables 3 and 4.

CONCLUSIONS

Based on the current results the following conclusion may be drawn:

Table 3. The influence of different concentration of residual brine sludge (BR-2) on the extent of metal solubilization.

Strain	% BR-2 (w/v)	% Metal removed			
		Cr	Cu	Mn	Zn
T.T. + T.F.	1	56	40	62	69
BNL-3-26	2	51	42	61	65
+	4	53	48	67	72
BNL-2-45	6	58	52	74	67
	8	64	50	75	*
	10	56	46	66	*

*not determined.

Table 4. The influence of different concentration of residual brine sludge (BR-5) on the extent of metal solubilization.

Strain	% BR-5 (w/v)	% Metal removed			
		Cr	Cu	Mn	Zn
T.T. + T.F.	1	91	40	88	73
BNL-3-25	2	83	46	90	75
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	12	79	55	71	47

1. Choice of microorganisms may well be pre-determined by the composition of a particular residual sludge. Thus a sludge which, for example, is predominately rich in chromium may require a concentration of microorganisms most efficient for chromium and not necessarily efficient for other toxic metals, which may be present in trace amounts at concentrations well below the threshold limits;

2. The treatment cycle may also be shortened from say six to three days if only few metals are to be considered;

3. In terms of bioreactor design, efficient cycling, supply of nutrients and air will dictate a particular basic design concept, i.e., batch or continuous.

Preliminary results discussed above indicate that mixed cultures of different strains of microorganisms, the relative concentration of the residual brine sludges in a bioreactor and the number of toxic metals present in concentrations exceeding the threshold limits play critical roles

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Appendix J

CHEMICAL SAMPLING AND ANALYSIS TO CHARACTERIZE THE BRINE
(Electric Power Research Institute)

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September 2, 1988

EMSI-1110.2RPT
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Task Order Letter 9

Sampling and Analysis at the Salton Sea Deep Well

Site Summary Report

EPRI Mobile Geothermal Chemistry Laboratory

Submitted to:

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COMBUSTION ENGINEERING

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1.0 INTRODUCTION

The Electric Power Research Institute's Mobile Geothermal Chemistry Laboratory (EPRI CHEMLAB) visited the Salton Sea site during the June 1988 flow test to collect and analyze samples from the well (State Well 2-14).

Three types of sampling events took place during the flow test. These types are defined in terms of their objectives as follows:

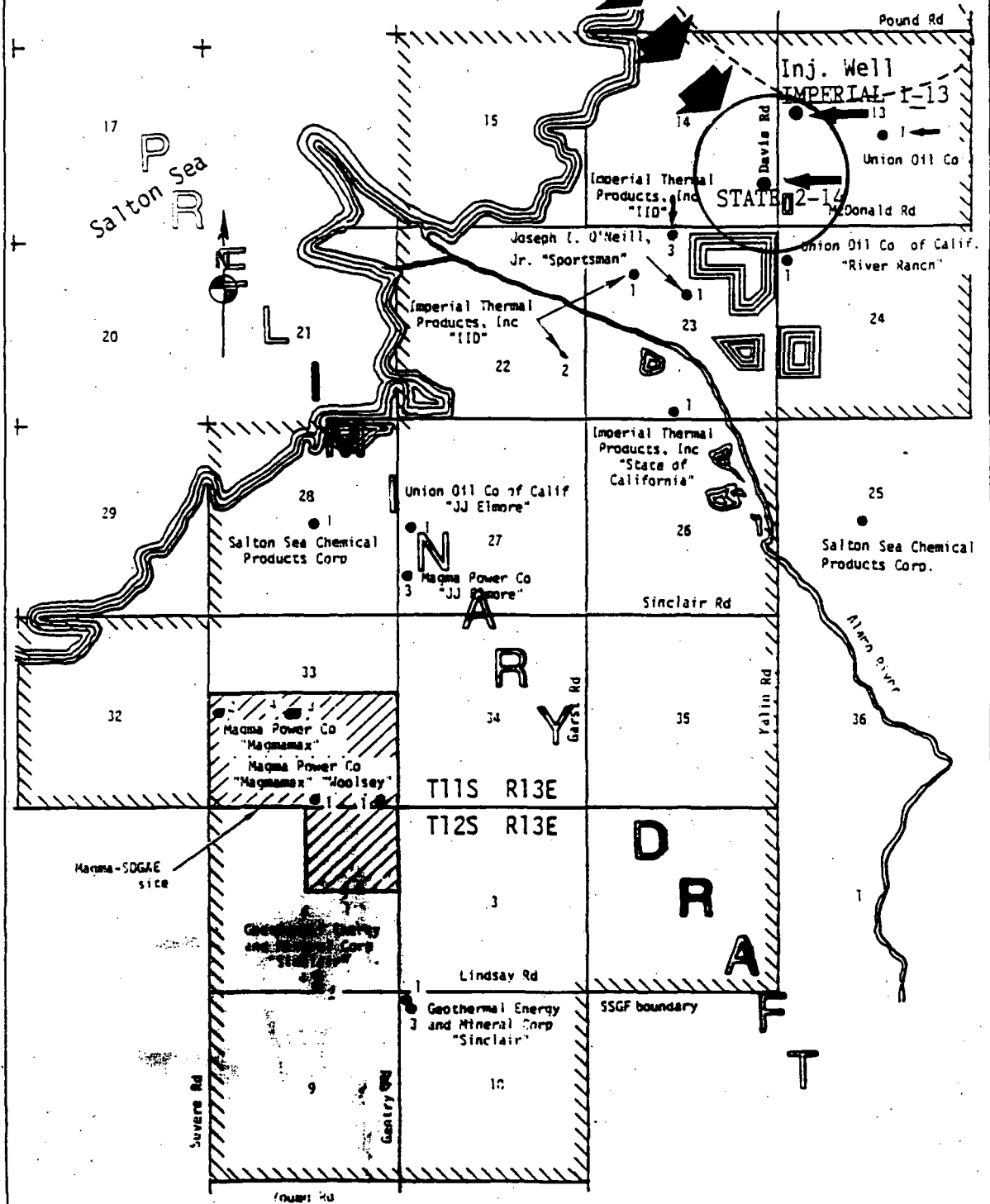
TEST TYPE	OBJECTIVE
Signature	To characterize chemical and physical attributes of the total flow from the well. This involves combining measurements of steam and brine to determine properties of the total flow.
Tracking	- To observe changes in selected parameters as a function of time.
Special	- To investigate flow streams or equipment of special interest.

The CHEMLAB remained on site throughout the flow test. CHEMLAB staff worked alongside other investigators some of whom also collected samples for chemical analyses. The location of the site is shown in Figure 1-1.

This report describes the field operations employed by CHEMLAB personnel and the analytical results of the signature, tracking, and special tests conducted by CHEMLAB personnel and support personnel from CHEMLAB's home base at CE Environmental in Camarillo, California.

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Figure 1-1
The Site Location Map



(Adapted from Lawrence Livermore Laboratory report dated December, 1975)

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2.0 FIELD ACTIVITIES

2.1 SCHEDULE

The CHEMLAB arrived at the Salton Sea site on June 1, 1988 along with the CHEMLAB staff who accompanied the move from the Heber Binary Plant in Heber, CA. The first week was spent preparing the laboratory for sampling and analytical operations. Sampling began on June 7 and the complete schedule of events for the Salton Sea trip is given in Table 2-1 below. Itemized in the table are the test location, sampling date, flow rates, and test type.

In summary, CHEMLAB conducted three signature tests, 11 tracking tests, and 7 special tests. Standard CHEMLAB Signature Tests were conducted three times during the flow test. Daily Tracking Tests occurred between the Signature Tests for a subset of Signature Test analytes (which will be described in greater detail later). A number of Special Tests were conducted to characterize some of the physical and chemical characteristics of the brine flow at the weir box, brine pond water, pond sludge, and injection brine.

Flow from the well stopped on June 20, which was the last day samples were taken for the flow test. Sludge samples were taken from the brine pond on July 7 just before departing from the site.

2.2 SET-UP

The set-up of the CHEMLAB included arranging for the electrical hook-up, the unloading of the Fluid Sampling System (FSS), the set-up of the stairs, and the unpacking of the CHEMLAB instruments and supplies. All analytical instrumentation was checked for proper operation.

Arrangements for the phone hook up were made. Laboratory water supply tanks were replenished by the local water distributing company. Deionized water in five gallon bottles provided the necessary water for the chemical analyses. Tap water for clean up and other general uses was pumped into the two 50 gallon storage tanks by the bulk delivery truck from Triple A Water Company. CHEMLAB set-up and instrument check out occurred for the remainder of the week.

2.3 SAMPLING

The site diagram appears in Figure 2-1 and illustrates the layout of equipment used in the flow test of the deep well. The flow stream diagram appears in Figure 2-2 and shows the flow stream equipment. The sampling of the separated fluids usually began after 24-48 hours flow, but due to the compressed flow test schedule the sampling for the first Signature Test occurred after only 21 hours of flow, which was the worst case encountered during the month. This was the result of an upset on June 6, for which the well was shut down for a period of about five hours.

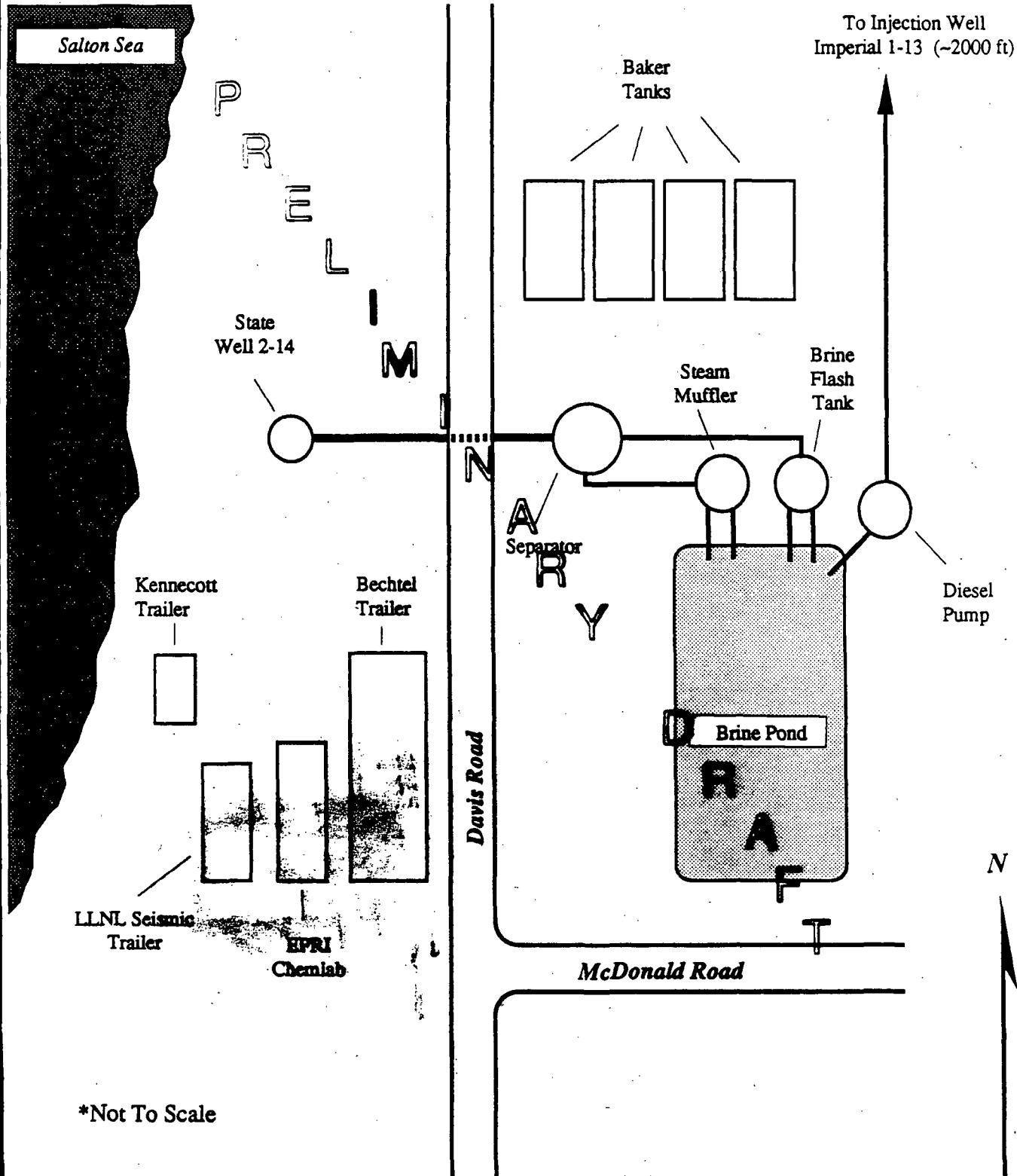
Table 2-1

SAMPLING ACTIVITIES, SALTON SEA DEEP WELL, IMPERIAL VALLEY, CALIFORNIA

Test Location ¹	Sampling Dates	Approx. Time	Flows (1000 lb/h) ³		Test Type	Rep #
			Brine	Steam		
WEIR BOX ²	6/1	1900	120.	not separated	SPECIAL	1
WEIR BOX ²	6/2	0100	161.	" "	SPECIAL	2
STEAM	6/7	1800	111.	20.2	SIGNATURE	1
BRINE	6/7	1900	111.	20.2	SIGNATURE	1
BRINE	6/7	2000	103.	20.2	TRACKING	1
BRINE	6/8	1700	90.5	18.9	TRACKING	2
WEIR BOX	6/8	1600	90.5	18.9	SPECIAL	3
POND SLUDGE ⁴	6/9	1400	222.	37.0	SPECIAL	4
BRINE	6/9	2000	197.	33.3	TRACKING	3
BRINE	6/10	1000	193.	30.3	SIGNATURE	2
STEAM	6/10	0800	193.	33.3	SIGNATURE	2
WEIR BOX ⁴	6/10	1700	181.	29.3	SPECIAL	5
INJECTION BRINE ⁴	6/10	1930	214.	30.1	SPECIAL	6
BRINE	6/11	1200	185.	29.1	TRACKING	4
BRINE	6/12	2000	349.	59.6	TRACKING	5
BRINE	6/13	2000	344.	60.0	TRACKING	6
STEAM	6/14	1700	344.	62.9	SIGNATURE	3
BRINE	6/14	1700	344.	62.0	SIGNATURE	3
BRINE	6/15	1800	45.	78.7	TRACKING	7
BRINE	6/16	1200	421.	74.9	TRACKING	8
BRINE	6/17	1100	562.	61.0	TRACKING	9
BRINE	6/18	1000	194.	26.	TRACKING	10
BRINE	6/20	1700	374.	60.7	TRACKING	11
STEAM	6/20	1700	374.	60.7	TRACKING	11
POND WATER/SLUDGE	7/7	1300	0	0	SPECIAL	7

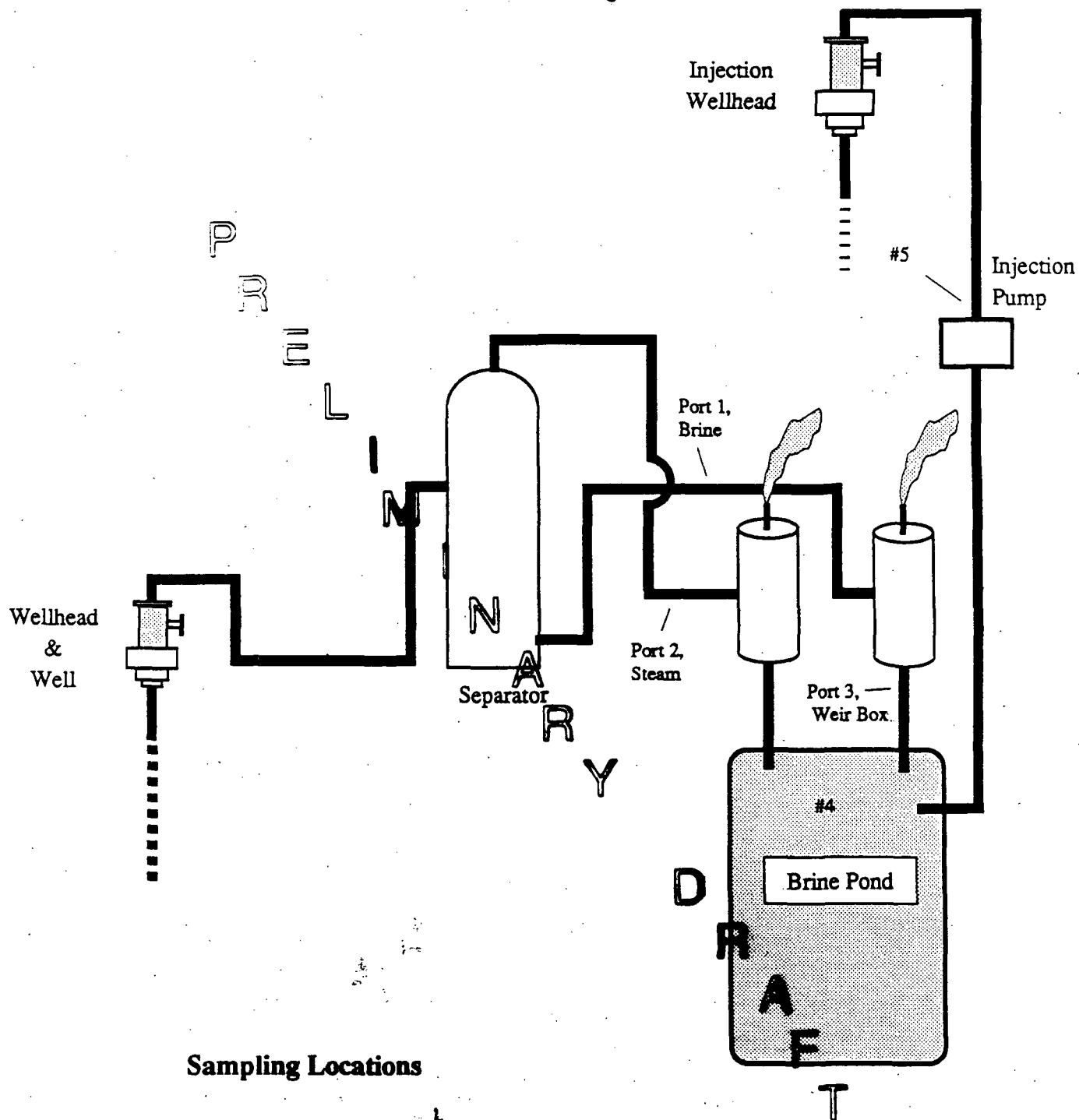
- "STEAM" and "BRINE" are at sampling ports on the lines leaving the separator.
- Samples taken by Dave Mulliner of Kennecott. Two additional samples were taken several hours apart later that same day.
- Flows as reported by the Mesquite Group, Inc.
- Samples taken by the Mesquite Group, Inc.

Figure 2-1*
Site Diagram



*Not To Scale

Figure 2-2.
Flow Stream Diagram



Sampling Locations

- Port 1 - Steam with LLE Sampling Probe
- Port 2 - Brine with LLL Sampling Probe
- Port 3 - Brine Weir Box
- Port 4 - Brine Pond
- Port 5 - Injection Pump

2.3.1 Signature Test Sampling

Well flow began on June 1, and the flow of the mixed fluid through the separator began on June 7 at approximately 0500 hours. Signature Test sampling began at approximately 1600 hours the same day. Both the steam and brine flow streams were sampled for the Signature Test using the Lawrence Livermore National Laboratory (LLL) sampling probe.

CHEMLAB's sampling plan included three Signature Tests at three different well flow rates. The well was typically allowed to flow for 24 to 48 hours (but never less than 21 hours) after a rate change prior to each Signature Test. A smoothed curve flow diagram of the well flowrate is shown in Figure 2-3. The flow rates at the time of each Signature Test are given at the bottom of Figure 2-3.

An isokinetic sampling rate for the first Signature Test was calculated to be approximately 100 cc's per minute for the steam, and 450 cc's per minute for the brine. This calculation was made based on the flow rate information obtained from the Mesquite Group, Inc. in the field.

The sampling probe was connected to the sampling ports with a 1 inch gate valve. The sampling probe was then transversed into the flow stream so that the fluid sampled came from the center of the flow stream. The sampling orifice was directed upstream. The isokinetic sampling rate then allowed the sample to be taken through the sampling probe at the same velocity as the flow stream velocity.

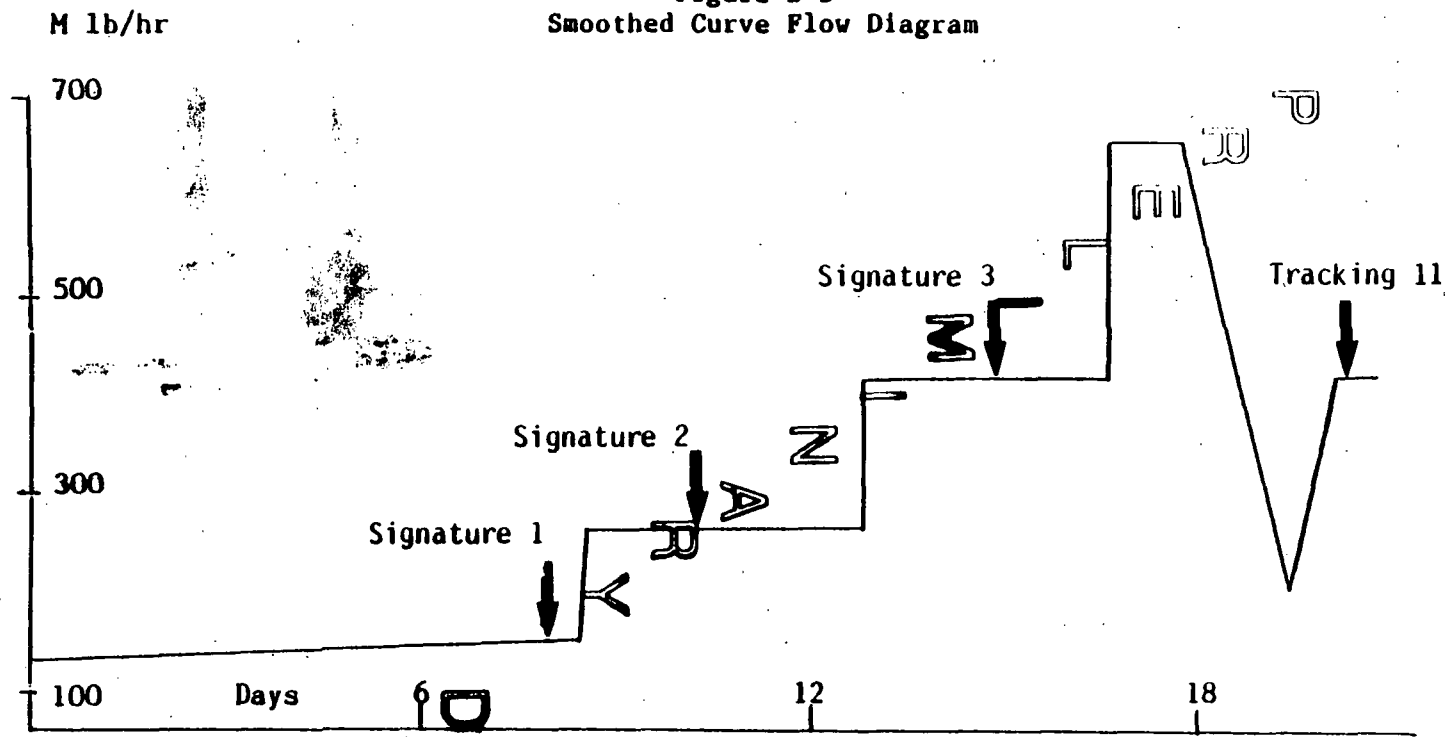
A Process Flow Diagram is shown in Figure 2-4. This diagram gives the reader a conceptual representation of the relative amounts of steam and brine flow as they were separated in the flow stream process.

Complete Signature Tests were conducted at three well flow rates. The Signature Tests included the measurement of 64 separate chemical and physical quantities. Standard methods of sampling and analysis (developed by CHEMLAB staff) included the collection of condensate samples with the use of a two-stage condenser made from coiled 3/8" stainless steel tubing. The stages consisted of a boiling water bath followed by an ice water bath.

Raw condensate samples were collected in order to measure pH, conductivity, Eh, dissolved oxygen, anions, carbonate and bicarbonate. Acidified samples (1% nitric acid) were taken for the analysis of about 30 different metals. Trapping solutions were utilized to trap and measure hydrogen sulfide and carbon dioxide. CHEMLAB's Fluid Sampling System (FSS) was used to obtain the noncondensable gases (at approximately atmospheric pressure and 25°C temperature) for analysis by gas chromatography.

Traps and raw liquid samples were collected for analysis for total carbonate, carbonate/bicarbonate, total sulfide, and ammonia. For each signature test, these were collected once (in triplicate) at the steam and brine ports using the (LLL) sampling probe. Acidified samples for metals analysis were also taken in triplicate at each port. In addition, silicon samples were collected using ice traps to inhibit polymerization.

Figure 2-3
Smoothed Curve Flow Diagram

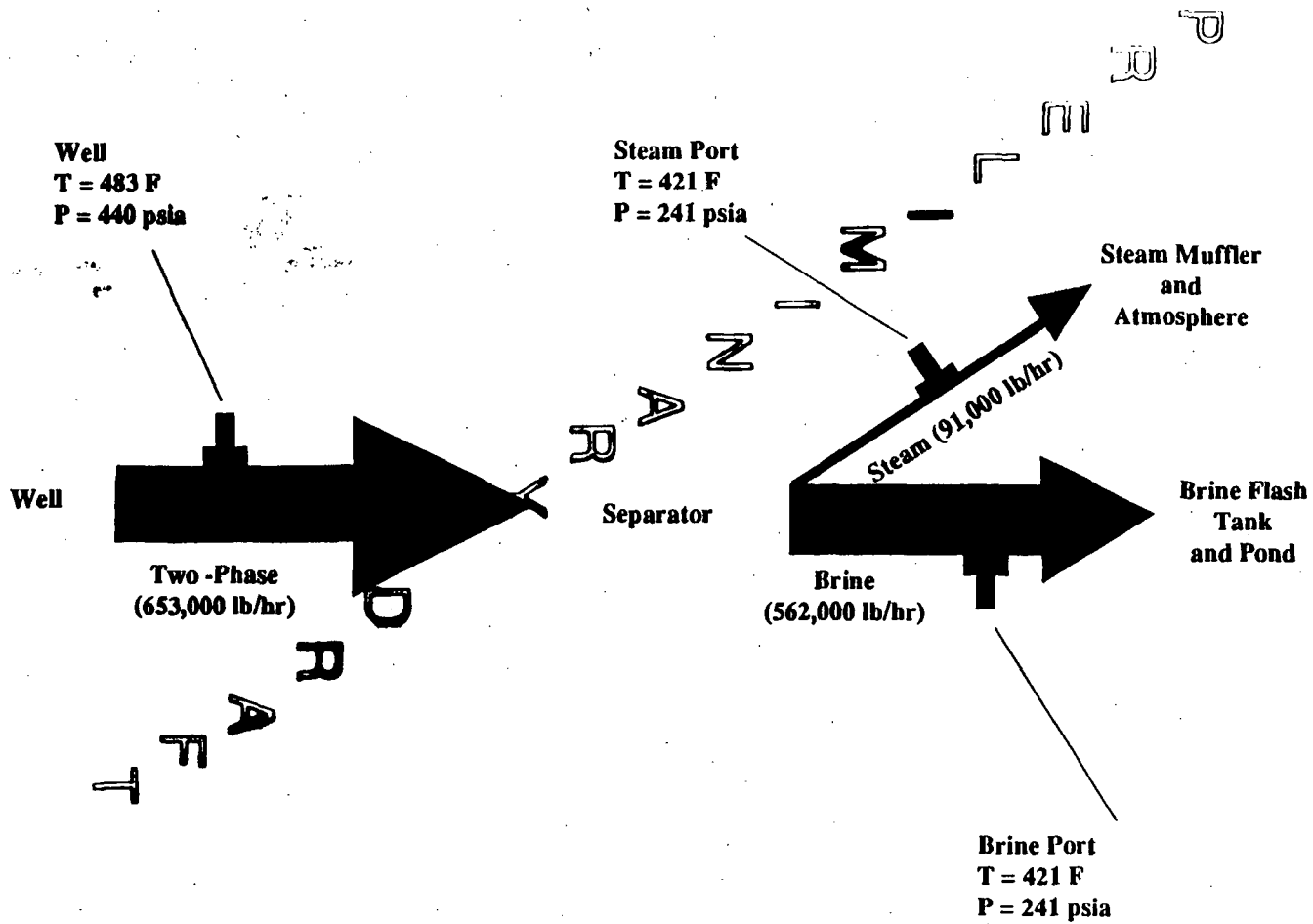


Flow measurements at time of brine and steam sampling:

	6/7/88 1900 hrs	6/10/88 0800 hrs	6/14/88 1700 hrs	6/20/88 1700 hrs
Steam Flow	20,240 lbs/hr	33,300 lbs/hr	62,800 lbs/hr	60,700 lbs/hr
Brine Flow	111,100	193,300	343,700	374,400
Total Flow	131,300	226,600	406,600	435,100

(Adapted from Dave Mulliner's report to Kennecott, July 1988)

**Figure 2-4. SALTON SEA WELLHEAD
SEPARATOR FLOW DIAGRAM**



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Maximum Flow Case: June 17, 1988 - Tracking Test 9

2.3.2 Tracking Test Sampling

Daily Tracking Tests were conducted at the brine port throughout the flow test period from 7-June-88 to 20-June-88, with the exception of June 19. A Tracking Test consisted of the collection of three samples with the double stage condenser as used in the Signature Tests. Two raw samples and one acidified sample were collected during each tracking event. The acidified sample was preserved by adding one percent concentrated nitric acid at the time of the sampling. All samples were obtained using the LLL probe provided by on site personnel.

2.3.3 Special Test Sampling

Special Tests were conducted on three occasions during the flow test. The first event was a "Tracking" event at the brine weir box (port 3 in Figure 2-2). The sample types collected and the analysis performed followed the prescribed schedule for other tracking samples. The objective was to have available the information necessary to correlate CHEMLAB's brine and steam data to the data of other investigators who were sampling at the weir box.

The second special event occurred at the request of Bechtel's project management, who expressed concern about the sludge accumulation rate within the brine pond. Raw samples were taken for a determination of the sludge accumulation rate. Samples were provided to CHEMLAB staff and a determination of the total suspended solids (TSS) going into the brine pond (port 3) and leaving the brine pond (port 5), the difference being used to calculate the sludge accumulation rate.

The objective of the third Special Test was to estimate the percent water of sludge samples from the brine pond (see port 4, Figure 2-2). Sludge samples were collected for the CHEMLAB staff by other on site personnel using a can wired to the end of 12 foot pole and scraping the bottom of the pond near the point indicated in Figure 2-2.

A fourth Special Test was conducted during the closing operations on the last day that the CHEMLAB staff was on site. Twelve one liter samples were collected at each end of the brine pond and in the middle of the pond. Both pond sludge and the pond supernatant were collected at each location in duplicate.

2.4 INSTRUMENTS AND ANALYSES

Sample analysis used standard CHEMLAB procedures with the exception of the metals analyses, which were performed by inductively coupled plasma spectrophotometry (ICP), anion analyses which were conducted by ion chromatography, and ammonia determinations which were determined colorimetrically with the Technicon spectrophotometric autoanalyzer at EMSI in Camarillo, CA.

2.4 INSTRUMENTS AND ANALYSES (continued)

The ICP method of analysis allows for the achievement of lower detection limits for the analytes of concern and reduces the possibility of matrix interferences in the analysis. This is due primarily to the fact that the ICP uses principles of spectral emissions, whereas the atomic absorption spectrophotometer (AA) uses principles of absorption. The brine samples of concern contain such high levels of dissolved (and suspended) solids that the spectral path of the AA becomes quite cluttered.

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3.0 PROBLEMS AND ISSUES

3.1 SAMPLING

During the sampling effort there were four problems. The first was that the brine contained suspended particulates of what was suspected to be silica which clogged the glass frit. Second, there was a deviation from the established isokinetic sampling rate for trap samples. The third problem was a leak on the second stage condenser of the Fluid Sampling System (FSS). Finally, measurement of the noncondensable gas fraction during the Signature Tests was conducted manually, because the wet test meter was inoperative. The details of each problem are given below.

3.1.1 Brine Trap Samples

Sampling for carbon dioxide and hydrogen sulfide calls for using trapping solutions to quantitatively capture the compounds from the flow stream. Plastic tubing is attached to the end of the second stage of the sampling condenser. At the end of the tubing a gas dispersion tube is connected to increase trapping efficiency by distributing bubbles of noncondensable gas throughout the trapping solution. During sampling at the brine port the glass frit became plugged with small spheroids of what was suspected to be silica.

Subsequent sampling was conducted by immersing the plastic tubing directly into the trapping solution. This deviation is not expected to change the analytical results as the dispersion tube becomes more critical only when the noncondensable gas fraction of the flow stream becomes significant. For the steam sampling the gas dispersion tube was used successfully.

3.1.2 Steam Trap Samples

In order to achieve isokinetic sampling with the LLL probe, an unusually high flow rate (high for trap sampling) was required. The procedure calls for capturing approximately 125 cc's of brine (or steam condensate) in roughly the same volume of the appropriate trapping solution. The trapping was performed by flowing the sample into the bottom of the 250 cc graduated cylinder. In the case of the steam condensate a significant amount of noncondensable gas was present in the flow stream, so that if the sampling rate were too high the trapping solution could be blown out the top of the graduated cylinder.

For this reason the flow rate of the sampling line was slowed down to a reasonable rate (about 100 cc's per minute) for the traps taken at the steam port. An acidified sample was then taken at the same rate, and then a second acidified sample was taken at the isokinetic rate. The sodium analytical results from these two samples can be used to detect any significant difference in the amount of water collected during the sampling at the two sampling rates. The sodium results agreed to within about 5%, indicating that the water fraction was consistent at both flow rates, so there was no need to correct the gas trap values for excess water. Furthermore, the consistency of sodium values at the two flow

rates suggests that similarly consistent results would be expected for other species.

3.1.3 Fluid Sampling System

During the third Signature Test a leak developed in the second stage condenser of the Fluid Sampling System (FSS). Bubbles were observed in the second stage condenser ice bath. It should be noted that the FSS condensers are separate from those used for the collection of regular condensate samples. An attempt was made to stop the escape of the noncondensable gases from the condenser in the ice bath, however, the CHEMLAB staff was unable to obtain any gas bomb samples during this Signature Test. Later in the flow test a gas sample was taken at a similar flow rate (Tracking Test 11).

The wet test meter used to quantify gas flow was not functioning properly during the first sampling event. Field sampling flow rates of the noncondensable portion of the flow streams were measured using an inverted graduated cylinder in a bucket of water. Although this method was more time consuming, it is felt that the flow rates measured are at least as good as the wet test meter values. The detection limit of the method used is actually better than the detection limit with the wet test meter. With the manual method as little as 1-2 cc's can be detected visually after flowing 10 liters of brine. The wet test meter on the other hand needs about 50 cc's in 10 liters of brine to deflect the meter significantly.

3.2 ANALYSES

The problems associated with the chemical analyses of the geothermal fluids are discussed below by analyte group, because each problem applies to all analytes which require similar analyses.

3.2.1 Gases

During the first Signature Test the Hewlett-Packard Model 5880A gas chromatograph experienced electronic circuitry problems which were corrected at that time. All gas chromatography analyses were performed with the repaired instrument. (The best measures of CO₂ and H₂S, however, come from the carbonate and sulfide traps, and not from gas chromatography analysis of gas bombs).

3.2.2 Metals

Problems with silicon analysis by flame atomic absorption (AA) were encountered due to the high TDS of the brine samples. Erroneous high results were indicated by the analysis, with poor signal to noise ratio even with background correction. The analyses for silicon were conducted by inductively coupled argon plasma (ICP) at the two most predominant emission wavelengths were in agreement with each other.

An additional analytical run for silicon by flame atomic absorption (flame AA) was conducted. The results indicates a matrix interference with respect to the silicon analysis by flame AA. Therefore, the data for this report were generated by the ICP analytical method.

3.2.3 Anions

The chloride determinations on the brine and steam samples analyzed by ion chromatography were in good agreement with the chloride data from the coulometric titrations conducted in the field. The other anions in the brine matrix were more difficult to analyze, and detection limits were higher than usual. Nitrate proved difficult due to interference from the relatively high chloride concentration (200,000 mg/l). Another analytical run using another method could be performed to quantify the nitrate.

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3.2.4 Ion Analyzer

The Model 301 ion analyzer was used for the measurements of the sulfide ions in the sulfide trapping solutions. This meter only displayed readings to the nearest millivolt, whereas the Model 701 ion analyzer displays readings to the tenths of millivolts. This did not affect the steam values generated, but did in effect raise the detection limits for the sulfide analyses. (The detection limit increased from 0.5 to 1.0 ppm, an insignificant change compared to typical steam sulfide values of around 500 ppm).

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3.2.5 pH Titrations

The pH titrations for total carbonate in the brine fluid had to be modified to accommodate the high acidity of the brine. The first set of trap titrations (Signature Test A) yielded extremely high results, reflecting the high acidity of the brine rather than the concentration of the carbonate ion.

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The samples were reanalyzed using the Winkler method, as were all subsequent samples. This method calls for two titrations of the trapping solution: one with barium chloride and one without barium chloride. The barium chloride precipitates the carbonates from the trapping solution so the difference between the titrant volumes represents the carbonate present.

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The detection limit of the Winkler method is twice that of the regular method, since the data reduction calls for the subtraction of two titrant values, rather than just manipulating a titrant volume with an equation. The detection limit of both methods can be varied by changing the concentration of the titrant and the sensitivity of the pH meter employed for the analysis. In the test as performed, brine carbonate was measured as approximately 500 ppm, and the detection limit was 10 ppm.

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4.0 RESULTS AND DISCUSSION

The signature and tracking results have been divided into sections based on their sampling location (steam, brine, weir box, pond or injection pump). The analytical data have been arranged chronologically for the summary tables in the following sections.

Table 4-1 gives a summary of all the samples taken during the test, including the date, time, description of location, and well flow parameters at the time of each sampling. Subsequent tables report the analytical values, which have been arranged so that samples taken later in time appear lower in the summary tables. Column headings indicate the particular analyte along with a descriptor for any exceptions to standard analytical methodology employed for the analysis.

Tracking Tests for the Salton Sea flow test included pH, conductivity, Eh, dissolved oxygen, chloride, and approximately 30 metals. The special tests were conducted as needed for individual parameters such as the TSS of the brine or the moisture content of the sludge.

4.1 SIGNATURE TESTS

Signature Tests included 64 separate chemical species and were conducted at three different well flow rates already mentioned in Figure 2-3 and the text of Section 2. The last Tracking Test (T-11) conducted included a gas bomb sample taken from the steam line, since no bomb was taken during the third signature. A set of traps for the determinations of hydrogen sulfide and carbon dioxide was also taken during Tracking Test No. 11. For this reason, T-11 will be included in the discussion of the signature data.

4.1.1 Steam

The analytical results from the Signature Test samples are given in Tables 4-2 through 4-8 and are discussed below. The major constituents will be addressed first, along with some of the physical properties determined by the CHEMLAB staff.

The noncondensable gases (NCG) consisted primarily of carbon dioxide with much smaller amounts of the other gases. The gas to brine ratio (which is really the gas to steam condensate ratio) reported for the first signature (Table 4-6) is about four percent and the ratio reported for second signature is about three percent. Therefore the higher NCG values reported for the first signature are consistent with the gas to brine ratio.

Table 4-1
 SAMPLES AND CONDITIONS
 (RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

[261,30]GEOSUM.132;V5
 Status as of 8/30/88

Abb. ID	Date	Appr. Time	Description	Ice	Acid	Raw	Trap	Gas	FLOW CONDITIONS (1000-lb/hr)			
									PWH*	PSep*	Brine	Steam
SPEC-1	6/1	am-pm	WEIR BOX			T			450	-	-	-
SPEC-2	6/2	am-pm	WEIR BOX			T			487	-	-	-
SIG1-ST	6/7	1800	STEAM	O(1910)	A(1600)	A(1600)	A(1800)	A(1430)	514	213	111	20
SIG1-BR	6/7	1900	BRINE	O(2000)	A(1900)	A(1900)	A(2000)		514	213	111	20
T-1	6/7	2000	BRINE		T	T			514	212	103	20
T-2	6/8	1700	BRINE	A(1730)	T	T	A		507	198	114	19
SPEC-3	6/8	1600	WEIR BOX		T	a			507	177	91	19
SPEC-4	6/9	1400	POND SLUDGE			w			535	207	222	37
T-3	6/9	2000	BRINE		T	T			537	202	197	33
SIG2-BR	6/10	0800	BRINE	O	A	A	A		537	201	193	33
SIG2-ST	6/10	1000	STEAM	O	A	A	A	(2030)	540	201	193	30
SPEC-5	6/10	1700	WEIR BOX			w			540	198	181	29
SPEC-6	6/10	1930	INJECTION BRINE			w			533	209	214	30
T-4	6/11	1200	BRINE	T	T	a			540	208	185	29
T-5	6/12	2300	BRINE	T	T	a			513	211	348	60
T-6	6/13	2000	BRINE	T	T	a			518	214	344	60
SIG3-ST	6/14	1700	STEAM	O(1800)	A(1700)	A(1730)	A(1800)		500	216	344	63
SIG3-BR	6/14	1700	BRINE	O(1630)	A(1700)	A(1700)	A(1730)		500	216	344	63
T-7	6/15	1800	BRINE	T	T	a			491	260	453	79
T-8	6/16	1200	BRINE	T	T	a			505	237	421	75
T-9	6/17	1100	BRINE	T	T	a			440	241	562	91
T-10	6/18	1000	BRINE	T	T	a			563	221	194	26
T-11-BR	6/20	1700	BRINE	T	T	a	A		525	224	374	61
T-11-ST	6/20	1700	STEAM		a		A(1600)	A(1730)	525	224	374	61
SPEC-7	7/7	1300	POND WATER & SLUDGE			T			-	-	-	-

KEY: T - Samples Taken A - Samples Analyzed
 O - Analysis Ordered
 a - Samples Analyzed for ph, Cond, EH, DO, & Cl Only
 w - Analyzed for weight per cent only

*PWH - Well Head Pressure (psig)
 *PSep - Pressure at the Separator (psig)

NOTE: BRINE and STEAM sampled after separator

Table 4-2

[261,30]GEOSUM.132;V5
Status as of 8/30/88ANALYSIS SUMMARY
(RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	Cl-	Na	K	Ca	Mg	Fe	Au	As	CO3=	S=	Na(AA)
SPEC-1	6/1	T	T	T	T	T	T	T	T			T
SPEC-2	6/2	T	T	T	T	T	T	T	T			T
SIG1-ST	6/7	N	1.93	0.61	1.13	<0.01	0.11	<0.01	.169	N	44.7	1.32
SIG1-BR	6/7	206,000	-	19,300	33,500	20.89	1850	N	8.31	517	7.0	71,100
T-1	6/7	199,000	-	18,000	35,600	20.8	1720	N	T			72,000
T-2	6/8	200,000	T	T	T	T	T	T	T	N	2.5	69,900
SPEC-3	6/8	214,000	T	T	T	T	T	T	T			67,700
SPEC-4	6/9	T	T	T	T	T	T	T	T			T
T-3	6/9	206,000	T	T	T	T	T	T	T			72,000
SIG2-BR	6/10	210,000	78,800	18,700	42,400	19.3	1850	N	9.23	278	5.7	73,900
SIG2-ST	6/10	N	14.3	5.35	8.94	0.05	1.72	<.05	0.268	18,500	590.	11.6
SPEC-5	6/10	T	T	T	T	T	T	T	T			T
SPEC-6	6/10	T	T	T	T	T	T	T	T			T
T-4	6/11	208,000	T	T	T	T	T	T	T			77,000
T-5	6/12	212,000	T	T	T	T	T	T	T			77,700
T-6	6/13	212,000	T	T	T	T	T	T	T			82,000
SIG3-ST	6/14	N	0.629	0.150	0.563	0.05	0.268	<.05	0.151	21,020	N	0.36
SIG3-BR	6/14	213,000	79,900	18,500	43,700	19.0	2060	*0.05 ppb	16.4	501.	N	75,600
T-7	6/15	206,000	T	T	T	T	T	T	T			76,300
T-8	6/16	217,000	T	T	T	T	T	T	T			76,300
T-9	6/17	209,000	T	T	T	T	T	T	T			77,000
T-10	6/18	202,000	T	T	T	T	T	T	T			76,300
T-11-BR	6/20	211,000	T	T	T	T	T	T	T	390.	<0.4	81,300
T-11-ST	6/20	N	T	T	T	T	T	T	T	19,300	171.	0.85
SPEC-7	7/7	T	T	T	T	T	T	T	T			T

Notes: All values listed are in units of mg/l.
 All metals analyzed by ICP unless otherwise specified.
 Cl- analyzed by coulometric titration, CO3= & S= by trap methods
 * Analysis performed by method of Neutron Activation

T - Sample Taken
 O - Analysis Ordered
 N - No Data from Sample

Table 4-3

[261,30]GEOSUM.132;V5
Status as of 8/30/88ANALYSIS SUMMARY
(RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	Cd	Pb	Ba	Sr	Ag	W	Co	Mn	Zn
SPEC-1	6/1	T	T	T	T	T	T	T	T	T
SPEC-2	6/2	T	T	T	T	T	T	T	T	T
SIG1-ST	6/7	<0.01	0.0176	0.0443	0.0423	<0.01	<0.10	<0.01	0.024	<0.01
SIG1-BR	6/7	0.66	111.	163.	483.	0.206	4.29	0.046	1680	601.
T-1	6/7	0.68	116.	146.	502.	0.218	4.40	0.045	1750	608.
T-2	6/8	T	T	T	T	T	T	T	T	T
SPEC-3	6/8	T	T	T	T	T	T	T	T	T
SPEC-4	6/9	T	T	T	T	T	T	T	T	T
T-3	6/9	T	T	T	T	T	T	T	T	T
SIG2-BR	6/10	0.74	102.	101.	459.	0.234	4.51	0.039	1580	566.
SIG2-ST	6/10	<0.01	0.026	0.101	0.169	<0.01	<0.10	<0.01	0.18	0.023
SPEC-5	6/10	T	T	T	T	T	T	T	T	T
SPEC-6	6/10	T	T	T	T	T	T	T	T	T
T-4	6/11	T	T	T	T	T	T	T	T	T
T-5	6/12	T	T	T	T	T	T	T	T	T
T-6	6/13	T	T	T	T	T	T	T	T	T
SIG3-ST	6/14	<0.01	0.030	<0.01	<0.01	<0.01	<0.1	<0.01	0.019	<0.01
SIG3-BR	6/14	0.63	100.	100.	527.	0.27	4.62	0.049	1610	653.
T-7	6/15	T	T	T	T	T	T	T	T	T
T-8	6/16	T	T	T	T	T	T	T	T	T
T-9	6/17	T	T	T	T	T	T	T	T	T
T-10	6/18	T	T	T	T	T	T	T	T	T
T-11-BR	6/20	T	T	T	T	T	T	T	T	T
T-11-ST	6/20	T	T	T	T	T	T	T	T	T
SPEC-7	7/7	T	T	T	T	T	T	T	T	T

Notes: All values listed are in units of mg/l.
All metals analyzed by ICP

T - Sample Taken
O - Analysis Ordered
N - No Data from Sample

Table 4-4

[261,30]GEOSUM.132;V5
Status as of 8/30/88ANALYSIS SUMMARY
(RP2390-1; TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	S	Cr	V	Cu	Ti	Al	Ni	Mo	Sb	Sn	Li
SPEC-1	6/1	T	T	T	T	T	T	T	T	T	T	T
SPEC-2	6/2	T	T	T	T	T	T	T	T	T	T	T
SIG1-ST	6/7	221.	<0.01	<0.01	<0.01	<0.01	0.13	<0.01	<0.01	<0.01	<0.01	<0.01
SIG1-BR	6/7	232	0.115	0.38	2.29	<0.01	0.200	0.026	0.034	0.63	<0.01	224
T-1	6/7	223	0.118	0.38	1.82	<0.01	0.10	0.031	0.035	0.67	<0.01	234
T-2	6/8	T	T	T	T	T	T	T	T	T	T	T
SPEC-3	6/8	T	T	T	T	T	T	T	T	T	T	T
SPEC-4	6/8	T	T	T	T	T	T	T	T	T	T	T
T-3	6/9	T	T	T	T	T	T	T	T	T	T	T
SIG2-BR	6/10	231.	0.027	0.476	3.71	<0.01	0.283	0.045	0.021	0.93	<0.06	231.
SIG2-ST	6/10	90.0	0.013	<0.01	0.033	<0.01	0.030	<0.02	<0.02	<0.06	<0.06	0.120
SPEC-5	6/10	T	T	T	T	T	T	T	T	T	T	T
SPEC-6	6/10	T	T	T	T	T	T	T	T	T	T	T
T-4	6/11	T	T	T	T	T	T	T	T	T	T	T
T-5	6/12	T	T	T	T	T	T	T	T	T	T	T
T-6	6/13	T	T	T	T	T	T	T	T	T	T	T
SIG3-ST	6/14	71.2	<0.01	<0.01	<0.01	<0.01	0.032	<0.02	<0.02	<0.06	<0.06	<0.05
SIG3-BR	6/14	239.	0.29	0.90	5.24	<0.01	0.281	0.045	0.029	0.99	<0.06	247.
T-7	6/15	T	T	T	T	T	T	T	T	T	T	T
T-8	6/16	T	T	T	T	T	T	T	T	T	T	T
T-9	6/17	T	T	T	T	T	T	T	T	T	T	T
T-10	6/18	T	T	T	T	T	T	T	T	T	T	T
T-11-BR	6/20	T	T	T	T	T	T	T	T	T	T	T
T-11-ST	6/20	T	T	T	T	T	T	T	T	T	T	T
SPEC-7	7/7	T	T	T	T	T	T	T	T	T	T	T

Notes: All values listed are in units of mg/l.
All metals analyzed by ICP.

T - Sample Taken
O - Analysis Ordered
N - No Data from Sample

Table 4-5

[261,30]GEOSUM.132;V5
Status as of 8/30/88GC ANALYSIS SUMMARY
(RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	CO2	H2	H2S	N2	CH4	C2H6	C3H8	n-C4H10	i-C4H10	n-C5H12	i-C5H12
SPEC-1	6/1											
SPEC-2	6/2											
SIG1-ST	6/7	36,600	18.9	141	56.1	82.7	38.5	48.0	36.7	103.	29.7	23.3
SIG1-BR	6/7	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
T-1	6/7											
T-2	6/8											
SPEC-3	6/8											
SPEC-4	6/9											
T-3	6/9											
SIG2-BR	6/10	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
SIG2-ST	6/10	28,800	4.06	16.1	40.5	53.7	19.9	27.8	<14.5	68.6	<14.5	<14.5
SPEC-5	6/10											
SPEC-6	6/10											
T-4	6/11											
T-5	6/12											
T-6	6/13											
SIG3-ST	6/14											
SIG3-BR	6/14	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
T-7	6/15											
T-8	6/16											
T-9	6/17											
T-10	6/18											
T-11-BR	6/20	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
T-11-ST	6/20	28,700	5.51	40.0	110.	42.9	9.28	14.5	<14.5	39.7	<14.5	<14.5
SPEC-7	7/7											

Notes: All values listed are in units of (mg of non condensable gas)/(kg of steam after separator).
Results are from gas chromatography analysis of the non condensable gas fraction of the steam after the separator.
Less than numbers calculated from the estimated gas to brine ratio (less than 1 ml gas for 10 l of brine).

Table 4-6

[261,30]GEOSUM.132;V5
Status as of 8/30/88ANALYSIS SUMMARY
(RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	TDS mg/kg	Conduct. umho/cm	pH -log[H ⁺]	Eh mV	Diss. O ₂ mg/kg	Turbidity NTU	Gas:Brine	B mg/l	TSS mg/kg	Density g/ml
SPEC-1	6/1	T	T	T	T	T	T	N	T	T	
SPEC-2	6/2	T	T	T	T	T	T	N	T	T	
SIG1-ST	6/7	T	2150.	5.87	-311.	<0.005	688	0.0372	17.2	T	
SIG1-BR	6/7	T	535,000	4.89	-58.	<0.005	563	N	570.	T	1.22
T-1	6/7	T	535,000	4.89	-58.	<0.005	T	N	576.	T	
T-2	6/8	T	535,000	5.47	-118.	<0.005	T	N	T	T	
SPEC-3	6/8	T	693,000	4.57	10	0.020	T	N	T	T	
SPEC-4	6/9	T	T	T	T	T	T	N	T	T	
T-3	6/9	T	629,000	6.74	-49	0.02	T	N	T	T	
SIG2-BR	6/10	331,000	T	8.31	T	T	147.	N	T	7,490	
SIG2-ST	6/10	21.	T	6.15	T	T	T	0.029	T	<10.	
SPEC-5	6/10	T	T	T	T	T	T	N	T	T	
SPEC-6	6/10	T	T	T	T	T	T	N	T	T	
T-4	6/11	T	628,000	5.04	29	0.005	T	N	T	T	
T-5	6/12	T	685,000	5.16	-40	0.02	T	N	T	T	
T-6	6/13	T	645,000	5.14	-50	0.02	T	N	T	T	
SIG3-ST	6/14	15.8	2560.	6.38	-292	0.30	81.	N	T	T	
SIG3-BR	6/14	332,000	648,000	5.3	-38	0.007	76.	N	T	9130	
T-7	6/15	T	627,000	5.48	-48	0.007	T	N	T	T	
T-8	6/16	T	640,000	5.49	-72	0.007	T	N	T	T	
T-9	6/17	T	648,000	5.46	-95	0.005	T	N	T	T	
T-10	6/18	T	632,000	5.47	-71	0.007	T	N	T	T	
T-11-BR	6/20	T	636,000	5.48	-81	0.01	T	N	T	T	
T-11-ST	6/20										
SPEC-7	7/7	T	T	T	T	T	T	N	T	T	

Notes: B analyzed by ICP

T - Sample Taken
O - Analysis Ordered

N - No Data from Sample

Table 4-7

[261,30]GEOSUM.132;V5
Status as of 8/30/88ANALYSIS SUMMARY
(RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	F-	Cl-	NO3-	SO4=	Br-	I-	NH4+	As	Hg	Se
SPEC-1	6/1	T	T	T	T	T	T	T	T	T	T
SPEC-2	6/2	T	T	T	T	T	T	T	T	T	T
SIG1-ST	6/7	<0.05	7.30	0	6.99	<0.05	<0.01	403.	0.16	<0.002	<0.001
SIG1-BR	6/7	235.	205,000	0	110.	<50.	<100.	478.	8.31	<0.002	<0.001
T-1	6/7	232.	204,000	0	<50	0	0	T	T	T	T
T-2	6/8	234.	204,000	0	<50	0	0	T	T	T	T
SPEC-3	6/8	T	T	T	T	T	T	T	T	T	T
SPEC-4	6/9	T	T	T	T	T	T	T	T	T	T
T-3	6/9	T	T	T	T	T	T	T	T	T	T
SIG2-BR	6/10	0	219,000	0	0	<50.	<100.	0	9.13	<0.002	<0.001
SIG2-ST	6/10	0	9.63	0	0	<0.05	<0.01	0	0.27	<0.002	<0.001
SPEC-5	6/10	T	T	T	T	T	T	T	T	T	T
SPEC-6	6/10	T	T	T	T	T	T	T	T	T	T
T-4	6/11	T	T	T	T	T	T	T	T	T	T
T-5	6/12	T	T	T	T	T	T	T	T	T	T
T-6	6/13	T	T	T	T	T	T	T	T	T	T
SIG3-ST	6/14	0	10.8	0	0	<0.05	<0.01	0	0.185	<0.002	<0.001
SIG3-BR	6/14	0	225,000	0	0	<50	<100.	0	16.2	<0.002	0.0012
T-7	6/15	T	T	T	T	T	T	T	T	T	T
T-8	6/16	T	T	T	T	T	T	T	T	T	T
T-9	6/17	T	T	T	T	T	T	T	T	T	T
T-10	6/18	T	T	T	T	T	T	T	T	T	T
T-11-BR	6/20	T	T	T	T	T	T	T	T	T	T
T-11-ST	6/20	T	T	T	T	T	T	T	T	T	T
SPEC-7	7/7	T	T	T	T	T	T	T	T	T	T

Notes: Anions analyzed by Ion Chromatography, Ammonia analyzed by Spectrophotometry.
As and Se analyzed by AA hydride, Hg analyzed by cold vapor AA.

T - Sample Taken N - No Data from Sample
O - Analysis Ordered

Table 4-8

[261,30]GEOSUM.132;V5
Status as of 8/30/88ANALYSIS SUMMARY
(RP2390-1, TOL-9, Salton Sea Deep Well, June 1988)

Abb. ID	Date	Si-ice mg/l	Si-acid mg/l	HCO3- mg/l	CO2 mg/kg	H2S mg/kg	Au-AA mg/l	He mg/kg	Rn-gas picocuries	Rn-filt
SPEC-1	6/1									
SPEC-2	6/2									
SIG1-ST	6/7	1.09	0.37	1490	4320	475		<30	1.58	
SIG1-BR	6/7	171	13.7	42		7.4	<1.			
T-1	6/7									
T-2	6/8					2.7				
SPEC-3	6/8									
SPEC-4	6/9									
T-3	6/9									
SIG2-BR	6/10	164	178	10	147	6.1	<1.			
SIG2-ST	6/10		3.84	1470	13,600	627		<30	2.3	.23, .25, .20
SPEC-5	6/10									
SPEC-6	6/10									
T-4	6/11									
T-5	6/12									
T-6	6/13									
SIG3-ST	6/14	2.71	1.25	1490	15,400					
SIG3-BR	6/14	147	167	9	270		<1.			
T-7	6/15									
T-8	6/16									
T-9	6/17									
T-10	6/18									
T-11-BR	6/20		219		264					
T-11-ST	6/20	2.88	14.4		14,200			<30	2.0	
SPEC-7	7/7									

Radon values have been reported in pico curies/liter
CO2 and H2S were converted from the CO3= and S= values on Table 4-2, respectively

T - Sample Taken
O - Analysis Ordered
N - No Data from Sample

4.1.1 Steam (continued)

Eleven gases were analyzed using a Model 5880 Hewlett-Packard gas chromatograph equipped with a thermal conductivity detector (TCD). Hydrogen was quantitated on a separate analytical run using a different carrier gas. An attempt was made to detect helium, but the detection limit was 30 ppm (in the gas phase). This corresponds to a detection limit of about 1 ppm when normalized back to the separated steam flow stream, and about 0.15 ppm in the original well bottom fluid.

Carbon dioxide and hydrogen sulfide were sampled using trapping solutions. Sodium hydroxide is used for trapping carbon dioxide, which reacts to form carbonate. A Sulfide Anti-Oxidant Buffer (SAOB) is used to trap hydrogen sulfide. In both cases the volumes of trapping solution and sample trapped are recorded to normalize the analytical results back to the stream being sampled.

The carbonate and sulfide results determined from the trapping solution analyses are given in Table 4-2. The trap values reported are lower than the results of the gas chromatography analysis but the traps provide a better measure of CO₂ and H₂S due to better precision.

Other species of special interest in the steam line include sodium, potassium, calcium, iron and arsenic. The values for these compounds can be found in Table 4-2. The values for SIG2-ST (signature 2, steam) are higher than those seen in the other Signature Tests. The data indicate that some wet steam was sampled during the this steam signature test. However, this difference will not significantly affect the normalized well bottom values because the steam carries very little of the flow of these species.

Arsenic values have been reported in the steam at unusually high levels. The data indicate that one or two percent of the arsenic from the brine is being carried over into the steam fraction, possibly due to the formation of a volatile arsenic complex.

The iron detected probably comes from the pipes carrying the steam. Trace levels of manganese, lead, barium and strontium were also identified in the steam samples. Only a small fraction (~0.01%) of the amounts of these species in the brine were carried over into the steam, in contrast to the case of arsenic, where percentage amounts carried over into the steam.

4.1.2 Brine

Testing of the brine included three Signature Tests and 11 Tracking Tests. In the case of the brine Signature Test, no gas flow was detected and no gas samples taken. The detection limit for gas flow is approximately 0.2 cc's of gas per liter of fluid, which is equivalent to 0.4 mg/kg if the gas were 100% CO₂. According to the gas chromatographic analysis of steam samples, over 98% of the noncondensable gas is CO₂, and carbonate levels in the brine were determined using the trapping methods mentioned earlier in Section 3.2.5.

The brine fluid was a yellowish color with a pH less than 5 which is more acidic than the steam fraction of the separated fluids. This acidic

nature required modifications to some of CHEMLAB's chemical analyses. This has already been mentioned in section 3.1.1 earlier. The brine contained over thirty percent dissolved solids with a density of about 1.2 grams per cubic centimeter. Unless preserved with acid (to pH < 2), the brine did not retain the dissolved solids, and began to precipitate out an iron oxide looking precipitate.

The chloride values (shown in Table 4-2) accounted for the major part of the dissolved solids. All of the chloride values appearing in this first column were analyzed by coulometric titrations. It should be noted that these values have not been corrected for the small amounts of bromide and iodide present in the brines. The analysis for bromide and iodide anions by ion chromatography did not produce quantifiable results because of the relatively low concentrations. Therefore the chloride values should not be affected significantly.

The results for all other anionic species normally analyzed for by the CHEMLAB are listed in Table 4-7. Fluoride and sulfate were the only other anionic species quantifiable by ion chromatography and the results are also shown in Table 4-7. For the limited set of chloride data presented in the tables, the precision of the numbers produced by the ion chromatographic technique is better than that for the coulometric titrator.

An alternate method for the ion chromatographic technique would be to perform a spectrophotometric determination of the nitrate by complexing it with an appropriate reagent and passing the solution through a spectrophotometric cell tuned to the appropriate wavelength. Nitrate standards are also run and concentration is proportional to the absorbance (i.e., the Beer-Lambert law). Sample data would then be reduced by method of linear regressions.

The charge balances between the chloride anion and the cationic metal species analyzed were in good agreement for the Signature Tests. The values for chloride and the most abundant metals are shown in Tables 4-2 and 4-3. The most abundant metals, listed in their order of abundance, are sodium, calcium, potassium, iron and manganese. The brines also exhibited high levels of zinc, boron, strontium, lithium, barium, and lead. These are again listed in order of their reported abundances.

Preliminary results indicated ppm levels of gold in the fluids when analyzed by ICP spectrometry. Subsequent analyses by flame AA for gold using methyl ethyl ketone to extract the metal showed there to be less than 1 ppm gold. The value reported for gold in Table 4-8 is 0.05 parts per billion and was determined by neutron activation analysis of a sample from signature test number three. The measurement uncertainty for this value is approximately 0.01 ppb, and the detection limit for gold is 0.03 ppb.

4.1.2 Brine (continued)

While performing the neutron activation analysis for gold, the analyst was able to qualitatively estimate the platinum concentration to be approximately 40 parts per billion. However, the uncertainty is 20 ppb, with a detection limit of approximately 20 ppb for platinum.

Other values quantified include arsenic, tungsten, antimony, copper, vanadium, cadmium, and silver. These elements have routinely been determined on geothermal fluids in the past by flame AA, but have rarely been detected.

Barely detectable amounts of dissolved oxygen were measured and could be due in part to atmospheric oxygen contaminating the sample during the measurement itself.

4.2 TRACKING

The results obtained within 24 hours of each set of daily tracking measurements agreed well with each other and with the Signature Test results. These included pH, Eh, conductivity, dissolved oxygen, and chloride.

Daily Tracking Tests were conducted at the brine port from June 7 to June 20 (except for June 19). This port sampled the separated brine emerging from the separator as in the Signature Test. An additional Tracking Test was conducted at the weir box in order to allow for the comparison of data generated by other investigators who sampled at the weir box rather than at the brine port. One tracking test was conducted at the steam port on the last day of the test.

Raw samples were collected during Tracking Tests for immediate measurement of pH, conductivity, Eh, dissolved oxygen, and chloride (by coulometric titration). Acidified samples were taken for analysis of approximately 30 metals at C-E Environmental's analytical facility (EMSI) in Camarillo, California, by inductively coupled argon plasma spectrophotometry (ICP).

Eleven sets of tracking tests were conducted at the brine port at four different flow rates from the well. The ports to be used and the types of samples to be collected (raw, acidified, trap or flow) were preselected by EPRM and EMSI staff. Tracking samples were collected in delta-T mode, in which the temperature is dropped in a cooling bath before the pressure is changed. The delta-T mode utilized two condensing coils in series at the sampling port. Additional liquid samples were collected under ice for silicon.

4.3 SPECIAL

Sampling locations for the Special Tests were at the weir box, injection pump, and brine pond for sludge and liquid. In addition, a test of the noncondensable gas flowrate was conducted at the brine port. There were four events at the weir box, two of which were samples taken by Dave Mulliner of Kennecott on June 1 and June 2. There were two sampling events at the brine pond (the first for sludge and the second for both

sludge and the pond liquid). There was one event at the injection pump, and this sample was taken by the Mesquite Group, Inc.

4.3.1 Noncondensable Gas in the Brine

One of the Special Tests conducted at the brine sampling port was a determination of the noncondensable gas fraction of the brine. The brine sample was routed to an inverted 1-liter graduated cylinder filled with water so that any noncondensable gas would be trapped in the graduated cylinder. The total volume through the trap was determined by measuring the flow rate and elapsed time. This verified that it would not be necessary to use the FSS for getting gas bomb samples from the brine.

4.3.2 Weir Box

The weir box Special Tests included the collection of the standard set of samples being taken with the LLL probe at the steam and brine ports. The brine weir box samples were obtained by dipping the sample bottles into the brine discharge flowing from the weir box into the pond. During sampling cubic crystals of sodium chloride were observed in the weir box. The raw samples were collected for a determination of the total suspended solids (TSS) at three points along the flow stream. These results were made available to the Bechtel project management during the test in an effort to help with estimating the sludge accumulation rate in the brine pond. These samples were taken at the weir box, in the pond and at the injection pump.

In addition to the grab samples taken at the brine weir box at the beginning of June, a weir box sample was collected concurrent with a standard Tracking Test. This test was conducted in order to allow for the comparison of the brine weir box samples taken by other investigators at the start of the test.

4.3.3 Brine Pond

Sludge samples were taken from the brine pond in order to quantify the moisture and salt content because of the concerns about the scope of waste disposal work required after the flow test. Using filtering techniques coupled with water rinses, the weight percent water and soluble salts was determined.

4.3.4 Injection Pump

As part of the effort to determine sludge buildup, a sample of brine being discharged from the pond was taken at the injection pump by removing the pressure gauge and filing a sample bottle directly from the orifice. The weight percent TSS was determined on this sample and represents the fluid leaving the pond for injection. The difference in the TSS measurement between the injection pump and the weir box (brine into the pond) provided the quantitative information necessary to estimate the sludge accumulation rate.

5.0 CONCLUSIONS

The conclusions that can be drawn from the data to date (August 31) are limited to wellhead signature data collected at four different well flow rates. The results from the three complete Signature Tests and one limited signature (labeled Tracking 11) are summarized in Table 5-1, and have been normalized to the well bottom flow conditions. The equation used to calculate the normalized well bottom values was:

$$\begin{aligned} & \text{Concentration of analyte in well bottom fluid} = \\ & (\text{Concentration of analyte in brine}) \times (\text{brine mass fraction}) \\ & + (\text{Concentration of analyte in steam}) \times (\text{steam mass fraction}). \end{aligned}$$

The mass fractions used were derived from flows reported by the Mesquite Group, as listed in Table 2-1.

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Table 5-1

ANALYSIS SUMMARY
(RP-2390, TOL-9, Salton Sea Deep Well, June 1988)

WELL CHARACTERISTICS

	SIG1	SIG2	SIG3	TRK11
TOTAL WELL FLOW RATE (1000 b ³ /hr)	131	226	407	435
MASS FRACTION STEAM	0.15	0.15	0.15	0.14
ANALYTE	CONCENTRATION IN WELL BOTTOM FLUID (mg/l)			
	SIG1	SIG2	SIG3	TRK11
CO ₂		2,080	2,360	2700
H ₂ S	82	95		
Chloride	174,000	179,000	179,000	
Sodium*	59,800	67,400	65,800	
Potassium	16,200	13,600	18,700	
Calcium	28,200	36,800	35,900	
Magnesium	17.6	16.5	16.2	
Iron	1560	1580	1770	
Silicon	143	153	141	146
Lead	93	87	78	
Cadmium	0.56	0.64	0.64	
Silver	0.073	0.201	0.224	
Gold*			0.5 ppb	
Arsenic	7.01	7.9	16.1	
Mercury	<0.002	<0.002	<0.002	
Selenium	<0.001	<0.001	0.001	

* Sodium analyzed by flame Atomic Absorption Spectrophotometry. All other metal analyses performed by ICP spectrophotometry, except for gold which was measured by neutron activation analysis.

Table 5-1 (continued)

ANALYSIS SUMMARY
 (RP-2390, TOL-9, Salton Sea Deep Well, June 1988)

ANALYTE	CONCENTRATION IN WELL BOTTOM FLUID (mg/l)			
	SIG1	SIG2	SIG3	TRK11
Aluminum	0.189	0.234	0.261	
Boron P	482.			
Barium R	137.	87.	107.	
Cadmium E	0.56	0.64	0.51	
Cobalt	0.038	0.033	0.040	
Chromium L	0.097	0.233	0.250	
Copper I	1.93	3.18	4.41	
Lithium M	231.	231.	244.	
Molybdenum I	0.029	0.018	0.022	
Nickel N	0.022	0.039	0.039	
Lead A	93.4	86.	77.6	
Sulfur R	230.	211.	214.	
Antimony Y	0.53	0.80	0.86	
Tin	<0.06	<0.06	<0.06	
Strontium	406.	392.	440.	
Titanium D	<0.01	<0.01	<0.01	
Vanadium R	0.41	0.41	0.42	
Tungsten A	3.87	3.87	3.91	
Zinc F	543.	483.	543.	

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Table 5-1 (continued)

ANALYSIS SUMMARY
 (RP-2390, TOL-9, Salton Sea Deep Well, June 1988)

ANALYTE	CONCENTRATION IN WELL BOTTOM FLUID (mg/l)			
	SIG1	SIG2	SIG3	TRK11
Carbon Dioxide	5490	4320		4030
Hydrogen ^P	2.99	0.61		0.77
Hydrogen Sulfide ^R	21.2	2.42		5.6
Nitrogen ^E	8.42	6.08		15.
Methane	12.4	8.06		6.0
Ethane	5.78	2.99		1.29
Propane	7.2	4.17		2.0
n-Butane	5.5 ^M	10.3		2.0
i-Butane	15.5	<2.2		5.6
n-Pentane	4.46	1.2 ^N		<2.0
i-Pentane	3.50	<2.2 ^A		<2.0
Ammonia	466.			
Fluoride	198.			
Sulfate	93.8			

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Appendix K

SEISMIC MONITORING
(Lawrence Livermore National Laboratory)

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Seismic Monitoring of the June, 1988 Salton Sea Scientific Drilling Program Flow/Injection Test

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M Abstract

The purpose of the seismic monitoring project was to characterize in detail the micro-seismic activity related to the Salton Sea Scientific Drilling Program (SSSDP) flow-injection test in the Salton Sea Geothermal Field. Our goal was to determine if any sources of seismic energy related to the test were observable at the surface. We deployed our recording stations so that we could detect and locate both impulsive microearthquakes and continuous seismic noise energy.

Our network, which was sensitive enough to be triggered by magnitude 0.0 or larger events, found no impulsive microearthquakes in the vicinity of the flow test in the 8 month period before the test and only one event during the flow test. This event has provided the opportunity to compare the detection and location capabilities of small networks and arrays in a geothermal environment.

At present, we are carefully scanning all of the data that we collected during the flow test for evidence of anomalous seismic noise sources and for impulsive events smaller than the network detection threshold (magnitude 0.0).

F T Background

Geothermal reservoirs often produce detectable geophysical signals both before and during production. These signals, if understood, could provide valuable information about the processes taking place within the reservoir. This kind of information can be used to guide reservoir development strategies. Some geophysical signals, such as resistivity and gravity, are well understood, and their contribution to reservoir engineering models has been demonstrated in many geothermal fields. Other geophysical signals, including seismic

signals, are not so well understood. Lawrence Livermore National Laboratory (LLNL) has a program to collect case histories of surveys of geophysical signals produced during injection and production of geothermal fields. In this paper, we describe a case study of seismic signals produced during a small-scale injection-production test at the Salton Sea Geothermal Field.

Several different types of seismic signals have been observed in geothermal areas. Low-frequency (< 20 Hz) tectonic earthquakes associated with geothermal production have been observed at the Geysers Geothermal Field [Eberhart-Phillips and Oppenheimer, 1984]. Acoustic emissions (high-frequency microearthquakes) have been observed during hydraulic fracturing at Fenton Hill [Fehler and Bame, 1985], and during reservoir production in Japan [Niitsuma et al., 1985]. Geothermal "noise" (anomalously high seismic signals having no clear onset and lasting longer than several tens of seconds) has been observed near several geothermal areas [Douze and Laster (1979), Goforth et al., (1972)].

The flow-injection test conducted as the second phase of the SSSDP provided an opportunity to study seismic signals associated with the initial fluid production from a well-studied area. During the first phase of the SSSDP, the State 2-14 well was drilled to a depth of 3 km. During the flow/injection test, fluids produced from an open section of State 2-14 between approximately 2000 m and 3200 m depth were injected into Imperial 1-13, about 600 m to the north (Fig. 1). The flow continued for approximately 30 days. We installed a seismic recording system to monitor microearthquakes and continuous seismic noise signals associated with the initial production of these two wells.

Seismic Network Description and Data Collection Procedure

Figure 1 shows the configuration of the LLNL seismic stations during the flow test. Two sets of stations were deployed; 1) seven three-component stations within a 3 km radius of the two wells, which we will refer to as the network stations, and 2) three small groups of six to nine sensors within a 100 m square area, which we will refer to as arrays A, B, and C. The network of three-component stations, which provide primarily phase arrival times, was used to detect and locate microearthquakes in the traditional manner. The network of three arrays, which can provide direction, velocity, and depth information for any incoming seismic energy, was used to monitor all possible low-frequency (3-25 Hz) sources of seismic energy originating from the flow/injection zone.

The seismic signals were digitized at each station at a rate of 120 samples/sec and the digital signals transmitted to the central recording site located near well 2-14. The frequency range covered by the three-component stations was 1 to 30 Hz. The arrays were optimized for signals between 3 and 25 Hz. All of the sensors were buried several inches below the ground surface.

Our recording procedure during the flow/injection test was designed to detect both the impulsive and continuous sources of energy. To record microearthquakes, an event detection process at the central recording site monitored all of the signals continuously and archived all

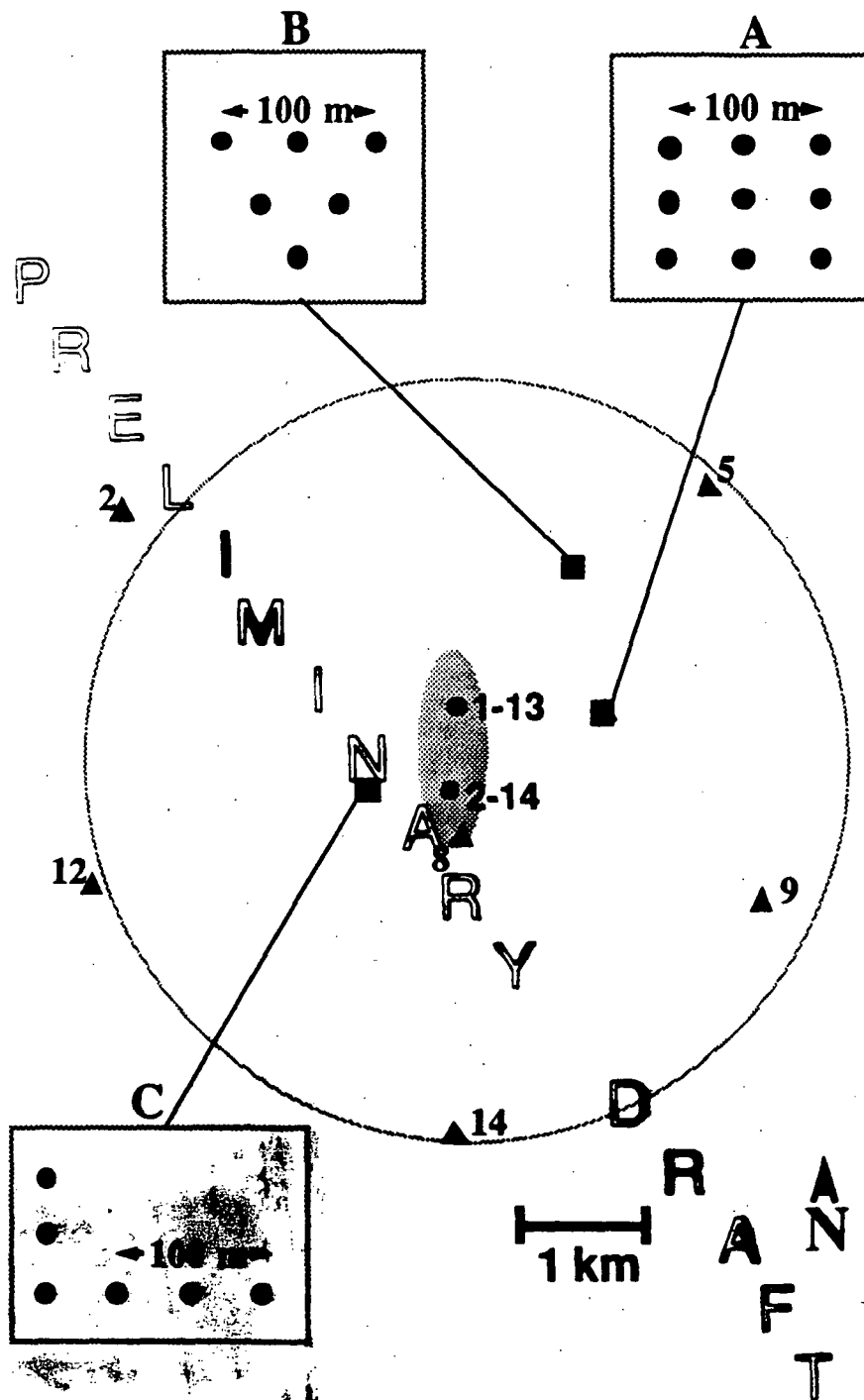


Figure 1. Map of the LLNL seismic network during the June, 1988 flow/injection test. The triangles are three-component station locations and the squares are the array locations. The insets show the geometries of the arrays A, B, and C. The shaded elliptical zone delineates the area within which we expected to see seismic activity related to the test.

of the waveforms when a detection threshold set to produce an acceptable false alarm rate was exceeded at the required number of stations. To record continuous sources and/or impulsive events smaller than the network detection threshold, we archived data for two minutes twice an hour. This recording network and recording system is capable of detecting all types of events previously seen in geothermal fields, except for acoustic emissions with dominant frequencies greater than 30 Hz.

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Microearthquake Monitoring

We monitored the flow test zone for background seismicity between Sept. 1987 and the beginning of the flow test on June 2, 1988. During this time, the system operated in the event-detect mode. We have not finished processing the data, but between Sept. 1987 and March 1988, no detectable microearthquakes occurred within the zone. We have recorded numerous earthquakes located just outside our network, however, and from the size of these events can estimate the lower detection threshold of our system to be magnitude 0.0.

Preliminary results from the data collected during the flow/injection test do not indicate any microearthquake activity larger than magnitude 0.0 within the zone of interest. This negative result indicates that neither stress nor thermal effects were large enough to induce microearthquakes larger than this threshold during the shallow test. We are continuing to process the data to search for both smaller magnitude microearthquakes and continuous energy sources that may have occurred before and during the flow test. By searching the two-minute force-recorded segments, we have so far been able to detect one event that will be discussed in detail below.

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Analysis of Flow Event

When State 2-14 was first opened, we recorded a single small (magnitude -0.5) seismic event followed a few seconds later by an air wave. We have not yet determined the cause of this signal, but it provides us an opportunity to compare the monitoring capabilities provided by the traditional networks with the experimental array method. We will present here in detail the information that we have been able to infer about these signals using both the seven station three-component network and the three arrays.

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Characteristics of Flow Event

Three vertical component waveforms for the flow event are plotted in Figure 2. The event-to-station distance is increasing from the top to the bottom trace. The seismic wave and the air wave are clearly differentiated by the difference in moveout across the network.

The same information can be obtained by computing the narrow band 2-dimensional wavenumber [Aki and Richards, 1980] from the signals at one of the arrays (array A). Figure 3 shows contour plots of power as a function of the narrow band 2-dimensional

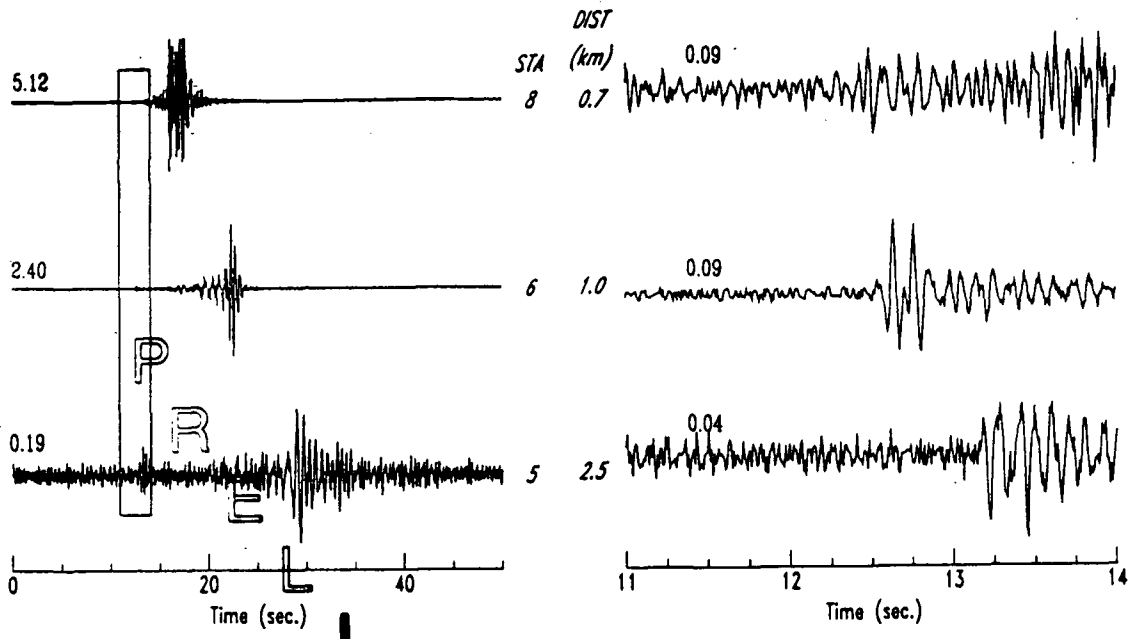


Figure 2. Seismograms from the flow event from stations at three different distances. At left is a 50 second segment dominated by the high-amplitude air wave. At right is the smaller seismic portion of the signal enclosed by the box in the left figure. Zero time is June 2, 1988 00:41:44, 10 minutes after State 2-14 was opened. The number above each trace is the maximum amplitude of the seismogram times 10^{-4} nm/sec. The distance between the station and the event is shown between each pair of traces.

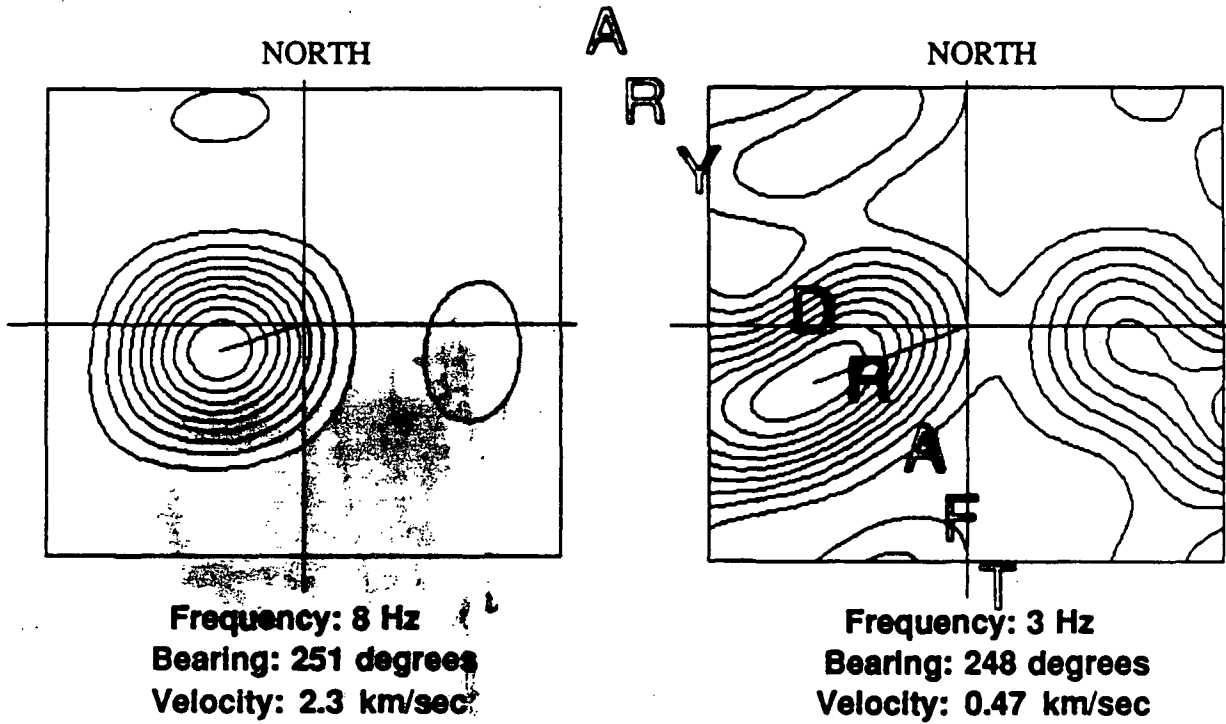


Figure 3. Contours of narrow-band 2-dimensional wavenumber power for the seismic (left) and air (right) waves recorded at array A. The bearing is measured clockwise from north. The wavenumber is 0 km^{-1} at the center and 10 km^{-1} at the edge of the plot.

wavenumber for the air wave and the seismic phase. The azimuth of arrival is obtained from the azimuthal position of the peak power. The wavenumber of the arrival is obtained from the radial position of the peak. The apparent velocity is the ratio of the frequency at which the spectrum is calculated and the observed peak wavenumber.

It can be seen from Figure 3 that the two phases are arriving from the same azimuth, but that their apparent velocities are quite different. For the air wave, the frequency is 3 Hz and the peak wavenumber is 6.4 km^{-1} , yielding a velocity of 0.47 km/sec., which is slightly higher than the velocity of sound (0.33 km/sec.). For the seismic wave, the frequency is 8 Hz and the peak wavenumber is 3.48 km^{-1} , resulting in an apparent velocity of 2.3 km/sec.

Location of Flow Event

We were able to determine the location of the seismic phase using both the 3-component network and the arrays. The network location was obtained from the P- and S-arrival times at 5 of the stations by using a standard location algorithm. The array location was obtained by estimating the bearing from each of the three arrays.

We used a standard location algorithm [HYPO71 (Revised), Lee and Lahr, 1973] to locate the seismic phase using the phase arrival times. The algorithm finds the hypocentral location that minimizes the sum of the squares of the travel-time residuals. The velocity model was derived from vertical seismic profile (VSP) data from well 2-14 interpreted by Daley et al., 1988

The epicentral location for the event derived from the network arrival times is shown on Figure 4, and the depth calculated for the event is 900 m. We estimate that the uncertainty in this location is 200 m vertically and 300 m horizontally. The area defined by the epicentral location and its uncertainties is shown on Figure 4 as a circle with a radius of 300 m.

The location defined by the three arrays is obtained graphically from the intersection of the bearing measurements from the three arrays, as shown in Figure 4. The uncertainty in each of the beams (± 3 degrees) is illustrated by the shaded wedges emanating from the arrays.

Depth Estimation for Flow Event

The depth of the source can also be estimated using the arrays. To obtain absolute depth, precise information about the velocity model is needed. This can be obtained from independent sources such as VSP data, or by calibration of the arrays with explosions or earthquakes at several different known depths.

Because the event we are studying is fairly shallow, we can use a simple velocity model to estimate the depth from the array data. The material under the array is saturated alluvium, which has a seismic velocity of 1.5 km/sec. According to a nearby seismic refraction study by Frith (1978), the velocity increases to 2.0 km/sec at a depth of about 100 m. We can use this velocity model to calculate the depth of our source from the apparent velocity observed by the

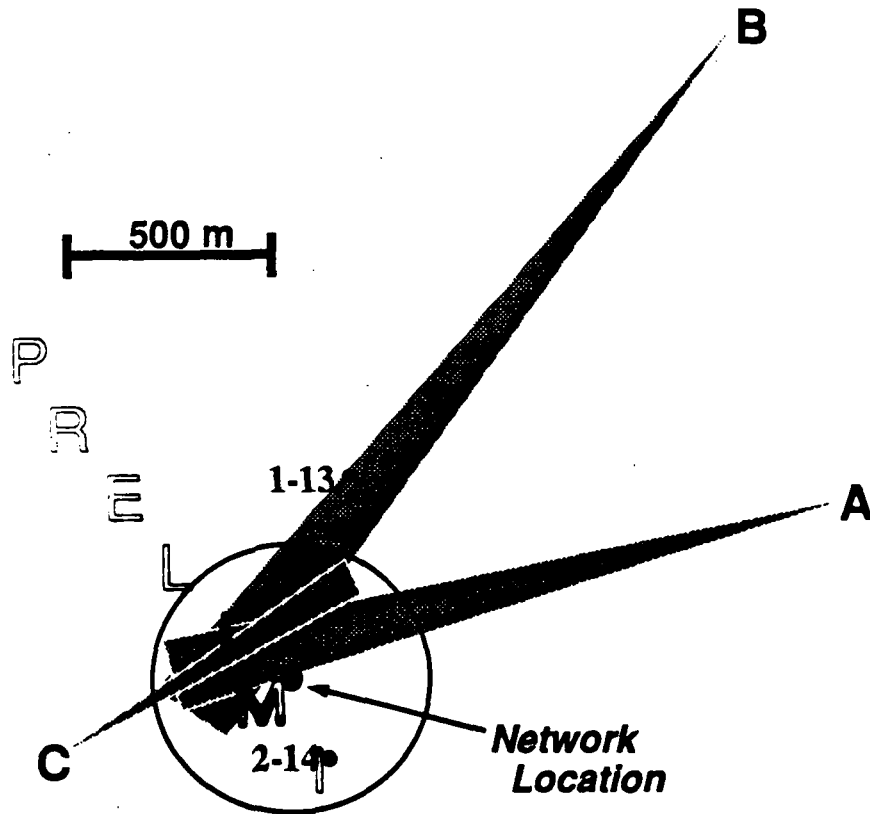


Figure 4. Summary of location results for the seismic part of the flow event. The array location is defined by the intersection of the beams from the three arrays. The network location is obtained from the arrival times at the network stations. The uncertainty in the network location (400 m) is indicated by the circle centered on the location. The network and array locations are the same, within the uncertainties of each measurement.

array. Using the observed apparent velocity of 2.3 km/sec, and a horizontal distance of 1500 m, the calculated depth is 900 m.

For deeper events, depth calculation becomes more difficult because more layers are involved and refracted arrivals have to be considered. For this reason, calibration with earthquakes or explosions is desired. If calibrations are not available, the arrays can still be used to determine relative depths of events.

Discussion/Conclusions

The lack of microseismicity associated with this flow test is probably a result of the fact that the pressures produced by the injection were not high enough to induce stresses sufficient to fracture the relatively weak, highly permeable material in which the flow took place. The origin of the event we analyzed here is still not known. We do know that it occurred within 400 m of well 2-14 shortly after the well was opened. The event seems to have occurred at a

depth (1100 to 700 m) shallower than the open section of the well (3200 to 2000 m). The timing of the arrival of the air wave suggests that it originated at the depth of the seismic phase and propagated up to the surface via the open well.

The data that we have analyzed allows us to assess the capability of the relatively unproven array methods compared to the more traditional network methods. The network provides better locations if events are large (greater than magnitude 0.0 for this network) and impulsive. The arrays, on the other hand, are more useful when the events are smaller and not recorded well by all of the network stations. This is primarily a result of their ability to enhance the signal amplitude relative to the noise. Our example event, which was not recorded well by all of the network stations, bears this out because the uncertainty in the array location appears to be smaller than the uncertainty in the network location (Figure 4).

Another advantage of the arrays that we have not been able to illustrate here is their ability to provide information about seismic sources that are not impulsive. This includes continuous noise sources and events with onsets that are not clearly identifiable. These kinds of signals cannot be located with arrival time location methods, but the arrays can be used in the same way that we used them to locate the event analyzed in this paper.

Acknowledgments

We would like to acknowledge the contributions of Craig Johnston, Don Rock, and Dan Ewert to the fielding of the seismic network. Unocal Geothermal Division and Kennecott-Australia Exploration Ltd. provided instrument sites. Bechtel Corporation provided support at the recording site. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48. Funding was provided by the Department of Energy Geothermal Technology Division.

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Appendix L

METAL ION CONCENTRATIONS
(New Mexico State University)

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Salton Sea Scientific Drilling Project

Well State 2-14
June 3-5, 1988

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Title: Measurement of Metal Ion Concentrations in Geothermal Brines.

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On June 3, 4, and 5 brine samples were taken from the two-phase flowline near the wellhead. An additional sample was taken from the weirbox on June 5.

The weirbox sample was obtained by dipping a container into the active flow stream. Some of that fluid was then suction filtered and an aliquot placed into a sample bottle. The sample was clearly not complete since suspended solids, mostly related to silica precipitation, were visibly abundant and provided the main motive for filtering. Solid sodium chloride was abundant in the weirbox as a consequence of steam losses which resulted in its supersaturation. Additional sodium chloride precipitated from the sample while filtering.

Samples from the flowline were taken with a teflon lined probe/cooling coil assembly. Access was through a gate valve on the flowline about 40 feet from the wellhead. The probe, 1/4-inch O.D. stainless steel, was inserted into the flow space of the flowline through an access valve assembly located at a 3-o'clock position on the horizontal flowline. Flowline temperatures at the sampling point were essentially those of the wellhead, and near 492°F.

Although the flowline carried a mixture of steam and brine, it was intended to locate the tip of the probe near the pipe wall where a continuous liquid phase might be encountered. Cooled brine

discharging from the coil end was directed into a pre-weighed sample container containing dilute nitric acid.

At the time of flowline sampling the attempt to obtain steam-free brine appeared successful. It was possible to adjust the probe tip position so that no gas bubbles (effervescence) were associated with the discharge from the sampling assembly. Success is further indicated by the essential identity of apparent in situ concentrations for the brine samples collected on successive days (1). Additionally, the relative difference in salt contents of the flowline and weirbox samples (after adjustment for precipitation) are in good correspondence to what would be expected from steam release between the two locations. Scale deposition in the probe/coil sampling equipment appeared minor and is not considered further.

All samples were sent to a commercial laboratory for neutron activation analysis for precious metals. The samples, contained in scintillation vials with a volume of 17.3 ml, plus comparator standards, were irradiated for 30 minutes in a TRIGA Mark I Nuclear Reactor at a flux of 1.8×10^{12} n/cm²-sec. After a decay of one day, the samples for gold, platinum and palladium were wet-ashed in the presence of gold and palladium carriers. Palladium was separated using dimethylglyoxime. Gold was separated as the metal using sulfur dioxide. The separated samples were then counted on a Ge(Li) detector coupled to a multi-channel gamma-ray spectrometer. The elements gold, platinum and palladium produce Au-198, Au-199 and Pd-109 with half-lives of 2.75 days, 3.15 days and 13.5 hours respectively. The samples for silver and iridium were allowed to decay for several weeks to remove the Na-24 activity. They were then counted as above. The elements silver and iridium produce Ag-110 m, Ir-192 with half-lives of 245 days and 4 days respectively. The results are tabulated in Table 1.

The analytical data shown in Table 1 are particularly confusing for silver. None of the flowline samples indicated silver above the detection limits which ranged from 140-540 ppb. On the other hand the weirbox sample showed the presence of nearly 1 ppm (890 ppb) silver. The weirbox sample had considerable precipitate which was removed prior to collection of the sample. Data provided elsewhere in this report (1), indicates that the precipitate contained iron, silica, lead, arsenic, cadmium and copper. Iron is suspected of being co-deposited with silica, but the severe loss of copper, arsenic and cadmium suggests losses due to sulfide formation, and hence silver

and gold would also be expected to be lost as sulfides (1). (In support of this hypothesis, the gold content in the weirbox sample ranges from 20-80 percent of that found in the flowline sample). Nevertheless, the weirbox sample was the only one which showed silver above detection limits.

Gold concentrations in the flowline samples were uniformly low and ranged from 0.0325 to 0.120 ppb. Platinum, on the other hand was detected at the 5 ppb level in two of the flowline samples, but it was below the detection limit in the other four flowline samples. Considering that the platinum detection limit for these four samples ranged from 4-16 ppb, these data are not inconsistent. Iridium and palladium were not observed above detection limits in the two samples analyzed.

The variation of detection limits for various samples for the same element deserves some comment. Neutron activation analysis detection limits vary with the size of the sample irradiated, with the irradiation time, with the time elapsed between irradiation and counting, with the time of counting and with the carrier recovery. Thus unless all these factors are constant throughout the analysis, the detection limit will vary for even duplicate samples.

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Reference

1. Appendix E, Well Test Engineering Report on Testing of Kennecott State 2-14, June 1-25, 1988, Salton Sea Scientific Drilling Project, prepared by Mesquite Group Inc. for Bechtel International.

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TABLE 1. Neutron Activation Analysis of Precious Metals in Salton Sea Geothermal Water: Well State 2-14

Sample	Metal Concentration (PPB)*					Comments
	Ag	Au	Pt	Ir	Pd	
DMA 05	ND < 540.	0.0717±0.0122	ND < 16	-	-	Sample from flowline collected 6/3/88 after 500 ml passed through sampler.
DMA 08	ND < 290.	-	-	-	-	Sample from flowline collected in dilute nitric acid immediately after collection of DMA 05.
DMA 02	-	0.0586±0.0047	5.25±1.47	-	-	Sample from flowline (unacidified) collected immediately after DMA 08.
DMA 03	-	0.0683±0.0057	4.80±1.10	-	-	Sample from flowline (unacidified) collected 6/4/88 after 1000 ml passed through sampler.
DMA 06	ND < 500.	-	-	-	-	Sample from flowline (acidified) collected immediately after DMA 03
DMA 01	890.±134	0.058±0.0054	ND < 12.	-	-	Sample collected 6/5/88 at Weirbox after geothermal water exposed to atmosphere. Sample was filtered through 0.45µ filter prior to collection.
DMA 07	ND < 140.	-	-	ND < 0.8	-	Sample from flowline collected 6/5/88 and acidified.
DMA 04	-	0.0325±0.0036	ND < 4.	-	ND > 6.5	Sample from flowline (unacidified) collected immediately after DMA 07.
179	ND < 140	0.120±0.008	ND < 8.4	-	-	Sample from flowline (acidified) collected immediately after DMA 04

* ND - Not Detected below limit of detection

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Appendix M

TRANSPORT OF PLATINUM GROUP ELEMENTS, GOLD, AND SULFUR IN
THE SALTON SEA GEOTHERMAL BRINES
(University of California Riverside)

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Progress Report

August 9, 1988

TRANSPORT OF PLATINUM GROUP ELEMENTS, GOLD AND SULFUR
IN THE SALTON SEA GEOTHERMAL BRINES

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and

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We collected fluid and solid samples during the June 10 and 15 1988 flow-tests of the Salton Sea Scientific Drilling Project well California State 2-14 (S2-14). Samples of flashed brine and steam condensate were collected from the brine and steam flow-lines exiting the separator. Following the flow-tests, silica and hydroxide scales were collected from the valve between the wellhead and separator, and from an orifice plate valve on the brine flow-line after the separator. These fluid and solid samples are currently being analyzed for their contents of Pt, Pd, Rh, Au, H₂S, SO₄, I, Tl, Sc, As, Sb, Rb, Ga and In. Techniques being used are isotope dilution and fire assay inductively-coupled plasma mass spectrometry and graphite furnace atomic absorption spectrometry. Additionally, the sulfur isotopic composition ($\delta^{34}\text{S}$) of H₂S and SO₄ are currently being analyzed by a conventional gas source mass spectrometry.

Preliminary results on Pt group elements and Au indicate that significant levels of these elements are not being transported by the Salton Sea geothermal brines. These results conflict with the results of other researchers, who have used analytical techniques that may be prone to serious matrix interferences caused by the high salinity, Fe and Mn contents of the SSGS brines.

Our preliminary results have significant implications for the formation of Pt group element ore deposits. It is often proposed that transport of Pt by saline hydrothermal fluids is geologically important during the late stages of crystallization in magma-hydrothermal systems. Our results imply that this may not be the case for fluids having salinities, oxidation states and pH values similar to the SSGS brines.

Results from the sulfur isotopic analyses are not yet available. However, results from previous flow-tests of the S2-14 well indicate that fluid H_2S and SO_4 are in sulfur isotopic equilibrium, and that H_2S is generated by hydrothermal reduction of SO_4 derived from evaporitic anhydrite in the reservoir rocks. This places constraints on the nature of sulfur transport in the SSGS, and on the scaling and corrosion behavior of the brines during geothermal power production.

Our preliminary results should be available in time for presentation at the annual Geothermal Resources Council meeting, to be held in San Diego in October of 1988.

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PROGRESS REPORT
August 25, 1988

ISOTOPIC AND CHEMICAL CONSTRAINTS ON FLUID DISTRIBUTION
AND WATER-ROCK INTERACTION IN THE SALTON SEA GEOTHERMAL SYSTEM

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Samples from the Salton Sea Scientific Drilling Project well number State
2-14 were collected from separated brine and steam flow lines and from the
weir box on both June 10, 1988 and June 15, 1988.

Raw brine and steam condensate samples are presently undergoing analysis for
stable isotope ratios of D/H and $^{18}O/^{16}O$. Brine samples were also collected,
stabilized, and are being analyzed by a variety of techniques measuring major,
minor and trace element abundances. We expect information on at least 25
solute species which are typically above analytical background. Gas/steam
ratios (which roughly give the content of carbon dioxide in the production
fluid) were measured giving values on the order of 2500 ppm (somewhat higher
than similar measurements made for previous tests of the State 2-14 well).
Hydrogen sulfide was also collected from the separated steam phase for gravi-
metric analysis. Yields from our H_2S precipitation analysis are somewhat
suspect but confirm the low sulfide content (on the order of 10 ppm) observed
in other wells and previous flow tests of State 2-14.

Analyses of major brine constituents will be utilized to compute a reservoir
fluid density for comparison with similar computations (Fournier, 1988;
Williams, 1988) of fluid from other Salton Sea area wells and previous State
2-14 flow tests. Unfortunately, the producing interval for this long term
flow test is not well constrained so a vertical density distribution in the
State 2-14 well cannot easily be produced. Well controlled samples from the
long term flow test will be compared with previously acquired data from other
Salton Sea geothermal system wells. This will permit us to evaluate less well
controlled sample analyses, both chemical and isotopic, and will allow us to
make refinements on our model of fluid distribution and water-rock reactions
in this well studied active geothermal system.

We hope that data from the State 2-14 will be available for presentation
during the Geothermal Resources Council meeting (October 1988, San Diego,
California) and at the Geological Society of America Convention
(October-November 1988, Denver, Colorado).

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Appendix N

URANIUM SERIES ISOTOPE MEASUREMENTS
(University of Southern California)

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Preliminary Uranium Series Isotope Measurements from June 1988
Flow Test of the State 2-14 Well.

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Abstract. A wide range of isotopes in the ^{238}U , ^{235}U , and ^{232}Th decay chains was measured in geothermal brines collected during an extended flow test of the Salton Sea Scientific Drilling Project well (SSSDP). High concentrations of radium, radon, and lead isotopes are generated and maintained by the input of these isotopes from solid phases into brine by both recoil and leaching processes, by the high chloride content of the brine which complexes radium and lead, and by the apparent absence of suitable unoccupied adsorption sites. In contrast, uranium, thorium, actinium, bismuth, and polonium isotopes all have low concentrations due to their efficient sorption from brine to rock.

Introduction

^{238}U , ^{235}U , and ^{232}Th decay to stable isotopes of Pb through a series of shorter-lived intermediate daughters (Figure 1). In a closed system, these daughters grow into secular equilibrium with their parents, so that the daughter/parent activity (disintegration) ratio becomes unity. However, ground water and geothermal waters are not closed systems, but interact with the solid phases they contact. Because of the different geochemical properties of the intermediate isotopes in each chain, significant radioactive disequilibria often exist in these waters, and sometimes in solid phases associated with them. Both thermodynamic and kinetic factors play a role in creating and maintaining these disequilibria, and a number of workers have discussed these factors. Langmuir and his associates have provided recent reviews of the thermodynamic properties controlling the behavior of uranium, thorium, and radium in natural waters [Langmuir, 1978; Langmuir and Herman, 1980; Hsi and Langmuir, 1985; Langmuir and Riese, 1985; and Langmuir and Melchior, 1985]. Others have focused on physical factors, such as recoil during alpha decay [Tanner, 1964; Krishnaswami et al., 1982; Laul et al., 1983; Laul et al., 1985], migration of nuclides along microfractures and grain boundaries [Rama and Moore, 1984], and the possible preferential emplacement of uranium-bearing phases along grain boundaries [Krishnaswami and Seidemann, 1988].

Studies of uranium and thorium series disequilibria are of value for several reasons. First, the behavior of actinides and their daughters in thermal saline waters and their associated rocks is pertinent to the management of radioactive waste, as a natural analog of nearfield conditions of radioactive waste repositories in salt

[Elders and Moody, 1984]. Second, while studies of saturation states can give insights to possible mineral alterations [Langmuir and Melchior, 1985], the radioisotope disequilibria observed in fluid and solid phases are useful for estimating rates of brine-rock interaction. Third, radioactive disequilibria may be useful for estimating parameters of geologic interest in hydrothermal systems, such as brine flow rates, fracture sizes, and ages of vein deposits [Sturchio and Binz, 1987; Zudin et al., 1987; Hammond et al., 1988]. The SSSDP well has provided a unique opportunity to study the *in situ* behavior of the naturally occurring U-Th series radionuclides in deep geothermal brines.

Methods

Details regarding the drilling and plumbing system used to produce fluid from the well are described elsewhere [Michels, 1986]. Brines were produced from two zones in the well during four separate flow tests. The first sampling occurred when the well was 1898 m deep on December 29-30, 1985, with production presumed to come from a fracture zone near the bottom. The second set of samples was collected when the well was 3220 m deep on March 20-21, 1986, with production also originating primarily near the bottom. The third and fourth set of samples were taken during an extended flow test during June 1988, with the third set collected on June 10 and the fourth set collected on June 15, 1988 (Table 1). Because the volume of brine that could be produced during the first two flow tests was limited by the size of a pit built to receive water discharged from the well, only 4000 m³ could be produced during each test. Measurements of major constituents and stable isotopes suggest that for the first test this brine volume was sufficient to clear the well of fluids introduced during drilling. However, the second flow test showed evidence that the fluid produced contained 5-10% of contaminant material introduced during drilling operation [Sturtevant and Williams, 1987]. Our measurements of radioisotopes in the brine should not be noticeably influenced by such contamination, except perhaps for isotopes of U and Th that are present in relatively small concentrations. Another possible complication is that sulfate contamination from drilling fluids may have caused some barite to precipitate during the mixing of brine and drilling fluid, and this barite may have scavenged some radium from solution. While we think this effect should be small, it cannot be evaluated. Thus, the radium concentrations measured during the second flow test are lower limits, but measured ratios of radium

isotopes should be accurate. Contamination is assumed to be negligible during the flow test during June of 1988, since discharge from the well was being reinjected and samples were collected after the well had been flowing for several days.

A steel pipe was attached to the wellhead to transport brine and steam to a cooling tower before its discharge into a waste pit. The pipe was fitted with a series of sampling ports separated by orifice plates, providing different pressures and temperatures for sampling the two-phase flow. Sampling ports were constructed so that either brine or steam could be withdrawn from the flow line. During the June 1988 flow test samples were collected from a sampling port located just before the entry of the flow into the cyclone separator. Previous work at other SSGF sites has shown that radium and lead concentrations in the brine are not strongly influenced by the flash process [Zukin *et al.*, 1987]. Therefore different locations in this flow line should yield equivalent samples, at least for Ra and Pb. Brine samples were collected by allowing hot brine to flow through a cooling coil immersed in an ice-water bath into a polyethylene container filled with dilute HCl (Table 1). Samples were not filtered, so measurements of uranium and thorium may be upper limits due to possible contamination with particulates transported in the brine [Zukin *et al.*, 1987]. Gas samples for ^{222}Rn analysis were collected by allowing steam to flow through a cooling coil where condensation occurred, and the remaining non-condensable gas fraction was passed into a glass bottle fitted with inlet and outlet tubes.

Analyses for isotopes in the brine were carried out as described by Zukin *et al.* [1987] (Table 2), with some modifications. The CO_2 fraction in the gas sample was measured using gas chromatography, and the radon fraction using alpha scintillation techniques. The brine radon concentration was then calculated from the measured Rn/CO_2 ratio and *in situ* CO_2 concentration [Michels, 1987]. Results from the June 1988 flow test were calculated using the same value for *in situ* CO_2 concentration as the earlier flow tests, and therefore the concentrations may have to be adjusted, but the radium ratios will be unaffected. ^{223}Ra was determined from gammas emitted by its short-lived daughters ^{219}Rn and ^{211}Pb at 401 and 405 keV from the BaSO_4 precipitate collected for analysis of ^{228}Ra and ^{224}Ra (about 300 ml brine used). The ^{210}Po results are upper limits, based on an analysis for ^{210}Po made about 0.5 days after sample collection. The ^{210}Po was calculated assuming that no ^{210}Bi was present initially. Pb isotope results for the June 1988 samples are not

available yet since ^{210}Pb ingrowth is necessary. In addition ^{227}Ac requires an ingrowth period approaching one year before measurement.

When more than one sample was taken for analysis of a constituent, the results given represent the average, weighted by the uncertainty of individual analyses. All uncertainties quoted are \pm one standard deviation, derived from counting statistics. Data for the first two flow test have been corrected for evaporative losses (5-15%) prior to collection, based upon estimates of the flash fraction for different sample ports [Michels, 1986]. Results are reported as isotope activities (disintegration rate) in the brine *in situ*.

Results

Our results (Table 3) from the SSSDP brines generally corroborate those reported previously for saline hydrothermal systems. The measurements obtained are similar to those for other portions of the Salton Sea Geothermal Field [Zukin *et al.*, 1987], and, consequently, this discussion will include only a brief summary of the geochemistry of uranium and thorium series isotopes in saline, reducing hydrothermal waters. The June 1988 samples have lower concentrations for most isotopes, with the exception of ^{222}Rn and ^{223}Ra which had similar concentrations to the SSSDP1&2 flow tests. Until we can rule out contamination or reaction with the casing we will not attempt to interpret these difference, although they may be real. The concentrations of uranium and thorium are low, and the $^{234}\text{U}/^{238}\text{U}$ ratio is also low in comparison to most groundwaters [Hammond *et al.*, 1988]. The low uranium concentration suggests that uranium is in the +4 valence, and low uranium isotope ratio indicates either that uranium exchanges rapidly between brine and rock, or that measurements are biased by incorporation of rock fragments in samples [Zukin *et al.*, 1987]. In contrast, radium concentrations are 1000-10000 times greater than those of their parent. These high concentrations must be maintained by input from surrounding solid phases. The persistence of radium in solution probably reflects complexation with chloride [Langmuir and Riese, 1985; Hammond *et al.*, 1988]. Lack of suitable adsorption sites may also maintain the high concentrations that are observed [Langmuir and Melchior, 1985]. It is also possible that Ra concentrations are related to elements forming sulfides [Hammond *et al.*, 1988]. Radon concentrations have an activity comparable to, or greater than those of its parent ^{226}Ra , suggesting that dissolved radium greatly exceeds

both adsorbed radium and that located within recoil range of solid surfaces [Laul *et al.*, 1985; Zukin *et al.*, 1987]. Some daughters of these isotopes (^{228}Ac , ^{228}Th , ^{210}Po) are much lower in concentration, reflecting the low solubilities of these elements and their rapid sorption from solution. In summary, in SSGF brines, radium, radon and lead are quite soluble while uranium, thorium, actinium, polonium, and bismuth have much lower solubilities.

Several samples were collected for radium analyses at different times during the flow tests, and the isotope ratios observed are of interest (Table 4). The $^{224}\text{Ra}/^{228}\text{Ra}$ ratio was uniform during the second flow test, although the ratio observed in each flow test is different. The lack of change in this ratio during the 14 hours of the second flow test indicates that the values of less than one that were observed here and in the nearby Fee wells [Zukin *et al.*, 1987] were not a transient effect due to initiation of flow, but must reflect steady state *in situ* values. Formation water should have $^{224}\text{Ra}/^{228}\text{Ra} \geq 1.17$ if alpha recoil is the only mechanism for radium input [Krishnaswami *et al.*, 1982]. If the system is in a dynamic equilibrium, the low ratios observed here must reflect the importance of one or more of the following effects: (1) weathering of solids, (2) growth of crystals that incorporate ^{228}Th to depths comparable to the recoil range, so that the fraction of ^{224}Ra recoiled into solution from the sorbed ^{228}Th is less than the 50% expected, or (3) recoil input that is limited by slow diffusion down microfractures. The variation in $^{228}\text{Ra}/^{226}\text{Ra}$ ratios observed during the the 1986 and 1988 flow tests exceeds analytical error, but the cause of this variation is not apparent. It is possible that flow from multiple zones with different ratios of radium isotopes occurred during these tests, and the relative contributions from these zones varied with time.

Summary

Sampling and analyses of brines from the Salton Sea Geothermal Field have produced data for the distribution of the natural radionuclides of the ^{238}U and ^{232}Th decay series. The data are of potential use to the prediction of the behavior of radwaste radionuclides stored in geological repositories such as salt beds. The behavior of uranium and thorium series isotopes in brines from the SSSDP well is very similar to that expected in a high temperature, high salinity brine. Uranium, thorium, actinium, bismuth, and polonium are all relatively insoluble, indicating their rapid sorption from solution. In contrast, radium, lead, and radon are all found in

high concentrations. These high concentrations reflect the importance of weathering, leaching, and recoil inputs of these elements into brine from adjacent solid phases, complexing of radium and lead by chloride which helps keep these elements in solution, and lack of suitable unfilled adsorption sites capable of removing these elements from solution.

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Table 1. Sample Inventory of Geothermal Brines Collected During June 1988 Flow Test

ID ^a	Time of sampling	Acid added(l)	Sample wt (kg) ^b	Spikes Added	Desired Analysis
3-3	1700	1	1.43	none	Ra isotopes
3-4	1700	none	2.17	none	222Rn
4-53a	1848	1	2.2	none	Ra isotopes
4-106	1849	.25	.3	none	226Ra
4-45	1850	4.5	12.5	232U, 228Th	238U, 234U, 232Th, 230Th
4-B2	1853	1.1	2.49	208Po, 230Th	210Po, 228Th
4-1	1900	.25	.3	none	226Ra
4-52a	1903	1	2.36	none	Ra isotopes
4-3	1915	none	2.17	none	222Rn
4-2	1916	none	2.17	none	222Rn
4-111	1936	.245	.3	229Th	228Ac, 212Pb
4-108	1938	.25	.3	none	226Ra
4-B3a	1940	.07	3.7	229Th	228Ac, 212Pb
4-B1	1943	1.1	2.4	208Po, 230Th	210Po, 228Th

a) ID# = date-sample#(3- 6/10/88, 4- 6/15/88).

b) Wt. for gases is volume in liters STP.

Line conditions P= 17.9 atm and 212 °C.

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Table 2. Uranium and Thorium Series Isotopes Measured in the SSSDP Well Brine Samples

Isotope Measured	Method of Analysis
238U	Alpha-spectrometry
234U	Alpha-spectrometry
232Th	Alpha-spectrometry
230Th	Alpha-spectrometry
228Th	Alpha-spectrometry
228Ra	Gamma-spectrometry
228Ac	Gamma-spectrometry
227Ac	Alpha-spectrometry
226Ra	Alpha Scintillation/ ²²² Rn ingrowth
224Ra	Gamma-spectrometry
223Ra	Gamma-spectrometry
222Rn	Alpha Scintillation
212Pb	Gamma-spectrometry
210Pb	Alpha-spectrometry/ ²¹⁰ Po ingrowth
210Po	Alpha-spectrometry
210Bi	Alpha-spectrometry

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Table 3. Uranium and Thorium Series Isotopes in the SSSDP Brine Samples

Isotope	SSSDP-1		SSSDP-2		SSSDP-3		SSSDP-4	
	dpm/kg	n	dpm/kg	n	dpm/kg	n	dpm/kg	n
^{238}U	0.071(4)	1	0.033(4)	2	-		0.018(7)	1
^{234}U	0.077(5)	1	0.038(4)	2	-		0.026(10)	1
^{230}Th	0.043(6)	1	<0.020	1	-		<0.008	1
^{226}Ra	2190(80)	2	1060(50)	2	526(10) ^a	1	526(10)	3
^{222}Rn	2130(150)	2	2600(1400)	3	1811(96)	1	2038(74)	2
^{210}Pb	3260(115)	2	3220(80)	2	-		-	2
^{210}Bi	<740	1	<1370	1	-		-	
^{210}Po	<0.95	1	<2.8	2	-		<1.15	2
^{232}Th	0.007(4)	1	<0.007	1	-		<0.008	1
^{228}Ra	1120(60)	2	720(40)	4	244(27)	1	329(14)	2
^{228}Ac	250(170)	1	150(90)	1	-		301(86)	2
^{228}Th	0.58(4)	1	0.41(3)	2	-		0.57(6)	2
^{224}Ra	1010(60)	2	540(30)	4	292(17)	1	356(15)	2
^{212}Pb	2250(280)	1	1440(140)	1	-		-	2
^{223}Ra	6(31)	2	11(7)	4	23(10)	1	15(9)	2

Data has been corrected to pre-flash conditions, based on temperature and pressure at the sample port. The flow tests were carried out at 1898 m and the second flow test also sampled fluids from 3220 m. The analytical uncertainties in the last digit ($\pm 1\sigma$ from counting statistics) are shown in parentheses, and the numbers of samples analyzed are given as n. If more than one analysis was made, averages were weighted by the analytical uncertainties in each measurement. Radium activities for SSSDP-3 are calculated from the average of the SSSDP-4 ^{226}Ra values and measured ^{226}Ra activity ratios.

Table 4. Radium Concentrations (as Activities) Observed at Different Times During SSSDP Flow Tests

Sample	Date	Time	226Ra	228Ra	224Ra	223Ra
			(dpm/kg)	226Ra	228Ra	226Ra
SSSDP-1- ³ 412-29-85		1600	2040(90)	--	--	--
-14	12-29-85	1710	2450(120)	0.51(1)	0.93(3)	0.017(27)
-18	12-30-85	1200	--	0.51(1)	--	0.001(15)
Average			2190(80)	0.51(1)	0.93(3)	0.003(18)
SSSDP-2-26	3-20-86	2210	--	0.64(1)	0.74(2)	0.020(27)
-28	3-21-86	1150	--	0.70(1)	0.74(2)	0.025(13)
-37	3-21-86	1120	1150(60)	0.75(2)	0.77(2)	0.002(9)
-45	3-21-86	1210	1020(50)	0.64(1)	0.77(2)	0.008(16)
Average			1060(50)	0.68(1)	0.76(2)	0.010(13)
SSSDP-3-3	6-10-88	~1700	--	0.48(1)	1.12(3)	0.046(19)
SSSDP-4-53a	6-15-88	1848	500(20)	0.56(1)	1.36(4)	0.013(32)
-52a	6-15-88	1900	613(14)	0.83(1)	0.80(2)	0.037(21)
-108	6-15-88	1938	398(18)	--	--	--
Average			526(10)	0.70(1)	0.91(2)	0.030(18)

Uncertainties in the last digits ($\pm 1\sigma$, derived from counting statistics) are given in parentheses. Averages are weighted means.

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	²³⁸ U series				²³² Th series				²³⁵ U series				
U	238 4.5by		234 248ky							235 0.7by			
Pa	↓ 234 1.2m		↓ 234 248ky							↓ 231 34ky			
Th	234 24d		230 75ky		232 14by		228 1.9y		231 26h	↓ 227 19d			
Ac			↓ 226 1.6ky		↓ 228 6.1h		↓ 224 3.8d			↓ 227 22y		↓ 223 11d	
Ra			↓ 226 1.6ky		↓ 228 5.7y		↓ 224 3.8d					↓ 223 11d	
Fr			↓ 222 3.8d				↓ 220 54s					↓ 219 3.9s	
Rn			↓ 222 3.8d				↓ 220 54s					↓ 219 3.9s	
At			↓ 218 3m				↓ 216 0.2s					↓ 215 1.8ms	
Po			↓ 218 3m	↓ 214 0.2ms	↓ 210 138d		↓ 216 0.2s		↓ 212 3us			↓ 215 1.8ms	
Bi			↓ 214 20m	↓ 214 0.2ms	↓ 210 5d		↓ 212 81m		↓ 212 3us			↓ 211 2.2m	
Pb			↓ 214 27m	↓ 210 22y	↓ 206		↓ 212 11h		↓ 208			↓ 211 36m	↓ 207
Tl							↓ 208 3.1m					↓ 207 4.8m	

Figure 1. The uranium and thorium decay series. Isotopes measured in this study are bordered by heavy lines. The mass number and half-life for each isotope are given. Vertical arrows indicate alpha decays, and short diagonal bars indicate beta decays.

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Appendix O

LIQUID AND GAS SAMPLING
(University of Utah Research Institute)

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CHEMICAL SAMPLING - UNIVERSITY OF UTAH RESEARCH INSTITUTE

Liquid and gas samples of the fluid from the Salton Sea Deep Hole were taken by Mike Adams and Michelle Lemieux of the University of Utah Research Institute during the long-term flow test. Three samples were taken during a one hour period from 0900 to 1000 on June 8, which corresponds to the lowest flowrate of the test. Four samples were taken during a two hour period from 0930 to 1130 on June 11, which corresponds to the highest flow-rate of the test.

The samples were taken from the brine and steam lines downstream of the separator. The liquid samples were taken by two different methods. The first method involved cooling the hot brine in a one fourth inch stainless steel tube coil prior to capturing the fluid in a preservative solution. Although this method is commonly employed, it may promote precipitation of silica in the cooling coil prior to collection. The second method was designed to prevent precipitation of silica prior to sampling. This method utilized a six inch by one eighth inch tube that was inserted directly into the preservative solution with no prior cooling. Both methods used a preservative solution of 5 wt% nitric acid for ICP analysis and 5 wt% hydrochloric acid for sulfate and ammonia. Non-diluted samples were collected for chloride, fluoride, and TDS. The acid to sample dilutions were 10 to 1.

Steam samples were collected through a one fourth inch stainless steel cooling coil. The samples were taken in evacuated

pyrex flasks that contained solutions of sodium hydroxide and cadmium chloride.

The liquid and gas samples are being analyzed to determine if differences in the chemistry of the fluid exist as a result of changing flow rates, and if silica does precipitate when a cooling coil is used during collection. Gas analyses of samples collected during the flow test are given in Table 1. Table 2 presents chemical analyses of liquid samples collected during the low flow portion of the test. The liquid samples listed in Table 2 were collected through the 1/4" cooling coil. Comparison of the silica concentrations in these analyses with those from the samples collected through the 1/8" short tube indicates that silica precipitated in the 1/4" cooling coil when sample MA-52 was taken. Silica concentrations were similar for both methods in Samples MA-50 and -51. However, the variability of the silica concentrations from sample to sample in a close spaced time interval indicates that silica may be precipitating in the wellbore, or, more likely, the separator.

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Table 1. Gas Analyses from the Salton Sea Deep Well. Concentrations are in parts per million by weight. WHT = well head temperature (deg F); WHP = well head pressure (psig); SEP T = separation temperature (deg F); SEP P = separation pressure (psig); FLOWRATE = combined steam and brine flowrates (lbs/hr) measured downstream of the separator; STEAM FRACT = steam fraction in the separator.

Sample	MA-53	MA-54	MA-55	MA-61	MA-62	MA-65	MA-66
Date	6/8/88	6/8/88	6/8/88	6/16/88	6/16/88	6/16/88	6/16/88
Time	10:00	10:10	10:23	09:45	10:10	11:50	12:00
WHP	508	508	508	504	504	505	505
WHT	490	490	490	498	498	498	498
SEP P	204	214	204	216	216	237	237
SEP T	400	400	400	415	415	415	415
STEAM FRACT	0.15	0.15	0.15	0.13	0.13	0.15	0.15
TOTAL FLOW	126,108	126,108	126,108	535,756	535,756	496,075	496,075
H ₂ O	9.76E+5	9.76E+5	9.75E+5	9.84E+5	9.84E+5	9.85E+5	9.85E+5
CO ₂	2.30E+4	2.34E+4	2.45E+4	1.52E+4	1.57E+4	1.47E+4	1.47E+4
H ₂ S	1.88E+2	1.91E+2	1.96E+2	1.02E+2	1.14E+2	7.36E+1	1.36E+2
NH ₃	4.22E+2	4.28E+2	4.31E+2	4.2E+2	4.29E+2	3.45E+2	3.77E+2
Ar	3.09E-1	3.61E-1	1.04E+0	8.28E-1	7E-2	1.51E-1	4.84E-2
N ₂	3.65E+1	4.1E+1	4.68E+1	5.75E+1	2.7E+1	3.02E+1	2.44E+1
CH ₄	4.92E+1	5.1E+1	6.88E+1	2.40E+1	1.90E+1	2.38E+1	2.39E+1
H ₂	9.22E+0	9.5E+0	9.89E+0	2.10E+0	1.43E+0	9.96E+0	1.84E+0

T

Table 2. Fluid Analyses from the Salton Sea Deep Well. The samples listed were taken through a 1/4" stainless steel cooling coil. Concentrations are in mg/kg. The conditions at the time these samples were taken were: well head temperature = 490 deg F; well head pressure = 508 psig; separation temperature = 400 deg F, separation pressure = 204 psig; combined steam and brine flow = 126,108 lbs/hr. N.D. = not detected, N.A. = not analyzed.

Sample	MA-50	MA-51	MA-52
Na	60789	60479	59568
K	18944	19208	18944
Ca	30777	30325	29984
Mg	47.7	50.4	48.2
Fe	1893	1874	1846
SiO ₂	75	441	386
B	448	456	449
Li	238	240	236
Sr	459	461	456
Zn	565	579	565
Ag	1.34	N.D.	1.88
As	15.6	19.5	17.8
Ba	253	262	256
Cd	2.55	2.72	2.56
Cu	3.74	3.25	3.01
Mn	1634	1660	1637
Pb	110	124	122
NH ₄		N.A.	412
HCO ₃		N.D.	N.D.
Cl		162000	162000
F		2.94	2.91
SO ₄		N.D.	N.D.
Br		110	104
I		6.70	2.9
Density	1.22	1.22	1.22

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