GL03962

DOE/AL/10563-T1

GEOTHERMAL RESERVOIR WELL STIMULATION PROGRAM – FIRST-YEAR PROGRESS REPORT

February 1980

Work Performed Under Contract No. AC32-79AL10563

Republic Geothermal, Inc.
Santa Fe Springs, California

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $6.00
Microfiche $3.50

DOE/AL/10563-T1
Distribution Category UC-66a

GEOTHERMAL RESERVOIR WELL STIMULATION PROGRAM

FIRST-YEAR PROGRESS REPORT

Prepared by

Republic Geothermal, Inc.
11823 E. Slauson Avenue, Suite 1
Santa Fe Springs, California 90670

for

U.S. Department of Energy
Under Contract No. AC32-79AL10563

February 1980

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

I. Summary

The Geothermal Reservoir Well Stimulation Program (GRWSP) group planned and executed two field experiments at the Raft River KGRA during 1979. Well RRGP-4 was stimulated using a dendritic ("Kiel") hydraulic fracture technique and Well RRGP-5 was stimulated using a conventional massive hydraulic fracture technique. Both experiments were technically successful; however, the post-stimulation productivity of the wells was disappointing. Even though the artificially induced fractures probably successfully connected with the natural fracture system, reservoir performance data suggest that productivity remained low due to the fundamentally limited flow capacity of the natural fractures in the affected region of the reservoir.

Other accomplishments during the first year of the program may be summarized as follows:

(a) An assessment was made of current well stimulation technology upon which to base geothermal applications.

(b) Numerous reservoirs were evaluated as potential candidates for field experiments.

(c) A recommended list of candidates was developed which includes Raft River, East Mesa, Westmorland, Baca, Brawley, The Geysers and Roosevelt Hot Springs.

(d) Stimulation materials (fracture fluids, proppants, RA tracer chemicals, etc.) were screened for high temperature properties, and promising materials selected for further laboratory testing.

(e) Numerical models were developed to aid in predicting and evaluating stimulation experiments. A symposium to disseminate results thus far to the geothermal community will be held in February 1980.

The GRWSP has spent approximately 40 percent of the total budget as of December 31, 1979. The first year costs were significantly higher (about $400,000) than originally planned, principally because the second field experiment was accelerated into the first year at the DOE's request. Acceleration of the second experiment has also resulted in minor delays in completing some of the other tasks on the original schedule.

The proposed second year of the GRWSP will include the completion of all laboratory testing of geothermal stimulation materials and four field experiments in moderate to high temperature geothermal reservoirs. This work is expected to be completed within the time frame originally provided in the contract. A symposium will be held in early 1981 to present the results of this contract and to disseminate the appropriate information to the geothermal industry.

II. Program Overview

The Geothermal Reservoir Well Stimulation Program (GRWSP) is proceeding into its second year of activity with significant progress made in the area of promoting industry interest in geothermal well stimulation work and in pursuing technical areas directly related to geothermal well stimulation activities. Republic Geothermal, Inc. and its subcontractors have formulated a development plan which will lead to the completion of six full-scale well stimulation experiments by March 1981. The project is organized into two phases. Phase I consists principally of studies (literature and theoretical), laboratory investigations, and numerical work. The main purpose of this work is to establish the technological base for geothermal well stimulation designs. The primary objectives of Phase II are to plan, execute, and evaluate six well stimulation treatments which utilize the technology developed in Phase I activities. Different types of geothermal well stimulation techniques will be used in appropriate reservoirs offering representative characteristics of industry applications.

The success of the GRWSP is highly dependent on the active participation of geothermal resource developers. In February 1979, letters were sent to all geothermal resource developers outlining the stimulation program and requesting any parties interested in participating in the well stimulation experiments to respond. In addition, the contract award and its objectives were announced in geothermal industry and government publications. As a result, six resource developers expressed an interest in actively participating in the field experiments. In several cases the operator restricted the possible field sites to specific reservoirs and wells, and a number of others did not choose to participate because of the requirements for releasing proprietary resource data. The reservoirs indicated to be available for stimulation experiments were: East Mesa, Westmorland, Raft River, Roosevelt Hot Springs, Baca, Desert Peak, Brawley, The Geysers, and Chandler.

It should be noted that, although the program will compensate the well operator for his activities directly related to a stimulation treatment, the participation represents a significant cost sharing with the GRWSP by the operator of the field. The wells, surface facilities, and injection systems are utilized at the risk of the operator and can be valued at several million dollars.

General information on the nine geothermal resources listed above was obtained from the public files of the U.S. Geological Survey and from the Lawrence Berkeley Laboratory geothermal data storage system. Additional data were requested from the developer on specific well sites to be considered for stimulation experiments. Although several operators were reluctant to provide this data without a commitment to stimulate the well,

it is believed that a sufficient quantity of information was obtained to allow a valid reservoir selection process. The selection involved not only an analysis of the data, but a correlation of the specific types of stimulation experiments with the wells having the characteristics most likely to result in a successful job. Even with the best of data, experience in the petroleum industry has shown that well stimulation is a high risk business. The selection process (described in the report "Geothermal Reservoir Well Stimulation Project - Reservoir Selection Task," of November 1979) resulted in the following recommended program:

Field Tests	Reservoir
1	Raft River
2	East Mesa
3	Baca
4	Westmorland
5 (2 experiments)	Brawley and The Geysers or Roosevelt Hot Springs

This program schedule should be considered tentative at this time. The proposed program will be reviewed after each field experiment to determine if any alteration of this sequence of field tests would be beneficial to the overall success of the GRWSP.

In mid 1979 the proposed sequence of field tests was altered at the request of the Department of Energy (DOE)/ Division of Geothermal Energy (DGE) to include two field experiments at the Raft River KGRA. The Raft River reservoir was not considered to be the best candidate for the first field experiment for several technical reasons outlined in the report "Proposal for Producing Well Hydraulic Fracture Stimulation - Raft River Field" of June 1979. The probability for a successful stimulation job was considered to be low and the cost of the experiments was expected to be high because of the mechanical condition of the wells; i.e., multi-legged, rugose open-hole completions. But the Raft River Project is of great importance to DOE/DGE and the geothermal industry; therefore, well sites RRGP-4 and RRGP-5 were selected for the first two hydraulic fracture stimulation treatments.

In addition to the Phase II field experiment schedule change, the Raft River jobs also had a negative effect on the completion of several Phase I tasks. The technology transfer task, the equipment review task, the review of stimulation technology development, the development of laboratory plans and the screening of frac fluids and proppants have all been delayed to some extent because the GRWSP personnel involved in these tasks were active in the planning and execution of the Raft River jobs. The 1980 project schedule, discussed later, reflects these changes, but the overall project schedule is not expected to be adversely affected significantly.

The subcontractors are proceeding with the Phase I tasks required to develop a viable geothermal well stimulation technology. The following sections detail the field experiments first and then the specific activities of the subcontractors, Maurer Engineering Inc., Vetter Research and Petroleum Training and Technical Services. It should be noted that all the subcontractors were involved to varying degrees in the two field experiments and that these efforts represent a considerable part of the GRWSP accomplishments to date.

III. Technical Review of Tasks

A. Field Experiments

1. The first geothermal reservoir well stimulation experiment under the GRWSP was performed at Raft River Well RRGP-4 on August 20, 1979. The stimulation treatment used the Kiel fracturing process (dendritic or reverse flow technique) to pump in 8,000 barrels of polymer-water solution carrying 108,000 pounds of frac sand at rates up to 52 BPM. This experiment utilized conventional petroleum industry techniques without difficulty because of the relatively low reservoir temperature. No significant equipment or material problems were encountered. Post stimulation production data indicate that the well RRGP-4 productivity was improved, but not to the hoped-for level of other wells in the field. The well was essentially non-productive prior to the fracture treatment.

A 20-hour flow test was run on August 25-26, 1979. The flow rate declined from an initial 250 gpm to about 60 gpm; however, at that point two-phase flow began to occur in the pipeline used to measure flow rate. The test was terminated and plans were made to test the well again for a longer period with improved flow monitoring and control equipment. The measured downhole flowing temperature was lower than expected (i.e., 251°F vs 290°F); however, the temperature appeared to be increasing. Downhole pressure transient data and fluid samples were obtained for analysis. The U.S. Geological Survey ran an acoustic televiewer survey of the wellbore which indicated that the fracture job had created a 200 foot vertical fracture in the wellbore open interval from 4705 feet to 4900 feet, as planned, with an east-west orientation.

A second production test of Well RRGP-4 was performed during September 6-12, 1979. A stable artesian flow rate of 60 gpm was maintained during the test while monitoring the transient downhole pressure response. Because of equipment failure, the late time pressure drawdown data were lost; however, the complete pressure buildup data were obtained. Fluid samples were taken from the well production so that the frac fluid content could be monitored in the return fluids.

A report detailing the first field stimulation experiment at Raft River Well RRGP-4 will be prepared when the data analyses and evaluations are complete. The report will also include the second experiment at Raft River as discussed below.

2. The second geothermal reservoir well stimulation experiment under the GRWSP was performed on Well RRGP-5 at Raft River on November 12, 1979. The stimulation treatment was a massive hydraulic fracture in which 7620 barrels of polymer-water solution, carrying 440,000 pounds of sand proppant at an average rate of 50 bpm, were injected into the open interval between 4587 feet and 4803 feet. The fracture treatment utilized conventional petroleum industry stimulation techniques. Definite formation pressure breakdown was observed during the fracture job. The post-treatment borehole televiewer survey, run by the USGS, indicated a new vertical fracture in the top 100+ feet of the open interval with a north-south orientation.

A six-hour production test was performed on November 25-26, 1979 in which the flow rate stabilized at about 200 gpm after 20 minutes with a wellhead pressure of 30 psia. Lawrence Berkeley Laboratory provided the downhole pressure and temperature survey equipment for this test. The pressure drawdown and subsequent buildup in the wellbore occurred very rapidly (on the order of minutes). A total pressure drawdown of 103 psi was measured with a maximum flowing temperature of 264°F at the 4550 foot setting depth. A static temperature survey was obtained after an 8-hour pressure buildup period. Sand fill was found at 4730 feet.

The well was cleaned out to 4900 feet following the production test. On November 27, 1979 a 2-hour production test resulted in a flow rate of 210 gpm with a 31 psia wellhead pressure. Water samples taken from the flow stream throughout the post-stimulation production tests did not indicate significant quantities of sand being produced. Return fluid samples will be analyzed for frac fluid products.

These tests produced flow rates not unlike the pre-stimulation well test data for RRGP-5. Preliminary evaluation of the pressure data does not indicate a long term response resembling the classical fracture flow phenomena. A final field stimulation experiment report on the Raft River RRGP-4 and RRGP-5 wells is being prepared. Data analyses and evaluation are currently underway by RGI, its subcontractors, and the USGS.

B. Maurer Engineering Inc.

During 1979 Maurer Engineering Inc. (MEI) made significant progress in almost all phases of the Geothermal Reservoir Well Stimulation Program. The main tasks assigned to MEI were the examination of fracturing fluids, proppants, and stimulation techniques as well as the physical testing of specific materials for high temperature applications. In order to complete this work, lab equipment was designed and built where required, and lab techniques were adapted or modified for the higher temperatures (up to 260°C) of geothermal wells.

Other tasks that were completed during 1979 were the literature surveys on various aspects of stimulation in oil and gas wells, and the technology transfer of analytical calculation methods which are required in engineering design of hydraulic or acid fracturing treatments. Also, computer programs were written and debugged so that they could be used for specific field experiments. Planning, design, and execution of two field experiments was participated in during 1979. The experiments were documented with planning and summary reports.

The following sections detail the 1979 accomplishments in each of the work areas as broken down by task. The most important tasks with the highest funding are discussed first to show where most of the emphasis and actual work was done.

1. Fluids and Fluid Testing

At the start of the project, requests for thermally stable polymers and additives used for compounding high-temperature fracturing fluids were submitted to BJ Hughes, Western, Halliburton, Dowell, Cardinal, Dresser Titan, General Mills, Stein Hall, and Hercules. Early responses were largely negative, and most companies delayed their response until after the April conference meetings. API standard tests and other high-temperature test procedures were considered as to how they best can be applied to test a potential geothermal stimulation fluid. A literature survey of all available fluids and their properties was made.

After the April meetings with the service companies, response to our request for data and samples greatly improved. All types of frac fluids were tested and check points were made on data that were provided. Test procedures are being finalized for physical fluid testing. The design of a high-temperature falling ball viscometer to measure proppant carrying capacity was prepared and completed because no commercial instrument was found to be available.

During June a screening test was devised in order to make a rapid determination of the temperature stability of potential fracturing fluids. The screening tests consist of measuring the shear stress-shear rate properties of a fixed concentration, 25 lb/1000 gal, of each polymer in Houston tap water at room temperature. The fluid is then exposed to a temperature of 300°F at a pressure of 100 psi for 3 hours. After cooling to room temperature, the fluids are retested. A total of 25 polymers shown in Table 1 were tested in this manner.

Several of the polymers retained a large portion of their starting viscosity after exposure to 300°F. To explore the

TABLE 1

POLYMERS EVALUATED IN SCREENING TESTS

	POLYMER	GENERIC NAME
1.	Methocel K-15	Hydroxpropyl Methylcellulose
2.	Galactasol 416	Guar Derivative
3.	Gendril Thik	Guar Derivative
4.	Gengel E-9	Hydroxypropyl Guar
5.	Natrosol 150 HHWR	Hydroxyethyl Cellulose
6.	Natrosol 250 HHXR	Hydroxyethyl Cellulose
7.	Natrosol 250 HHW	Hydroxyethly Cellulose
8.	NGL-6829 HP-8	Guar Gum
9.	Cellosize QP-100MH	Hydroxyethyl Cellulose
10.	Cellosize QP-100M	Hydroxyethyl Cellulose
11.	Romax RM-95	
12.	Romax RM-66	
13.	Cellosize QP-50,000	Hydroxyethyl Cellulose
14.	Hydroxypropyl Guar	
15.	Driscose	Carboxymethyl Cellulose
16.	Impermex	Corn Starch
17.	Drispac	Carboxymethyl Cellulose
18.	HV Driscose	High Viscosity Carboxymethyl Cellulose
19.	Cypan	Polyacrylate
20.	XC Polymer	Xanthan Gum
21.	Gengel E9-P	Hydroxypropyl Guar
22.	Guartec UF	Guar Gum
23.	Galactosol 210	Guar Derivative
24.	ASP-711	Cationic Polyacrylamide
25.	ASP-WFR-11	Anionic Polyacrylamide

physical properties of the polymers further, many of those shown in Table 1 will undergo Fann Model 50C viscometer testing to 150°C and later to 275°C. Some of the materials already tested retained a large portion of their starting viscosity as measured by the Fann Model 50C. Physical properties were obtained at polymer concentrations of 83.3 lb/1000 gal (1% by wt) in Houston tap water to allow for scaled up or scaled down concentrations for actual field experiments. This level is easily measured on the Model 50C Fann Viscometer.

Samples of each of the polymers listed in Table 1 were submitted to Vetter Research for chemical identification.

During July many viscosity tests were completed. Shear stress-shear rate data were obtained on the Fann Model 50C Viscometer at 100°F, 200°F, and 300°F for the following polymers at a concentration of 83.3 lb/1,000 gal (1% by wt) in Houston tap water:

Hydroxypropyl Guar Gum;
Hydroxyethyl Cellulose;
XC Polymer;
Acrylic Polymer;
Blends of Hydroxypropyl Guar/XC Polymer.

The effectiveness of methanol as a retarder was tested in HEC, XC Polymer and in the 5:1 blend of HP Guar/XC Polymer. Methanol, at 5% by volume, had very little effect on the high-temperature viscosity of these polymers. The 5:1 blend of HP Guar/XC Polymer was also treated with 10% by volume of methanol and little change in viscosity was detected at temperatures up to 300°F.

Sodium bisulfite, an oxygen scavenger, was also used to treat the 5:1 blend of HP Guar/XC Polymer. Addition of 11.8 lb/1,000 gal has little effect on the high-temperature viscosity of the blend. Combinations of sodium bisulfite and methanol were also found to have little effect in improving the stability of the blend at high temperature.

Dowell's recommended YF "HC" frac fluid was also tested. This frac fluid formulation contains almost twice as much polymer as those which were previously tested and, therefore, had a much higher viscosity at 300°F than any of the other previously tested fluids. It also retained a large portion of this viscosity during the one-hour test at 300°F. When the polymer concentration was reduced in half, the resulting frac fluid had similar viscosity characteristics to the other cellulosic polymer fluids at high temperatures.

Fluid loss tests on many fluids and fluid loss additives were made to find out the fluid properties required for fracture design information. Detailed physical testing on potential Raft River stimulation fluids were run at the expected reservoir conditions of 300°F.

First drafts of reports were completed on the following aspects of the project during August:

a. Available data compilation from the major service companies
b. Historical development of fracturing fluids
c. Standard lab test procedures for frac fluids
d. Literature search for new fluids
e. Matrix of fluid properties tested to date
f. List of remaining fluids to be tested

Construction on the falling ball viscometer began in August, and testing of the first design for feasibility and practicality was started. The first design was not successful because of lack of sensitivity of the electromagnetic pickups; therefore, a second design was started in September. The falling ball viscometer with a new electronic circuit and revised sensitive pickups was completed during December of 1979. Testing at high temperature (to 260°C) remains to be completed during 1980.

Reports a. and b. were started during 1979. Report No. 1 is now completed. It is a summary of all available physical property data on fracturing fluids. This is a lengthy report in two volumes that gives:

a. The viscosity versus temperature behavior for various concentrations of the available polymer fluids.

b. The fluid loss behavior of these fluids.

c. The stability of these fluids for extended times at high temperatures.

d. The tubing friction loss of these fluids through the normal tubular goods used in wells.

Report b. contains the MEI test data taken on available and new or experimental fluids specifically for geothermal applications. It is now being written and will issue during 1980.

Many new polymers have been tested at 350°F to look for the most desirable fluids in that range. This fluid temperature will be encountered during the next set of field treatments during 1980 in the East Mesa field. Some of the 350°F fluids (and their costs) have been sent to us from the service companies for testing so that their fluids and, of course, their companies may be considered for future work.

2. Proppants and Proppant Testing

A literature survey and a gathering of all available proppant data started out this phase of the work. No elevated temperature or geothermal temperature data on proppants was available. An MEI technical report was issued to include available data and the pertinent references and services. It was found that industry proppant testers were not commercially available. Therefore, MEI obtained engineering drawings of actual proppant testers using an API linear flow cell, and modified these designs and the seals for geothermal triaxial testing of proppants.

After the design was set, long lead time items were ordered and construction of the proppant test system began. Figure 1 shows a schematic of the final design of the proppant test system.

By May the proppant tester was completed and low temperature tests were begun. Coordination with Los Alamos Scientific Labs, LeGarde, and high temperature elastomer suppliers allowed MEI to obtain high temperature seals for the tester.

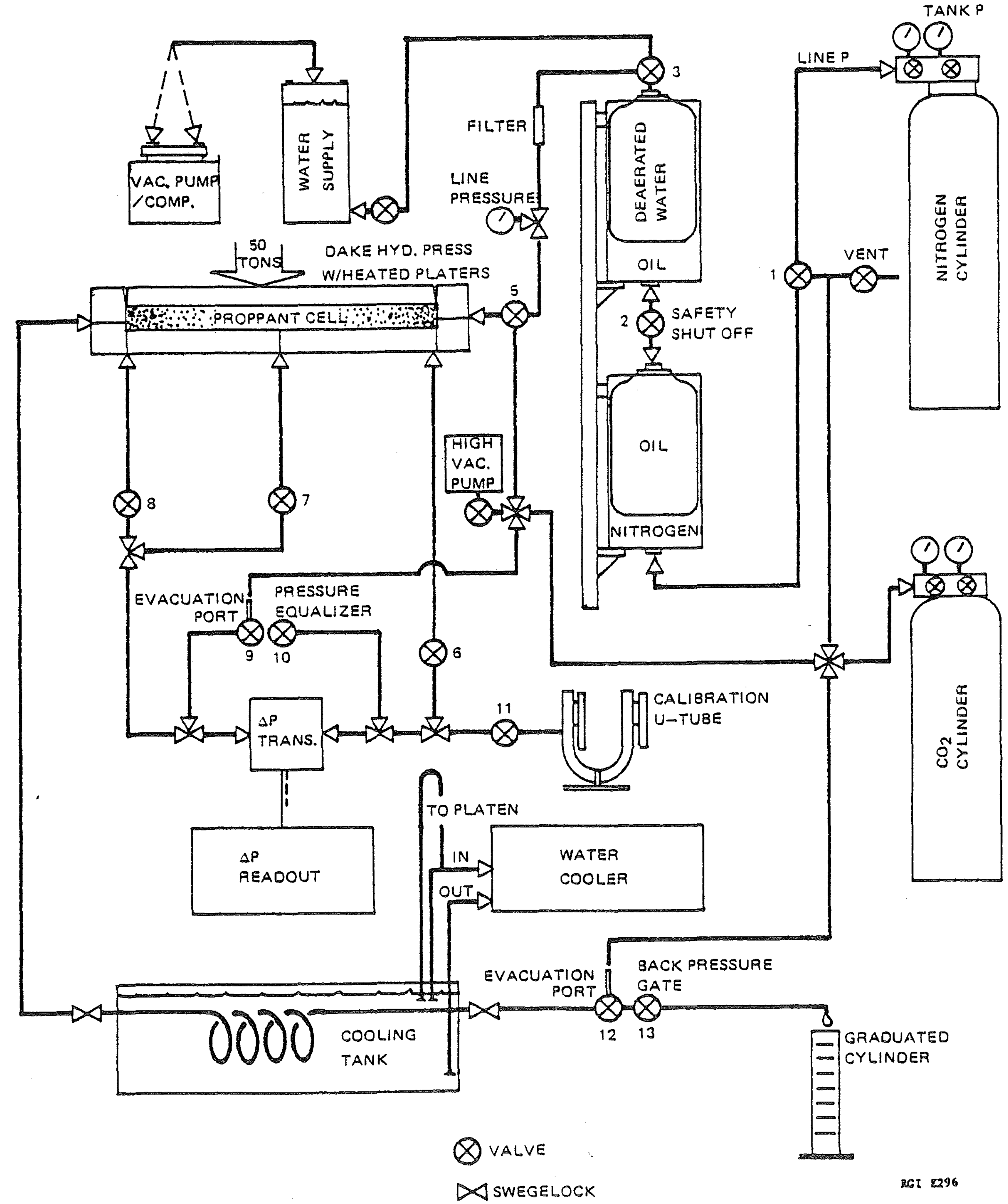
Samples of all types of proppants were gathered from many different sources and high temperature testing started in June and July. A report was issued on a detailed evaluation and testing plan.

A single grain proppant tester was also designed and built to obtain a physical strength (load divided by diameter squared) parameter for each proppant. This tester is used on single grains at elevated temperatures to test temperature sensitivity of the various proppants. This L/D^2 measurement on proppants as well as the measurement of density, acid solubility, roundness, etc., was made to complete the matrix of proppant properties. Samples of proppants before and after testing were collected and each of the samples was marked and forwarded to Vetter Research lab for further study of the crushing mechanism and chemical properties of each proppant.

A verified proppant test result found during 1979 was the extremely detrimental effect that temperature has on frac sand. This effect may eliminate or minimize the use of sand in most geothermal applications, and it will be reported upon as a major finding at the Geothermal Symposium in February of 1980.

High temperature testing of proppants at 350°F and 500°F was largely completed during 1979. The results show that most sands and glass beads are temperature sensitive proppants and may be unusable in higher temperature geothermal wells. Proppants such as resin coated sand and bauxite and uncoated bauxite showed almost no temperature sensitivities. These tests were run with both silica saturated and unsaturated water

FIGURE 1
SCHEMATIC OF GEOTHERMAL PROPPANT TESTER



without appreciably different results; however, a complete redesign of the system would be required to test silica saturated water on a routine basis.

3. Stimulation Techniques

A literature and patent search was completed to search out all techniques that have been used for stimulation. A survey of thirty+ petroleum producers and service companies was made to find out which stimulation techniques they favored and which ones they felt might work in geothermal wells. The study also included the latest reported techniques in stimulation from various symposia and from Society of Petroleum Engineers lectures. All of these techniques were categorized and discussed in great detail in the first draft of a report on this subject. The completed work will consist of two volumes on "Physical and Mechanical Stimulation" Volume I by MEI and "Chemical Stimulation" Volume II by Vetter Research. It will be completed early in 1980.

Table 2 shows a fold-out page where matrix stimulation techniques are discussed and commented on as to applicability to geothermal wells.

4. Technology Transfer

During 1979 key technical articles, on which fracture technology is based, were identified and studied. In addition, fracture design/data manuals were reviewed to determine what variations in standard practice would be required to apply design procedures to geothermal wells. The literature survey was expanded and completed during May, and the basic references were supplied to Vetter Research. All service companies and many oil companies were contacted and asked to share current technology in well stimulation. Most of the companies were very cooperative.

A computer program, based on "A Rapid Method of Predicting Width and Extent of Hydraulically Induced Fractures" by Geertsma and deKlerk, was written and checked out against data prepared by MEI. The project now has a fracture program based on approaches commonly used by the petroleum industry. This program was also made available to PTTS.

A list of thirty different companies was prepared so that personal and phone interviews could be made for the maximum technology transfer of current practices to our geothermal work. The people on the list were interviewed during July. The results of these interviews were written into the report on Technology Transfer along with actual data, schedules and results of high-temperature well stimulation treatments.

TABLE 2 MATRIX OF STIMULATION TECHNIQUES

Potential Type of Stimulation Treatment	Brief Description Of Treatment	Removes Wellbore Damage	Provides Reservoir Stimulation	Viscosity, Sand Carrying, and Fluid Properties	Type of Proppant	Chemical Effects	Fluid Compatibility	Formation Damage	Application to Geothermal Reservoirs	Comments
Water Frac	Planar Frac with water as the fluid, sand as the proppant. Usually high rate jobs.	Yes	Slight, because fractures are too short.	Poor to fair	Usually sand at low concentrations of up to 1 lb/gal.	Minimal	Water has to be compatible.	Minimal if water is compatible w/formations.	Yes, in certain areas to overcome wellbore damage by scale and to reduce pressure drop.	Plain water will not be as widely used as gelled water since it has no limit in safety factors.
Kiel-Dendritic Frac	Pump in/Flow back multiple stages to create branched fracture in formation, uses various fluids and proppants.	Yes	Yes, twice the average planar fracture.	Good because of sand slugs carried at high turbulent rates.	Usually fine to 20/40 mesh sand in slugs at high concentrations 2 to 8 lb/gal.	Minimal	Water has to be compatible.	Minimal if water is compatible w/formations.	Yes, for increased production fractures and fractured zones.	Good potential technique for fractured formations.
Pressure Cycling Fracturing	Uses low cycle fatigue of formation to enhance fracturing.	Yes	Yes	Fair to Good	Usually sand at low to medium concentrations, maybe slugs of sand.	Minimal	Water has to be compatible.	Minimal if water is compatible w/formations.	Yes, for increased production fractures and fractured zones.	Good potential technique for fractured formations.
Gelled Frac	Planar Frac using Polymer water and sand	Yes	Yes, Size Sensitive	Fair to Good	Sand usually at low concentrations 1 to 3 lb/gal.	Water Analysis + Polymer Chemistry.	Water has to be compatible	Polymer debris can damage, check w/core tests.	Yes, standard method.	Good potential in general geothermal work.
Cross-linked Gel Frac	Cross-linked polymers to fully suspend sand or proppant in a planar frac.	Yes	Yes, Size Sensitive	Excellent	Sand, Super Sand or Bauxite at any concentration to 10 lb/gal.	Water Analysis + Polymer Chemistry.	Water has to be compatible.	Check for damage, cross-link breakage, polymer breakage, residue.	Yes, but temperature sensitivity and cost may moderate or minimize use.	Fair potential in special geothermal work.
Foam Frac	Nitrogen/water mixture with a foaming agent to credit a planar fracture.	Yes	Yes, Size and rate sensitive	Excellent	Sand at low average concentration because sand only added to liquid.	Surfactants have complex chemistry	Water compatible	Minimal with water & chemistry checked.	No, cost and temperature sensitivity minimize effectiveness.	Poor potential because major attribute of quick clean up required.
Emulsion Frac	Polymer water in oil emulsion carrying sand and other proppant to make a planar frac.	Yes	Yes	Excellent Viscosity tailored to job.	Sand, Super Sand or Bauxite at any concentration to 8 lb/gal.	Oil, Water & surfactant chemistry check	Complex compatibilities	Usually minimal if checked out thoroughly with reservoir.	No, oil is not wanted in a geothermal well.	Not under consideration for geothermal, widely used in oil and gas wells.
Cool Frac	High rate water or polymer frac to create a planar water fracture in a hot formation.	Yes	Yes	Fair to Good	Sand at low concentrations (small sand to 20/40 mesh).	Minimal short-time fractures, quick trtmt.	Water compatible	Usually minimal.	Yes, high rates give good margin for error-extend fracture into very hot reservoir.	Good potential for long planar fracs in all types of geothermal reservoirs.
Super Sand Frac	Use of a cohesive proppant to prevent sand movement and loss of fracture conductivity at high closure stress-uses any fluids to make a planar frac.	Yes	Yes	Good, Size sand for job	Super Sand - a cohesive proppant retains permeability under high closure.	Minimal phenolic formaldehyde resin.	Water compatible	Minimal because no fines movement Super Sand is good downhole filter.	Yes, no sand flow back permanent stimulation.	Good potential in combination with cool, gelled and kiel-dendritic fractures techniques.
Bounded/Gravity Frac	Use of various densities of fluids, diverting agents, spacers, and proppant to control fracture vertical height and create a long planar frac.	Yes	Yes Height control	Fair to Good	Varies from Nylon, Plastics to sand, Super Sand to Bauxite and steel shot. Also diverting agents, spacers, & sealant.	Check heavy & lt. fluids because density is modified chemically-salts, etc.	Check any fluids used.	Intentional damage on top or bottom of fracture.	Possible, special situation.	Complex technique may be required in areas of low data input.
Matrix Acidize	Low rate acid injection	Yes	No	Poor to None	None	HCL or HF extreme	Before & After Reaction.	Possible and Temp. Effects	Possible, but not likely.	High-Temperature effects unknown.
Acid Frac	High rate acid injection to create an unpropped planar frac.	Yes	No	Poor	Usually only 100 mesh sand low concentrations.	HCL, HF, or organic acid extreme.	Before & After reaction.	Possible and Temp. Effects.	Possible in certain applications.	High-Temperature effects unknown.
Chemical Inhibitor	Injection of special chemicals & surfactants to control corrosion, inhibit reactions and to lower surface tension.	Yes	No, unless large or combination treatments.	Fair to Poor	Sand at low concentrations.	Each chemical might have an effect.	Check overall system for compatibility	Could have damage capability, ck.	Maybe required in certain reservoir for long-term production.	Potential and need unknown at this time.
Erosion Frac	Injection of various fluids at high rates to help clean damage and fine away from wellbore. Makes a planar frac.	Yes	Yes, if also large volumes	Fair to good.	Any abrasive proppant material 1 to 4 lb/gal usual concentration.	Minimal but check any new fluid.	Water Compatible	Minimal by high rate.	Yes, may be necessary for maximum flow conditions and scale removal.	Potential appears good, needs more evaluation.

5. Field Engineering and Testing

During 1979 two Raft River wells were selected for stimulation. During May detailed planning discussions took place to determine how best to stimulate these wells. Detailed fluid testing on specific fracture fluids for the Raft River wells were made to gain input for dynamic fracture design.

Discussions were held with service companies and consultant Othar Kiel (Kiel Consultants) to find the most effective fracturing techniques that were available to us. For the first job in an unknown area, the safest job was found to be the Kiel Frac or dendritic frac. As it turned out, it was also the least expensive technique available. A proposal report was submitted to DOE in June by RGI which discussed the hydraulic fracture design alternatives that were available for the specific conditions.

The Raft River RRGP-4 job was the first hydraulic fracturing treatment of a domestic geothermal well in a water-dominated reservoir. About 8,000 barrels of fluid and 100,000 pounds of sand were used to fracture the RRGP-4 well. Wellbore fracture height was measured at 200 feet with the USGS wellbore acoustic televiewer. A planar fracture design or conventional treatment was chosen for the next experiment in RRGP-5. It used 8,000 barrels of a viscous polymer frac fluid to carry over 400,000 pounds of sand into the well. A wellbore fracture height of about 100 feet was observed after the treatment using the acoustic televiewer.

6. Numerical Modeling

During 1979 several fracture design programs were written and debugged. MEI concentrated on writing programs based on those analytical calculations published in the literature. The programs were for calculating the dynamic fracture growth and the heat transfer effects during fracturing and during flow in the wellbore. Efforts were directed toward helping PTTS in their combining of the fracture growth and heat transfer program since these programs are essential to the engineering designs of the geothermal well stimulation program. MEI will continue to keep all of these fracture design programs operative during 1980 for use on the specific field experiments.

C. Vetter Research

The efforts of Vetter Research (VR) have been divided into the three categories of field studies and experiments, laboratory efforts, and data evaluation and reporting. The division into these three categories rather than into the tasks described in the Statement of Work was chosen because this format seems to lend itself better for a summary report of VR activities.

1. Field Studies and Experiments

Two field experiments at Raft River have been conducted. VR personnel were involved in designing and performing both these jobs. Use of a radioactive tracer in the first job (RRGP-4) was abandoned because of an equipment failure. However, the "tracer behavior" of the added polymers (frac fluid additives) will still allow study of the reservoir response in some detail.

A chemical tracer was used in the second Raft River job (RRGP-5). This tracer, plus the polymer behavior in this second job, will allow determination of the frac fluid behavior within the reservoir and wellbore.

In addition, two matrix acid jobs were conducted in RGI's East Mesa field before the work under this contract was started. The chemical evaluation of these acid jobs will be performed under this contract. Neither of these acid jobs was a significant success in the sense of increasing the commercial potential of the treated wells. However, these jobs are of high value for this project because they revealed some facts and relationships pertinent to high temperature acidizing which were suspected but never determined or measured before. These acid jobs are expected to provide some highly interesting know-how about high temperature acidizing.

All four jobs, i.e., the two fracture jobs in the Raft River field and the two acid jobs in the East Mesa field, must be described and analyzed in detail. This evaluation is in progress (see below).

2. Laboratory Efforts

The laboratory effort on the chemical aspects of the Geothermal Reservoir Well Stimulation Program has been structured into the following broad areas:

(a) Development of analytical methods and acquisition of special purpose equipment for characterizing chemical changes of materials under simulated and real (i.e., field) geothermal conditions.

(b) Conducting both static and dynamic experiments in the laboratory in order to define chemical reactions that will most likely be encountered in a geothermal reservoir during and after well stimulation.

(c) Interfacing with other organizations involved in the project by providing chemical data input and support in designing laboratory tests and field experiments.

The highlights of activities in 1979 in each of these areas are as follows:

Chemical Characterization - A variety of techniques is being used to investigate the properties of stimulation materials. These include high performance liquid chromatography (HPLC) for detailed characterization of the frac polymers, a scanning electron microscope, energy dispersive analyzer, and X-ray diffractometer - the latter three for characterization of solid materials.

While significant progress has been made by Vetter Research in using the HPLC, some problems still remain in fully characterizing the polymers and their degradation products. If these problems can be solved, HPLC will be a useful tool for frac polymer characterization. This result will be well worth the effort, and VR is working with polymer and instrument manufacturers to accomplish this. Until satisfactory HPLC methods are available, alternate methods of characterizing frac polymers have been developed and are being applied to the chemical analysis of produced fluids from the two Raft River jobs as well as the on-going laboratory effort.

Much of the laboratory equipment needed for the static and dynamic work is made from a special order of Hastalloy C material. There have been problems with equipment delays - primarily because of Hastalloy C material availability - and equipment on order since June 1979 has only recently been received. Minor but critical items such as special fittings are still on backorder. Where possible, work is continuing to get all this equipment operational.

Laboratory Testing - Testing has been confined thus far to the evaluation of frac polymer (i.e., guar, HP guar, and xanthan gum) reactions under static conditions. To some extent, the reactions observed have been related to changes that have been seen in the same materials used during the frac work at RRGP-4 and RRGP-5. The area of laboratory testing will receive increased emphasis during the next year as the equipment becomes operational.

Vetter Research has received and analyzed the produced fluids collected during the various flow tests for each of the two field Raft River experiments. In the case of RRGP-4, the waters have been characterized for make-up (i.e., pit water) content, formation water content, frac polymer and frac polymer decomposition products. Similar laboratory work is in progress on the samples collected from RRGP-5. In addition, these samples are being analyzed for ammonium nitrate, a chemical tracer added during the injection of the frac fluid. Separate reports are being prepared and will be issued shortly.

3. Data Evaluation and Reporting

VR is presently behind with respect to report requirements. The major first-year reports remaining to be finalized are:

(a) Technology Transfer and Literature Search

(b) Laboratory Plan

(c) Evaluation of the East Mesa Acid Jobs

(d) Evaluation of the Raft River Frac Jobs

D. Petroleum Training and Technical Services

In the first year of this project, Petroleum Training and Testing Service (PTTS) was primarily involved in three tasks. These were:

(a) Technology transfer from previous stimulation operations

(b) Numerical Modeling: development and conversion of computer codes for use in contract projects

(c) Symposium on geothermal stimulation: organization and delivery of a one-day symposium on the results of the first year's work.

In task (a), a comprehensive literature search was made on the hydraulic fracturing aspects of stimulation operations and this information was collected, compiled and edited into a Technology Transfer report. A current bibliography of pertinent publications was also prepared.

In task (b), several workable computer codes were put together by modifications and enhancements of existing codes. These include:

(1) An interactive fracture design model including temperature dependent fluid parameters

(2) A wellbore temperature model

(3) A single phase geothermal reservoir model with fractured systems capability.

In task (c), the first Geothermal Stimulation Symposium was initiated, developed and planned for San Francisco on February 7, 1980. There will be 14 speakers (authors) at this symposium, and a total of 10 presentations.

The objectives, technical accomplishments and results of the three tasks are indicated below. These tasks were run concurrently by the PTTS staff and included on-going meetings, exchanges and coordination with the prime contractor, Republic Geothermal, Inc. and the other subcontractors, Vetter Research, Maurer Engineering and MAPCO.

1. Technology Transfer

The objective of this task was to assess the stimulation technology developed in the oil and gas industry and to evaluate it as to applicability to the geothermal industry. In developing the technology transfer, PTTS determined which of the available online data bases of bibliographic information were pertinent and then performed an online search which provided over 500 articles and reports of possible interest to this program effort. These references covered governmental sources, industry and private sources and academic publications. Copies of these documents were purchased and a detailed analysis was made in the following areas:

(a) Stimulation Process Variables
(b) Frac Fluid Interactions
(c) Fracturing Problems
(d) Temperature Effects in Fracture Design
(e) Fracture Evaluation
(f) Stimulation Case Histories

An integral part of the analysis involved a breakdown of each stimulation report into seven categories with a total of 65 parameters. This allowed the investigators to quantify the efficiency of various treatments and design criteria in a more objective fashion to provide an ordered ranking according to productivity increase. The results of this phase are summarized in a final report on Technology Transfer.

2. Numerical Modeling

An interactive numerical design model and a reservoir/well response model were developed under this task. PTTS was involved in the development and/or modification of the following five computer codes:

(a) FRAC - an interactive fracture design model with temperature dependent fluid properties.

(b) WELTEM - a simplified wellbore temperature code using published closed form solutions.

(c) GEOTEMP - a finite difference transient heat simulator for wellbore temperatures.

(d) DIFFUS - a three-dimensional finite difference fluid or heat conduction model with fracture simulation capability.

(e) SHAFT78 - a multidimensional, multiphase energy and mass transfer simulator for geothermal systems.

The first task attempted was to get the respective codes compiled on a given computer system. Of the four codes obtained from other sources - GEOTEMP, DIFFUS, WELTEM, SHAFT78 - none would compile on either the IBM 370 or the CDC 6600 system. The reasons for these initial problems were:

(1) Incomplete code - missing statements, subprograms or data blocks

(2) Dead-end code - statements that did nothing or put the program in an infinite loop; e.g., 10 GØ TØ 10

(3) Machine dependent code - subscript notation, machine dependent I/O; conversion to standard FORTRAN

(4) Programming errors - incorrect FORTRAN

(5) Program Size - core and storage requirements were much greater than the industry norm; e.g., single arrays of 98,011 elements, data storage of 3.17 million elements.

Each code required specific technical enhancements or modifications for use by engineers or analysts in an operating environment. These efforts on each code may be summarized as follows:

(a) Interactive Fracture Design Program - (FRAC): This program was developed by combining the following functional elements:

WELTEM - a wellbore temperature model (to be discussed later)
GERTSM - a fracture parameter model (using the GERTSM approach to fracture design)

A fracture fluid temperature model utilizing the SINCLAIR approach or the WHITSITT-DYSART approach.

PTTS modified the GERTSM model provided by Maurer Engineering Inc. to accommodate a variation in input fluid temperature at the upstream end of the model and a time-distance dependent temperature profile in the fracture. The temperature effects in the fracture can be determined by either or both of the two published techniques, i.e., Sinclair (constant leakoff at a given time) or Whitsitt-Dysart (variable leakoff); or by a prescribed leakoff rate as a function of distance into the fracture.

The program is designed to provide either batch or interactive processing (from a terminal or cards) and to provide output to a plotter, a CRT or to a line printing device.

(b) WELTEM: This code is based on a Romero-Juarez publication ("A Simplified Method for Calculating Temperature Changes in Deep Wells," SPE Journal, June 1979). As published, the code determines the temperature profile within the flowing stream for a 7-1/8" casing and a 4-1/2" tubing at a time of one hour. PTTS modified the code to include any arbitrary wellbore size, tubular goods and pumping time by using a regression analysis on the independent variables. The model can now determine any bottomhole temperature for any geometry at any given time. Secondly, the WELTEM code was integrated into the interactive fracture design program to allow a realistic determination of the downhole temperature at the sandface during the fracture job.

(c) GEOTEMP: This code was developed by ENERTECH under Contract to SANDIA Laboratory. It simulated heat flow in and around the wellbore. To make the code operational for use by the contractors, PTTS removed all machine dependent code and modified the software to generalize the fluid properties allowed, remove limitations on tubular good geometry, and add interactive graphics capability.

This program can be used in batch mode or interactively to determine the wellbore temperature profile.

(d) DIFFUS: This program was obtained from the Department of Energy Morgantown Energy Technology Center. It is a comprehensive model capable of three-dimensional flow simulation within a fractured system.

The model worked for one-dimensional systems and some two-dimensional systems, but was not fully operational on fractured systems.

PTTS began by correcting the code to allow it to compile without errors. As a result of its size, the program was segmented into a manageable overlay structure to conserve computer resources and improve running efficiency. As published, the program requires two passes to complete a simulation run; the first pass determined the variable storage requirements, while the second pass performed the actual simulation run. The software has been modified to perform the simulation with only a single pass, thereby reducing the need for engineer or analyst intervention. The DIFFUS program can now simulate a 1-D, 2-D or 3-D system with a single fracture. The multiple fracture option is still not operational. Analysis and modifications of the code are being carried out at this time.

(e) SHAFT78: This program was obtained from Lawrence Berkeley Laboratory. Attempts were made to compile this program on the CDC 6600 in order to develop a predictive tool for geothermal reservoir work. The program was found to be too large for this system. The sheer size of the program and magnitude of errors made compilation a slow and very expensive process. The program would not run on an IBM system. The program overlay structure as received would not compile or execute on the Network CDC 6600 system. Modifications were made and the program compiled on the CRAY-I machine. The significant changes were on machine word size, code conversion and overlay modification. At this time, the code is not operational and work has been terminated on its conversion.

This task has produced four workable tools for the numerical modeling of geothermal stimulation work: WELTEM, GEOTEMP, DIFFUS and FRAC. In addition, these tools are designed to assist the engineer/analyst by providing interactive, readable information in a format that fits his needs. The only significant lack of accomplishment has been in making the SHAFT78 program operational.

3. Geothermal Symposium

PTTS will initiate, organize and deliver a symposium on Geothermal Reservoir Well Stimulation to facilitate the interchange of information on geothermal well stimulation technology. A list of attendees has been developed from the geothermal community and those industry groups which are currently involved in stimulation work. The speakers have been selected from the contractor and subcontractor groups involved in this project and also from several organizations and companies actively involved in geothermal stimulation work. The symposium will take place in San Francisco on February 7, 1980. A set of proceedings will be published after the presentations at the conference.

The following ten presentations are planned:

1. Bob Hanold - Opening speaker
2. Don Campbell - Contract Status Report
3. James Albright - Active and Passive Seismic Techniques in Mapping Fractures
4. Henry Crichlow - Fracture Design Modeling
5. Ali Daneshi - Proppants and Proppant Transport
6. Bob Hanold - Explosive Stimulation of Geothermal Wells
7. Richard Sinclair - High Temperature Proppants and Fluids

8. Charles Morris, Bob Verity, Bob Nicholson, Scott Keys - Case History: (a) Raft River: Mechanical Design and Operations
(b) Raft River Evaluation
9. Ralph Veatch - Massive Hydraulic Fracturing
10. Otto Vetter, Don Tysee, Viv Kandarpa
(a) Mathematical Treatment of Tracer Behavior in a Fracture
(b) Thermal Stability of Fracture Fluids in Aqueous Systems

IV. Program Reorganization, Budget and Schedule

A. Program Reorganization

As discussed in the foregoing, the original program schedule has been changed by the accelerated completion of a second field experiment at Raft River. Figure 2 illustrates the revised program schedule for the completion of all activities contained in the Statement of Work. The completed and planned field stimulation experimental program (based mostly on recommendations contained in the report "Geothermal Reservoir Well Stimulation Project - Reservoir Selection Task" of November 1979) is as follows:

(1) Dendritic ("Kiel") hydraulic fracture treatment of a low temperature reservoir - Raft River Well RRGP-4. (completed August 1979)

(2) Massive hydraulic fracture treatment in a low temperature reservoir - Raft River Well RRGP-5. (completed November 1979)

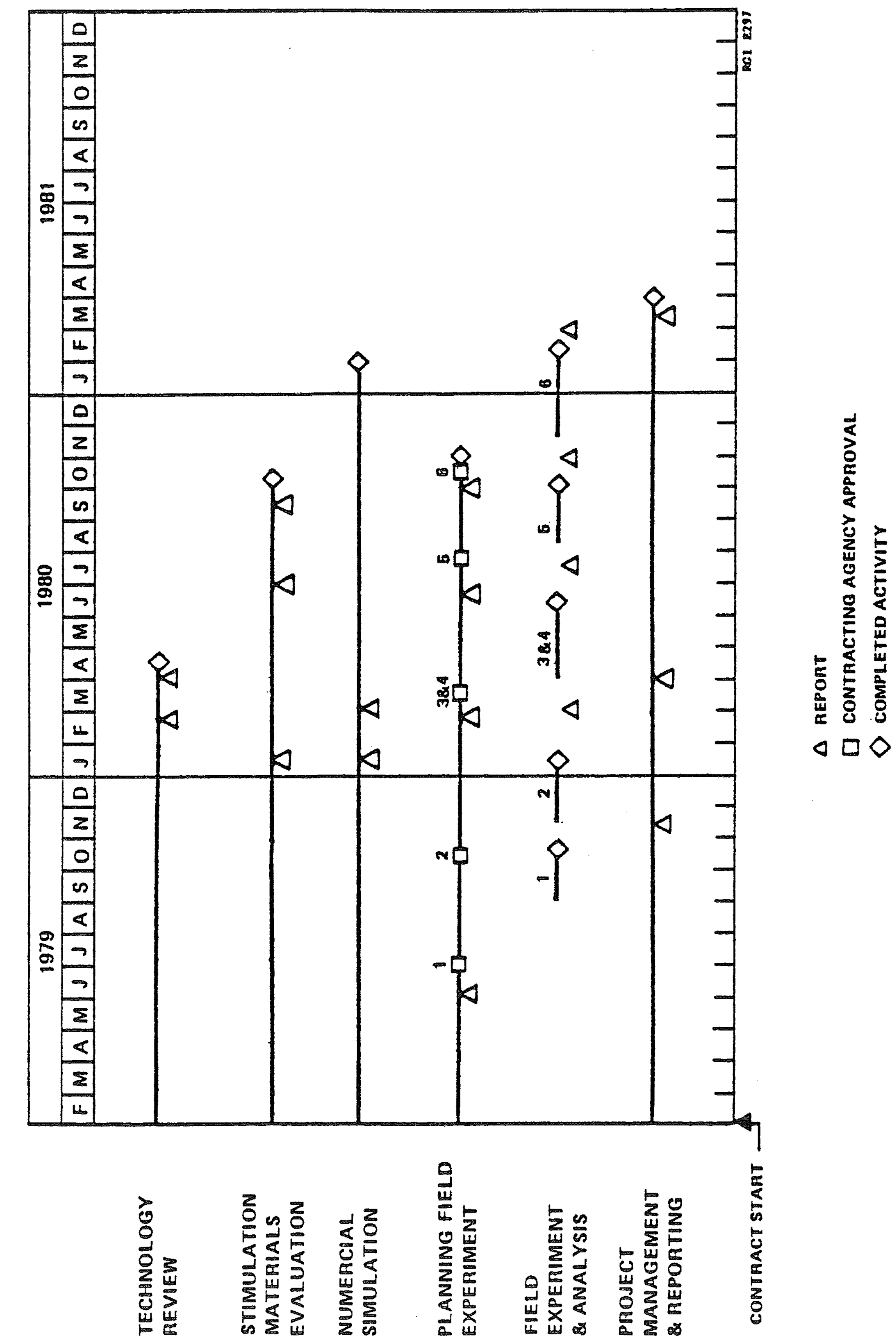
(3) and (4) Combined multi-stage hydraulic fracture and shallow hydraulic fracture ("mini-frac") treatment of a moderate temperature reservoir - probably East Mesa Well 58-30.

(5) An advanced type stimulation treatment (acid frac or ...?) of a high temperature reservoir - Baca, NM; Brawley, CA; Roosevelt Hot Springs, UT; The Geysers, CA.

(6) Multistage hydraulic fracture treatment with scale inhibitor experiments in a high temperature reservoir - probably Westmorland, CA.

It should be noted that the future experimental program is flexible. The final choice of field locations will depend upon the success and technology development obtained by the GRWSP in preceding experiments and laboratory work. As indicated, the program has made a preliminary choice of the East Mesa reservoir for the next field experiment. A proposal for the East Mesa job is being prepared for submission to the DOE/DGE at present.

FIGURE 2
GRWSP REVISED SCHEDULE



In addition to the experiment schedule changes, the tasks outlined in the original contract reporting documentation have been combined into more descriptive and appropriate groups. These combined task activities are shown in Table 3; e.g., tasks 1.1.1, 1.2.1 and 1.3.1 are now combined into the "technology review" activity. It is expected that this arrangement will simplify the project reporting and communication functions. Internally, RGI will continue to monitor all original task activities individually for administrative and budgetary control.

B. First-Year Financial Status

The financial status of the first year of the GRWSP is illustrated on Figure 3 and summarized on Table 4 according to the task categories discussed above. Tables 5 and 6 show the estimated total of costs associated with the Raft River experiments by task and contractor. A further detailed breakdown of all first-year funds spent is provided in the Appendix.

The project expenditures were $1,617,000 through December 31, 1979, which is approximately $400,000 more than planned for the first-year activities. The principal reason for the increased expenditures was the second Raft River field experiment. The original project schedule called for the completion of only one field experiment during 1979. The second field experiment performed in 1979 represents 85 percent of the excess; i.e., $342,000 for the Raft River RRGP-5 stimulation treatment (it should be noted that approximately $192,000 in expenses associated with the Raft River experiments has not been billed or included in this first-year summary as of December 31, 1979), and $58,000 for increased labor and labor related overhead costs.

Table 4 also includes an estimate of the percent complete for each task category. Only the technology transfer and stimulation materials categories show significant contrast between the percent spent and estimated percent complete values. The Technology Transfer category is primarily a literature survey and "state-of-the-art" technology assessment task. Documentation of the work on this task has been delayed because of the field experiments, but is expected to be completed within budget. The Stimulation Materials Evaluation category shows a high percentage of the funds spent because this task includes the development of special equipment required to evaluate materials for geothermal application. Activities during the second year on this latter task will be labor intensive charges because all major equipment orders have now been received. All the other task activities are essentially on schedule or even ahead of schedule.

TABLE 3

Task Reorganization

Technology Review	
1.1.1	Technology Transfer
1.2.1	Equipment Review - Surface
1.3.1	Equipment Review - Downhole
Stimulation Materials Evaluation	
1.4.1	Frac Fluid Evaluation
1.4.2	Frac Proppant Evaluation
1.4.3	Recent Stimulation Technology Development Analysis
1.5.1	Chemical Stimulation Analysis
Numerical Simulation	
1.6.1	Numerical Model Development
1.6.2	Numerical Analysis (Job)
Planning Field Experiment	
2.1.1	Reservoir ID, Evaluation and Qualification
2.2.1	Well ID and Recommendation
2.3.1	Prepare Specific Well Experiment
2.4.1	Environmental and Permitting
2.5.1	Field Experiment Administration Planning
2.6.1	Specifications and Subcontracting
Field Experiment and Analysis	
1.6.3	Radioactive Tracer
2.7.1	Design and Provide Surface Production Facilities
2.8.1	Field Experiment and Production Testing
2.8.2	Monitoring and Data Collection
2.8.3	Data Analysis and Interpretation
Project Management and Reporting	
2.9.1	Project Reporting and Management
2.9.2	Geothermal Well Stimulation Symposium

Figure 3
GRWSP FIRST-YEAR FINANCIAL STATUS

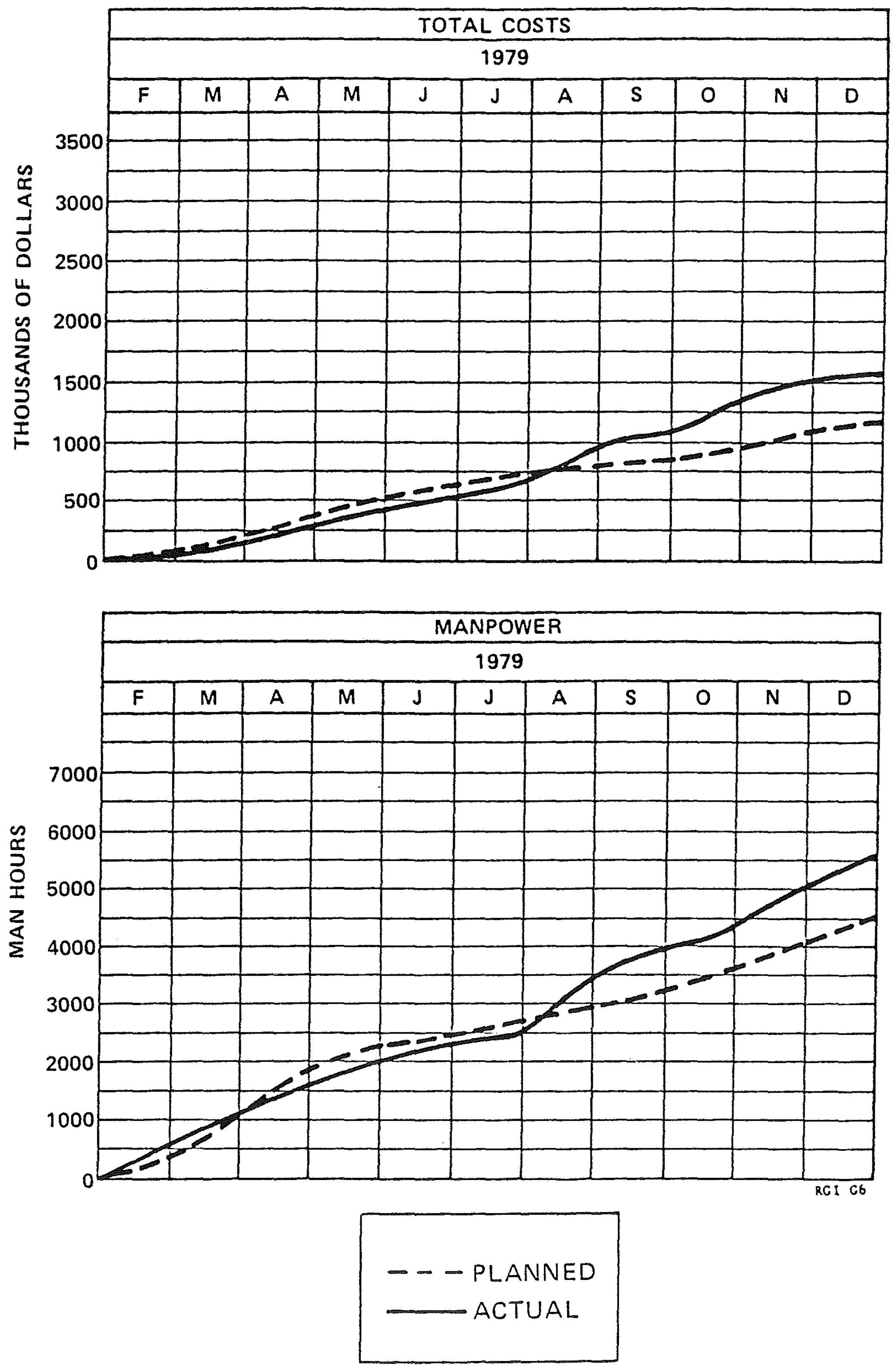


Table 4

GRWSP Financial Status - ($000)
December 31, 1979

Category(1)	Estimated Costs (2)	Spent(3)	% Spent	Estimated % Complete
Technology Review	$ 103	$ 94	91	70
Stimulation Materials Evaluation	681	447	65	50
Numerical Simulation	124	81	65	70
Experiment Planning	164	58	35	33
Field Experiments	2,442	717	29	33
Management	490	220	45	40
Total	$4,004	$1,617	40	40

(1) See Table 3 for grouping of major tasks by category
(2) Based on contract estimates
(3) Based on actual billings

C. Second-Year Schedule and Budget

As previously noted, Figure 2 shows the revised schedule proposed for completion of the program. Although there is a significant rearrangement of the field experiments, the project is expected to be completed within the original time frame while meeting all the requirements of the original Statement of Work.

The proposed budget for the completion of the program is given on Table 7. A $543,000 cost increase relative to the current contract amount is anticipated. The cost areas accounting for the increase are: inflation, changes in planned frac materials, labor and overhead. The largest single category, i.e., Field Experiment & Analysis, accounts for more than $363,000 of the overage. Specifically, the significant areas of cost concern may be summarized as follows:

(1) $306,000 Labor and labor related indirect overhead costs have increased over original estimates due to an error in the original estimate (recoginized at the time of contract negotiation), provision for increased on-site field experiment supervision, a higher hourly rate, and cost growths in departmental overheads and general and administrative expenses. See Appendix A for a more detailed explanation.

TABLE 5

FIELD EXPERIMENT BUDGET SUMMARY - ($000)

EXPERIMENT 1

Experiment Type: Dendritic ("Kiel") frac intended to improve communication with natural fracture system

Reservoir Type: Low temperature, fractured

Location: Raft River #4

	RGI LABOR	VR	MEI	MAPCO	SERVICE COMPANY	TOTAL
Field Experiment and Analysis						
Design and Provide Surf. Production Facilities	0	0	0	0	0	0
Field Experiment and Production Testing	24	3	4	0	306	337
Monitoring and Data Collection	1	26	0	0	0	27
Data Analysis and Interpretation	15	8	0	0	0	23
Radioactive Tracer	0	25	0	0	0	25
TOTAL FIELD EXPERIMENT AND ANALYSIS	40	62	4	0	306	412
Planning Field Experiment	33	0	0	0	6	39
TOTAL FIELD EXPERIMENT	73	62	4	0	312	451

TABLE 6

FIELD EXPERIMENT BUDGET SUMMARY - ($000)

EXPERIMENT 2

Experiment Type: Conventional massive planar frac intended to establish communication with natural fracture system in deep, hotter portion of reservoir.

Reservoir Type: Low temperature, fractured

Location: Raft River #5

	RGI LABOR	VR	MEI	MAPCO	SERVICE COMPANY	TOTAL
Field Experiment and Analysis						
Design and Provide Surf. Production Facilities	0	0	0	0	0	0
Field Experiment and Production Testing	33	31	3	0	394	461
Monitoring and Data Collection	8	1	0	0	0	9
Data Analysis and Interpretation	14	3	0	0	0	17
Radioactive Tracer	0	0	0	0	0	0
TOTAL FIELD EXPERIMENT AND ANALYSIS	55	35	3	0	394	487
Planning Field Experiment	12	0	0	0	4	16
TOTAL FIELD EXPERIMENT	67	35	3	0	398	503

TABLE 7

GRWSP Second-Year Budget - ($000)

Category	Spent	RGI	VR	MEI	MGI/PTTS	Total	Original Budget	Difference
		--------2nd Year Estimate--------						
Technology Transfer	94	10	12	0	3	119	103	16
Frac Materials Evaluation	447	3	218	37	0	705	681	24
Numerical Simulation	81	18	0	10	45	154	124	30
Planning Field Experiment	58	76	41	19	15	209	164	45
Field Experiment & Analysis	717	1,726	274	30	58	2,805	2,442	363
Project Management & Reporting	220	211	73	8	43	555	490	65
TOTAL	1,617	2,044	618	104	164	4,547	4,004	543

(2) $145,000 Actual field experiment costs at Raft River, excluding RGI labor, exceeded proposal estimates by $244,000 due to the nature of the jobs and remoteness of the location. Contract cost estimates were based on less extensive jobs and did not assume the Idaho location. However, a cost saving of $99,000 in production testing was realized because the test facilities were installed and operated by EG&G under separate funding from DOE.

(3) $86,000 An increase in expenditures for rigs, equipment, rentals, field services and stimulation materials is expected in the remaining field experiments. This figure is the net result of inflation and revisions in the procedure and materials for field experiments 36. This is an increase of 6.4% over the $1,343,000 originally budgeted in this category.

(4) $6,000 Other budget changes result in a net increase for this amount.

The items discussed above represent significant increases over the original contract cost estimates. However, it should be noted that several conservative assumptions were made in arriving at the estimated future experiment costs for proppant materials, production test facilities, inflation, and supervisory effort. The budget presented herein, reflects the best estimate of the cost of completing the remaining project activities. Tables 8 through 10 summarize the estimated costs for each of the future field stimulation treatments.

TABLE 8

FIELD EXPERIMENT BUDGET SUMMARY - ($000)

EXPERIMENT 3 & 4

Experiment Type: Multi-stage hydraulic frac intended to enhance productivity of deep, low permeability zones and a mini-frac to penetrate near-wellbore impairment in more shallow, high permeability sands

Reservoir Type: Moderate temperature, sandstone-shale formation

Probable Location: East Mesa 58-30

	RGI LABOR	VR	MEI	MAPCO	SERVICE COMPANY	TOTAL
Field Experiment and Analysis						
Design and Provide Surf. Production Facilities	8	0	0	0	60	68
Field Experiment and Production Testing	30	6	8	0	462	506
Monitoring and Data Collection	19	30	0	0	23	72
Data Analysis and Interpretation	7	16	2	0	0	25
Radioactive Tracer	0	31	0	0	0	31
TOTAL FIELD EXPERIMENT AND ANALYSIS	64	83	10	0	545	702
Planning Field Experiment	27	14	7	0	5	53
TOTAL FIELD EXPERIMENT	91	97	17	0	550	755

TABLE 9

FIELD EXPERIMENT BUDGET SUMMARY - ($000)

EXPERIMENT 5

Experiment Type: Acid frac or another advanced type stimulation treatment intended for productivity enhancement

Reservoir Type: High temperature, fractured

Probable Location: Baca, The Geysers, or Roosevelt Hot Springs

	RGI LABOR	VR	MEI	MAPCO	SERVICE COMPANY	TOTAL
Field Experiment and Analysis						
Design and Provide Surf. Production Facilities	4	0	0	0	60	64
Field Experiment and Production Testing	20	6	9	0	312	347
Monitoring and Data Collection	12	30	0	0	23	65
Data Analysis and Interpretation	6	16	2	0	0	24
Radioactive Tracer	0	30	0	0	0	30
TOTAL FIELD EXPERIMENT AND ANALYSIS	42	82	11	0	395	530
Planning Field Experiment	26	13	6	0	5	50
TOTAL FIELD EXPERIMENT	68	95	17	0	400	580

TABLE 10

FIELD EXPERIMENT BUDGET SUMMARY - ($000)

EXPERIMENT 6

Experiment Type: Two-stage hydraulic frac with scale inhibitor intended to reduce near-wellbore pressure drop and resultant scale deposition

Reservoir Type: High temperature, sandstone-shale formation

Probable Location: Westmorland

	RGI LABOR	VR	MEI	MAPCO	SERVICE COMPANY	TOTAL
Field Experiment and Analysis						
Design and Provide Surf. Production Facilities	4	0	0	0	60	64
Field Experiment and Production Testing	16	6	8	32	409	471
Monitoring and Data Collection	5	30	0	26	23	84
Data Analysis and Interpretation	6	16	2	0	0	24
Radioactive Tracer	0	31	0	0	0	31
TOTAL FIELD EXPERIMENT AND ANALYSIS	31	83	10	58	492	674
Planning Field Experiment	26	14	6	0	5	51
TOTAL FIELD EXPERIMENT	57	97	16	58	497	725

GRWSP
Labor Cost Variance Analysis

	Hours	Labor Dollars	Overhead	G&A	Total Labor Costs
Proposal (2 Years)					
Rates			76.87%	58.00%	
Effort	12,864	$187,034	$143,783	$108,480	$439,297
Actual (11 Mos to 12/31/79)					
Rates			100.79%	95.42%	
Effort	5,461	88,239	88,935	84,199	261,373
Balance Remaining	7,403	98,795	54,848	24,281	177,924
Estimate to Complete	9,054	157,829	158,564	167,299	483,692
Projected Variance	1,651	$ 59,034	$103,716	$143,018	$305,768
Increases Due to					
Omitted Hours	816	$ 13,848	$ 10,645	$ 8,032	$ 32,525
Field Experiments	835	18,353	17,986	19,454	55,793
Higher Hourly Rates	-	26,836	20,629	15,565	63,030
Departmental Overhead	-	-	54,470	-	54,470
G&A	-	-	-	99,967	99,967
Rounding	-	(3)	(14)	-	(17)
Total Increases	1,651	$59,034	$103,716	$143,018	$305,768

GRWSP

Increase Due to Omitted Hours

Increase in Labor Costs due to Omitted Hours

Omitted Hours	816
Estimated Labor Rate	$ 16.97
Direct Labor	13,848
Overhead @ Proposed Rate (76.87%)	10,645
G&A @ Proposed Rate (58.00%)	8,032
Total Increase	$32,525

Approximately one-half man-year of senior engineering time was included in work program but inadvertently omitted from proposed costs. This effort was included in the Statement of Work and, therefore, is not an overrun or change in the scope of the work.

GRWSP

Increase in On-Site Field Experiment Supervision

Field Experiment Supervisor

Hourly Rate	$ 21.98
Increased Hours	835
Direct Labor	18,353
Department Overhead @ 98%	17,986
G&A @ 106%	19,454
Total Increase	$ 55,793

On-site supervision by RGI personnel was substantially underestimated in the performance of experiments 1 and 2. The average was approximately 200 hours per job. Therefore, it is estimated that an additional 835 hours will be required during the remaining four experiments.

GRWSP
Increase Due to Higher Hourly Rates

Proposed			
Labor Dollars	$187,034		
Hours	12,864		
Average Rate per Hour	14.54	$14.54	
Actual			
Labor Dollars	$ 88,239		
Hours	5,461		
Average Rate per Hour to 12/31/79	16.16(1)	16.16	
Realized Increase	1.62		
Factor for Wage Increases		1.05	
Estimated Rate 2nd Year		$16.97	
Estimated Increase		2.43	
Affected Hours	5,461	7,403	
Increase in Direct Labor	$ 8,847	$17,989	$26,836
Overhead @ Proposed Rate (76.87%)			20,629
G&A @ Proposed Rate (58.00%)			15,565
Total Increase			$63,030

(1) Average labor rate is higher due to:
  (a) Technician was not hired; work had to be performed by senior engineering staff.
  (b) Labor hours spent on field experiments by senior staff were significantly higher than planned due to unanticipated complexity of actual experiments performed.

GRWSP
Increases Due to Indirect Rates

	Realized Increase	Estimated Increase	Total Increase
Departmental Overhead			
Proposed Composite Rate	76.87%	76.87%	
Actual Composite Rate	100.79%	100.79%	
Increase	23.92%	23.92%	
Affected Direct Labor	$ 88,239	$139,476	
Increase in Department Overhead (1)	$ 21,107	$ 33,363	$ 54,470
G&A Expenses			
Proposed Rate	58.00%	58.00%	
Actual Rate	95.42%		
Estimated Rate		106.00%	
Increase	37.42%	48.00%	
Affected Direct Labor	$ 88,239	$139,476	
Increase in G&A (2)	$ 33,019	$ 66,948	$ 99,967

(1) Increase is due to delays in other projects anticipated in original rate computations. Fixed overhead costs have not increased significantly while the direct labor base has not increased as projected.

(2) Original proposed rate was based on a subjective estimate of the base for allocation. Present method allocates G&A expenses based on recorded direct labor. The increase is also due in part to the reason stated in (1) above.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-640-258/2433