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GEOTHERMAL RESERVOIR WELL STIMULATION PROJECT – RESERVOIR SELECTION TASK

November 1979

Work Performed Under Contract No. AC32-79AL10563

Republic Geothermal, Inc.
Santa Fe Springs, California

U. S. DEPARTMENT OF ENERGY
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PREPARED FOR:

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Summary

The Geothermal Reservoir Well Stimulation Project has prepared a two-year program to develop and field test methods of stimulating geothermal wells. The program provides for six field experiments which progress in difficulty from low temperature reservoirs using current technology to high temperature reservoirs using advanced types of stimulation treatments. This report describes the process used to select the six field experiment locations and stimulation treatments. Tentatively, the following reservoirs are proposed:

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

The program will be reviewed after each field treatment to select a specific well candidate for the next experiment and to determine whether alteration of the sequence will be beneficial to the overall success of the project and the geothermal industry.

GEOTHERMAL RESERVOIR WELL STIMULATION PROJECT

RESERVOIR SELECTION TASK

Introduction

The purpose of this report is to describe the selection of the reservoir sites for field experiments in accordance with the technical goals of the Geothermal Reservoir Well Stimulation Project (GRWSP). The reservoir selection process thus far has been limited to those sites at which the developer has indicated a willingness to participate in the field experiments. Nine geothermal reservoirs currently under development were evaluated for possible well stimulation treatments. These reservoirs present a broad range of resource temperatures, petrophysical properties and fluid properties.

The selection criteria used were based on twelve specific reservoir and field attributes which would be favorable to a successful well stimulation treatment and evaluation program. Each reservoir was evaluated and ranked using these criteria. Superimposed upon this selection procedure were the specific well and reservoir conditions required for the field experiments such that the well stimulation technology is advanced with the completion of each job; i.e., the reservoir temperature, petrophysical properties, fluid properties, etc., are generally expected to present an increasing challenge to the existing stimulation technology. The six planned field experiments are expected to utilize at least four different geothermal reservoirs. Proposed reservoir sites will be reviewed after each field experiment to determine any need to alter the sequence of field tests proposed herein which will be beneficial to the overall success of the GRWSP. Other sites submitted for consideration at a later date will be included in the program only if they can be shown to offer significant technical and/or cost advantages for the program.

Well Stimulation Program Description

Republic Geothermal, Inc. (with Vetter Research, Maurer Engineering, Petroleum Training and Technical Services, and MAPCO Geothermal, Inc., as principle subcontractors) was selected by the U.S. Department of Energy, Division of Geothermal Energy, for the Geothermal Reservoir Well Stimulation Program Management contract award. The contract award is for two years. The program includes six field stimulation experiments in addition to laboratory tests and technical assessment of the various materials, equipment and methodology needed for the advancement of geothermal well stimulation capability.

The primary objectives of the program include the development, assessment, and field testing of methods for increasing and prolonging the productivity of geothermal wells. The GRWSP stresses the utilization of technology developed for petroleum well stimulation to attain results useful in geothermal production wells with emphasis on the stimulation of hot water-dominated systems. These activities will be oriented toward developing and field testing technology which can be readily applied to enhance geothermal development economics.

Phase I activities include: (a) assessing stimulation technology developed in the oil and gas industry as to its applicability to the unique problems of geothermal well stimulation, (b) determining the immediate additional technology needed to successfully stimulate geothermal wells, and (c) conducting laboratory and engineering analyses to fulfill that technological need. Activity (b) includes recommending equipment and hardware development which is necessary to conduct Phase II of this program and which is generally needed by the geothermal industry for successful stimulation operations.

The technique of explosively stimulating geothermal wells is presently not included in the GRWSP. The U.S. Department of Energy is supporting the development of this technology in a separate project. Field experiments using explosives are programmed this year in the The Geysers field.

The primary objectives of Phase II are to: (a) logically select and propose geothermal reservoirs and specific wells for field stimulation treatments; (b) plan and conduct the experiments using applicable results from Phase I; and (c) monitor and interpret the results of the stimulation treatments.

The field stimulation treatments, as originally proposed, are outlined below:

(a) The first field treatment will primarily be an extension of the petroleum industry technology applied to a low temperature geothermal reservoir in which a hydraulic fracture stimulation is performed. This test is intended to verify the applicability of existing predictive technology, operational techniques, and interpretive methods to geothermal wells.

(b) The second field experiment will be another hydraulic fracture stimulation in an appropriate reservoir with higher temperatures. This test may require some new developments in techniques, materials and hardware, and some modifications of the predictive and interpretive techniques.

(c) A third set of experiments will consist of two separate field jobs. One job will consist of a multi-stage hydraulic fracture stimulation combined with elaborate methods to maintain well productivity through scale inhibition. The selected reservoir for this job will have a history of scaling in the rock matrix during production in the immediate vicinity of the wellbore. A scale inhibitor squeeze will be incorporated with the hydraulic fracture stimulation. It is anticipated that the combination of fracturing and scale inhibition can improve the capability of producing at higher rates and can help prevent scale in the matrix and fractures. To assist in interpretation of the formation reaction during and after treatment, radioactive tracers will be included in the stimulation fluids and the fluid returns monitored. Concomitant with the multi-stage stimulation job an acid stimulation treatment (not necessarily in the same well or reservoir) will be carried out.

(d) The fourth test set will include two field jobs, at least one of which employs an advanced type of stimulation. Techniques such as dendritic hydraulic fracturing and acid etching hydraulic fracture treating will be considered. The second job will be directed primarily at penetrating near wellbore formation damage and will therefore be a "mini-frac" (shallow hydraulic fracture stimulation).

General Well Stimulation Considerations

The GRWSP is concerned with improving geothermal wells with particular emphasis on wells that are economic failures because of restricted flow. Stimulation is the creation or improvement of permeable paths from the reservoir to the wellbore by artificial techniques such as mechanical fracturing, or chemical reactions. By increasing the productivity of the well through stimulation technology, an otherwise non-commercial well may be made commercial. Currently, stimulation of geothermal wells is done only rarely. Deficient wells are normally either redrilled or replaced at a cost much greater than that of a stimulation job. Hydraulic fracturing is particularly useful in competent reservoir rock of low permeability or if natural flow channels in the rock near the wellbore have been plugged by drilling fluids, hydrating clays, or through long-term geochemical changes such as silica or calcite deposition. Chemical treatments, such as acid fracturing, have also been successful in controlling near wellbore geochemical changes.

Before a well is selected for stimulation treatment, it must be determined that the reservoir contains sufficient fluids in place and has adequate formation pressure available to produce at higher rates following stimulation. The cause for low productivity must also be determined so that an appropriate type of stimulation job can be recommended.

One of the best methods for evaluating the condition of the formation adjacent to the well and the condition of the reservoir in the interwell area is to analyze pressure buildup data. By analyzing the pressure buildup behavior of a well which is shut-in after production, the average permeability of the formation both near the well and in the reservoir can be determined. From this information any wellbore damage or "skin" effect can be calculated and the condition ratio or flow efficiency of the well can be determined.

With this information, certain causes for the low well productivity may be determined. Whether the causes arise from fluid chemistry problems or formation rock problems, one of three general type conditions result and, for each condition, a different course of action is required, for example:

(a) It may be the result of a permeability reduction near the well. The removal of this block by chemical treatment or by a small fracturing treatment (mini-frac) will often result in a substantial production increase;

(b) It may be a result of low permeability throughout the reservoir. If so, and if substantial recoverable fluid is in place, production can be greatly increased by deep penetrating fractures achieved with large volume, high injection rate fracturing treatments (massive hydraulic frac-MHF);

(c) Sometimes the reservoir pressure has been depleted even in the interwell area. In this case, well stimulation generally will not increase productivity enough to make a treatment profitable.

The general criteria for selecting wells for stimulation treatment have been published by many authors for oil and gas wells. The following criteria are believed to be applicable in most geothermal cases; however, no general rule should be used when data are available from pressure tests, core analyses, etc.:

(a) State of Depletion of the Producing Formation

Stimulation treatments are successful in increasing production rates because they increase permeability in the vicinity of the wellbore. If a formation is depleted of reservoir energy, stimulation generally will not increase production enough to justify the expense of the treatment. Larger and more sustained production increases can be expected if stimulation treatments are used early in the life of the field.

(b) Formation Composition and Consolidation

Limestone, dolomite, carbonates, sandstone, and conglomerate pay formations can be stimulated successfully; and although fracture treatments generally are not considered applicable in unconsolidated formations, there have been some successful ones. Fracturing a hard rock material can be more difficult because of the high pressures required to overcome the native stresses and the high rate of fracturing fluid leakoff when natural fractures are encountered. Acid treatments have proven successful in most types of formation material.

(c) Formation Permeability

As the permeability of the formation approaches the permeability of the created fracture, the possible production increase approaches zero. Therefore, a larger production increase can be expected from stimulating low permeability pay zones than from stimulating high permeability pay zones (for undamaged wells).

(d) Formation Thickness

Calculations and early experience indicated that better results could be expected in thin producing zones than in thick ones. Acid treatments, vertical fracturing, multiple fracturing, large size jobs, high injection rates, and improved equipment have reduced the importance of formation thickness for certain causes of low well productivity.

(e) Previous Workovers

Wells from which production increases were obtained by small size fracture treatments are good candidates for retreatment, and wells that have been acidized or shot can also be fractured successfully. New techniques, large size jobs, high injection rates, and improved and more economical carrying agents are responsible for highly successful fracture treatments of wells that have been treated previously by other stimulation methods.

(f) Isolation of the Zone to be Treated

Injected treating fluids will follow the path of least resistance into the reservoir. No production increase can be expected if a fracture is created in cement, shale, etc., instead of in the producing zone. Perforating only within the indicated limits of a pay zone is recommended so that the treating materials and the resulting treatment will be confined to the productive portions of the zone.

(g) Condition of Well Equipment

Bottom-hole treating pressures of 1 psi per foot of depth should be expected, and working pressure ratings of well equipment should be adequate to withstand these pressures.

(h) Production History of the Well

Wells with comparatively flat or steep production decline curves offer good opportunities for stimulation treatment. A comparatively flat production decline curve indicates that the well is draining a large area and that the rate of drainage can be increased by improving the permeability near the wellbore. A comparatively steep production decline curve indicates that the well may be draining a limited area and that the production rate can be increased by extending the radius of drainage.

(i) Offset Production History

If a well produces at a lower rate than offset wells, it can expect to have a larger production increase from a stimulation treatment than other wells in the field. A comparatively low rate of production indicates that the effective permeability near the well is less than the permeability in adjacent areas in the same pool. Stimulation will likely increase permeability near the well and thereby increase the production rate.

(j) Location of Multiple Aquifer Layers

Creating or extending fractures into an overlaying and colder aquifer would increase production, but at the cost of decreased total energy output in a geothermal well. Efforts should be made to avoid vertical fractures that extend beyond the desired producing zone.

The Reservoir Selection and Evaluation Process

This following discussion summarizes the specific reservoir selection investigations intended to identify, evaluate and qualify geothermal reservoirs having wells which might be candidates for the field stimulation experiments. In addition, individual wells of opportunity for testing were studied using available petrophysical logs, core analyses, well

flow data, well mechanical details, reservoir parameters, and environmental data. Reservoir selections were based on the data herein and the developers' cooperation in selecting appropriate candidates.

The first steps in the selection process were to place an announcement of the contract award in the Geothermal Resources Council Bulletin (April 1979, Vol. 8, No. 4) and send letters to 26 geothermal resource developers describing the program and soliciting their participation in the experiments. Participating developers are expected to provide the well in which to perform the experiments as well as the appropriate existing resource data for experiment design and evaluation. Table I lists the categories of data and information which were solicited from the developers for evaluation of a reservoir's potential stimulation treatment suitability under this program. Those reservoirs offered which had sufficient technical information and the most desirable stimulation features were investigated in greater detail to select specific well sites.

In determining candidate reservoirs, consideration was given to the following: the type and extent of reservoir and geologic data that were available; the development potential of the reservoir; the availability of wells that could benefit from stimulation and are accessible for experiments; the existence of sufficiently high temperature (150°-275°C) to prove the effectiveness of high temperature stimulation materials and techniques; and the reservoir fluid composition including its potential impact on fracture plugging, surface hardware problems, and injection difficulties.

Within geothermal reservoirs selected as prime stimulation sites, candidate well selection involved the interpretation of existing geologic, reservoir and production data from the entire developed area. High priority was assigned to poor producing wells located close to proven producers, wells located near existing subsurface fracture systems, wells with downhole conditions that minimize the cost of stimulation treatments and have sufficient available downhole data to minimize special logging and coring runs. Especially important were the availability and interest on the part of the developer. Low priority was assigned to wells with an established history of problems, with an inadequate injection or disposal potential, and which either are not in the vicinity of a producing well or not within an established reservoir boundary.

Individual wells in the selected reservoirs will be targeted for field treatments, and agreements for such operations will be solicited from the well owner/operator. Phase I results and potential benefits from particular stimulation treatments will be disseminated to the well owner/operator. A specific field testing program along with a precise time and activity schedule will be prepared for each approved field test site.

TABLE I

DATA FOR EVALUATION TO DETERMINE STIMULATION TEST CANDIDATE RESERVOIRS

I. Reservoir

- Primary logs - Coriband Suite or equivalent with sonic log
- Sidewall and full size cores
- Petrophysical evaluations of log and core analyses
- Geologic studies of reservoir
- Reservoir potential evaluations
  - Reserve estimates
  - Production capability estimates
- Pressure transient data for individual well tests
- Interference tests
- Static temperature surveys
- Fluid chemistry analyses

II. Production

- Production tests - rates, surface temperature, pressure
- Downhole surveys - static and flowing temperature, pressure gradients, spinner surveys, RA tracer surveys
- Disposal well injectivity
- Surface fluid chemistry - noncondensable gases, scaling potential

III. Physical

- Number and location of wells
- Downhole status - completion or abandonment details
- Tree details
- Separation facilities
- Transfer and disposal system
- Surface monitoring and measurement equipment

IV. Institutional

- Environmental assessment status
- Permitting situation - special provisions, agencies and necessary permits for field operations.

The data resulting from each stimulation treatment, or set of treatments, performed on a well will be reduced, analyzed and interpreted. Evaluation data generally will include but are not limited to:

(a) The relevant pre-stimulation fluid production characteristics of the well including shut-in pressure and temperature, flowing pressure and temperature, flow rate, and fluid composition as a function of time;

(b) The relevant post-stimulation fluid production characteristics of the well including shut-in pressure and temperature, flowing pressure and temperature, flow rate and fluid composition as a function of time;

(c) The physical and chemical alterations of the formation surrounding the well caused by the stimulation treatment.

Field test monitoring and data collection will be accomplished prior to, during, and after each field experiment. This will generally include:

(a) Pre-stimulation well data collection;

(b) Quality control of stimulation materials prior to the actual operation;

(c) Data collection during the stimulation operation;

(d) Data collection during production testing;

(e) Data reduction to produce useful information for interpretation and laboratory and engineering analyses of the data.

Data that are to be collected in the above tasks are outlined in Table II.

After the field data have been collected, the data will be analyzed to determine the downhole formation and reservoir response to the stimulation operation. This information will also be used to evaluate the applicability and relevance of all investigations performed in Phase I. Interpretation will specifically include analyses of the variances from the predicted response so that improvements can be made in future stimulation operations.

Clearly, the successful completion of this project will demand a close working arrangement and free exchange of information between the GRWSP and the selected owner/operator

TABLE II

FIELD EXPERIMENT DATA COLLECTION

I. Pre-Stimulation Well Data Collection

- Shut-in and flowing pressure and temperature
- Flow rates
- Fluid chemistry
- Downhole flowing temperature and pressure
- Inflow zones from spinner surveys

II. Stimulation Material Quality Control

- Fluid sample analyses (base fracturing fluid)
- Additive sample analyses
- Proppant sample analyses
- (Field handling of all materials shall be carefully monitored to ensure against contamination.)

III. Data Collection During the Stimulation Operation

- Injection pressure, temperature and rates throughout the operation as a function of time
- Samples of injection materials as a function of time
- Field measurements of the properties of the injected materials (i.e., density, viscosity, chemistry, etc.)
- Downhole pressure and temperature where feasible

IV. Data Collection During the Production Tests as a Function of Time

- Fluid sample returns as a function of rate
- Wellhead data - pressure and temperature
- Downhole data - pressure, temperature and spinner surveys
- Pressure buildup (one just after the operation and one at the end of production test)
- Monitoring of pressures in offset wells with very accurate pressure monitoring devices
- Solids in the return fluids
- Radioactive tracer monitoring

participant. Nine geothermal resourse developers, listed in Table III, have expressed an active interest in the program. It should be noted, however, that several developers consider the data proprietary in certain areas; e.g., The Geysers. The selection study had to be performed as indicated based on the data available in the public domain and the information supplied by the owner/operator. It is believed that a lack of specific well data for several of the geothermal reservoirs did not adversely affect the results of the reservoir selection task.

TABLE III

GEOTHERMAL RESOURCE DEVELOPERS

SUBMITTING STIMULATION CANDIDATES

Department of Energy, DGE/Idaho
Geothermal Kinetics, Inc.
Getty Oil Company
MAPCO, Inc.
Phillips Petroleum Company
Republic Geothermal, Inc.
Thermogenics, Inc.
Union Oil Company of California
Aminoil

General reservoir data for prospective stimulation sites, represented by these developers, are presented in Appendix A and include nine separate fields: Baca, Brawley, Chandler, Desert Peak, East Mesa, Raft River, Roosevelt Hot Springs, The Geysers, and Westmorland. Figure 1 shows the locations of these geothermal areas.

Candidate Ranking

The force ranking of the nine geothermal resource areas proposed by the prospective participants involves the many resource characteristics described above as well as some subjective evaluation of the potential for success of the stimulation treatment. Twelve items were considered herein to determine a candidate reservoir's potential for a geothermal stimulation treatment: (1) number of wells in the field, (2) stimulation potential, (3) available reservoir data, (4) surface facilities, (5) transport and disposal facilities, (6) reservoir temperature, (7) scaling problems, (8) general mechanical conditon of well, (9) rock and fluid properties, (10) monitoring capability, (11) permitting and environmental constraints, and (12) logistics. Table IV lists these selection criteria and the value and weight factors assigned to each criterion. These factors are an attempt to quantify the subjective expression of the contribution of that item to the overall desirability of a stimulation treatment in a reservoir. It should be noted that although several of the criteria are not of primary importance in the selection process, the inability to satisfy certain minimum requirements could result in no work being performed at that reservoir site; e.g., the obtaining of all necessary permits for the job. The significance of each criterion is further discussed below:

(a) Number of Wells

The number of wells in a reservoir is a general indication of the available knowledge associated with that field. The greater the number of deep production wells, the greater the engineers' and geologists' knowledge of the resource characteristics, the production potential of individual wells, and the probability of a successful stimulation treatment as discussed above. Any number of wells greater than three in close proximity to each other is considered to be adequate.

(b) Stimulation Potential

The reservoirs are characterized according to the potential of the wells within the field for successful stimulation treatments. This item is the most subjective of the criteria used, and is based on all the available technical data including past reservoir history, reservoir characteristics, well parameters, and types of stimulation treatments.

(c) Reservoir Data

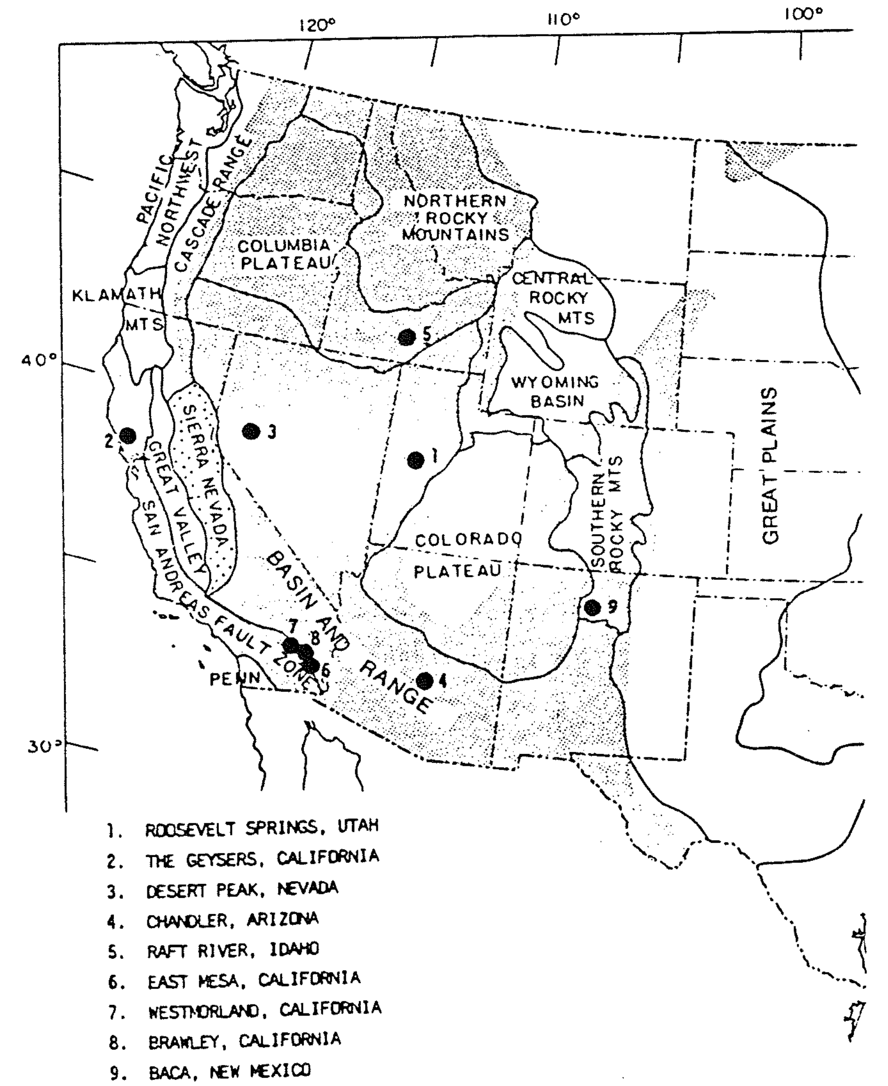
This item describes the completeness of available reservoir well data available to the GRWSP in terms of petrophysical logs, production surveys, flow tests, fluid chemistry data, and resource data analyses.

(d) Surface Facilities

"Surface facilities" refers to the availability of appropriate surface fluid handling equipment which can accurately measure the production rates, especially for two-phase fluid flow normally obtained during flow testing of wells in hot water-dominated geothermal reservoirs.

(e) Transportation and Disposal Facilities

This item refers to pipelines and/or other appropriate methods to move the geothermal fluids produced by the well to a disposal area or well. Each well chosen for a stimulation treatment must be flow tested to evaluate the treatment results.



Locations of geothermal areas studied for stimulation experiments

FIGURE 1

TABLE IV

GRWSP

RESERVOIR SELECTION CRITERIA

Selection Criteria	Weight Factor
1. Number of wells in field	10

Range	Value
0-1	0
2-3	3
4-5	6
6-7	8
-7	10

2. Stimulation potential based on overall reservoir characteristics and well productivities	9
3. Available reservoir data	8

Item	Value
Petro logs and surveys	3
Prod. tests	3
Analysis	2
Fluid chem.	2

4. Surface facilities	8
5. Transport and disposal facilities	8
6. Temperature	7

Range (°F)	Value
<300	1
300-400	5
400-500	8
>500	10

	Weight Factor
7. Scaling problems	7

Type	Value
Reservoir, wellbore, & surface	10
Wellbore & surface	5
Surface only	0

8. General mechanical condition of well	6

Type	Value
Open-hole	
poor wellbore	2
competent	5
Slotted liner	0
Cemented - jet perf.	10

9. Rock properties	5

Type	Value
Fractured	0-5
Matrix	6-10

10. Monitoring capability	3
11. Permitting and environmental	2
12. Logistics	1

(f) Temperature

The temperature of a reservoir is part of the selection criteria since the purpose of the GRWSP is to develop well stimulation technology for application in high temperature environments. Higher temperature reservoirs (500°F±) are considered most desirable.

(g) Scaling Problems

As discussed above, wells with near-wellbore damage caused by mineral deposits accumulated during production are prime candidates for particular stimulation experiments.

(h) General Mechanical Condition of Wells

The mechanical condition of a well refers to the capability of the casing, cement and wellhead equipment to withstand a stimulation treatment and provide zonal segregation. A slotted liner in the production interval results in the lowest ranking whereas a cemented and perforated casing is rated as having the highest suitability. An open-hole completion is ranked between these extremes with some adjustments for rock competency.

(i) Rock Properties

This item refers primarily to the type of rock matrix to be stimulated. A fractured, hard rock reservoir is considered to have less chance for a successful stimulation treatment than a competent permeable rock formation, such as sandstone, where the causes of reduced productivity meet other appropriate criteria.

(j) Monitoring Capability

"Monitoring capability" concerns the availability of surrounding observation wells and the probability of successfully monitoring the stimulated well with downhole pressure equipment. This capability is important to the evaluation of the stimulation treatment results.

(k) Permitting and Environmental

Permitting and environmental restraints are important in the selection criteria since a problem in this area could prevent a timely completion of the stimulation treatment. The safety aspect of any stimulation experiment is also considered in this item.

(l) Logistics

Well stimulation "logistics" refers to the availability and cost factors associated with obtaining service company contractors to perform the treatments. A remote location will adversely affect the pricing and scheduling of the available equipment.

Results

The nine geothermal reservoirs proposed by the developers were evaluated according to the selection criteria discussed above. Primary sources of data for this study were the open files of the USGS,[2] National Geothermal Information Resources,[3] Proceedings of the International Geothermal Conferences,[4] published literature on specific resources, and the developers of the reservoirs. Detailed well data for the geothermal reservoirs investigated in this study are presented in Appendix A along with the information relevant to a stimulation experiment such as geological features of the production zone, fluid chemistry data, temperature and pressure data, reservoir rock parameters, and the results of production tests, logging and coring of the wells.

As discussed above, the data essential to the determination of a stimulation treatment candidate well include a general knowledge of the resource sufficient to know if the well is not producing to its maximum potential and the probable cause for the restricted productivity. This requires some information as to the productivity of surrounding wells and the general reservoir parameters. It is obvious that the information required for evaluation of a candidate reservoir limits the choices to those with at least several commercial capacity wells, a proven resource, and close cooperation of the owner/operator.

In determining the overall stimulation potential success ranking, the nine proposed reservoirs were evaluated on a scale of 0-10 (10 being the best) for each selection criterion. Table V gives the results of this evaluation.

The procedure utilized to obtain a ranking then is to: (1) multiply the weight factor for each selection criterion by the reservoir evaluation value associated with that item, (2) add all the selection criterion products by reservoir, and (3) arrange the total values in descending order. The geothermal reservoir with the largest cumulative value will have the best overall characteristics contributing to a successful stimulation treatment. As can be seen on Table VI, the order of reservoir ranking for the stimulation treatments is:

1. East Mesa, CA
2. Westmorland, CA
3. Baca, NM
4. Brawley, CA
5. Raft River, ID
6. The Geysers, CA
7. Roosevelt Hot Springs, UT
8. Desert Peak, NV
9. Chandler, AZ

Summary and Recommendations

On the basis of the data collected, analyzed, and presented in this study, the overall stimulation success ranking of the nine reservoirs listed above was determined. However, the statement of work for the GRWSP proposes several distinct well stimulation treatments to be performed. These special treatments will require particular reservoir characteristics which may not correspond to the ranking given in Table VI. Under these circumstances, the reservoir chosen for a special stimulation treatment will be the reservoir of highest ranking with the required characteristics.

As described previously, the first proposed field test is primarily an extension of oil field technology applied to a low temperature geothermal reservoir. The stimulation success ranking given by Table VI clearly shows that East Mesa, at 330° to 360°F, should be the first choice. Although lower ranking, it may be even more appropriate to start with Raft River because of its even lower temperature (290°F).

The second proposed field test is to be a simple hydraulic fracture in a reservoir with higher temperature. The third test period calls for a complex multi-stage hydraulic fracture and chemical treatment in a selected reservoir which has a history of scaling in the matrix. An acid treatment will also be performed. The fourth and final test period will consist of an advanced type of stimulation treatment and a mini-frac. The Westmorland, Baca, and Brawley geothermal reservoirs would all qualify for these experiments since they each have a history of scaling and offer high reservoir temperatures.

In the end, subjective decisions must be made to choose reservoirs which meet the special requirements of the GRWSP and which offer the greatest potential for successful stimulation experiments. Tentatively, the following program is proposed:

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

TABLE V

GRWSP - Reservoir Selection Values

Selection Criteria	Baca	Brawley	Chandler	Desert Peak	East Mesa	Geysers	Raft River	Roosevelt H.S.	Westmorland
1	10	8	3	3	10	10	8	10	8
2	7	8	5	5	8	3	5	5	10
3	6	5	4	7	10	6	10	7	10
4	10	9	2	8	10	10	10	10	9
5	5	7	1	5	10	10	10	3	8
6	8	8	5	5	5	8	1	10	8
7	8	7	5	2	2	1	0	2	10
8	5	5	5	5	10	5	5	5	0
9	5	9	3	4	8	1	5	4	9
10	5	3	1	5	10	3	8	5	5
11	7	8	5	8	10	8	8	3	8
12	8	9	3	5	10	8	8	5	9

Table VI

RESERVOIR RANKING

Reservoir	Total Weight X Value Products
1. Baca	535
2. Brawley	534
3. Chandler	262
4. Desert Peak	370
5. East Mesa	621
6. The Geysers	466
7. Raft River	475
8. Roosevelt Hot Springs	465
9. Westmorland	597

The proposed program will be reviewed after each field experiment to select a specific well candidate for the next experiment and to determine whether alteration of the sequence will be beneficial to the overall success of the GRWSP and the geothermal industry.

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APPENDIX A

Reservoir Data

1. East Mesa, California
2. Westmorland, California
3. Baca, New Mexico
4. Brawley, California
5. Raft River, Idaho
6. Roosevelt Hot Springs, Utah
7. The Geysers, California
8. Desert Peak, Nevada
9. Chandler, Arizona

EAST MESA, CALIFORNIA

ESTIMATES OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (°C)	Range: 150-200 Best Estimate: 175
Total Dissolved Solids (PPM)	2,000 - 12,500
Electric Energy Potential (MWe 30 Years)	487
Overlying Rock	Deltaic River Sediments
Depth of Top of Reservoir (Meters)	1,000
Land Status	
Total KGRA acres	38,365
Total federal acres	32,525 (approx.)
Federal acres leased	18,729
Total state and private acres	4,840 (approx.)
State and private acres leased	No data

DEVELOPMENT STATUS AND ACTIVITY

The reservoir is a hot water geothermal system that permeates a sedimentary sand-shale interval present to depths of at least 9,000 feet.

Republic Geothermal, Inc. (RGI) completed ten deep wells in the northern area of the East Mesa KGRA by December 1979. A 49 MW (net) power plant is scheduled to begin construction in 1980. The Department of Energy (DOE) issued its first loan guaranty to RGI for the field development project.

The U.S. Bureau of Reclamation drilled five test wells to more than 5,500 feet by August 1975. These wells were intended to supply water to a desalineation pilot plant. This operation has been abandoned and the wells are now operated by DOE.

A field test facility to evaluate hardware components was built by DOE in 1977 at the East Mesa site. Geothermal brine is supplied by the previously described Bureau of Reclamation wells.

Magma Power Company operates in the southern portion of the field and has begun construction of an 11 MW binary geothermal power plant for research and development. Operations are now expected to begin in early 1980. Magma has completed eight wells in this portion of the field.

MAJOR DEVELOPMENT PROBLEMS

No major problems are likely to restrict development of the East Mesa KGRA. A primary concern has been the development of an economical and reliable downhole pump for the production wells. Recent well tests indicate that this problem has been overcome.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The East Mesa prospect area is located in the Imperial Valley, California, entirely within lands administered by the federal government. The two major habitat types identified on Republic Geothermal's leases are Sonoran creosote bush scrub community and partially stabilized desert dunes community. The Imperial Valley has a desert climate characterized by hot, dry summers and mild winters with very low annual precipitation. There are no surface waters in the area of operations and ground waters are saline. The nearest population centers are Holtville (3,580) which is 11 km west from the proposed project, and El Centro (21,300) which is 24 km west from the proposed project.

Many environmental documents have been prepared to date for the East Mesa leases: one Environmental Impact Statement, eleven Environmental Analyses, one Environmental Impact Report and one cooperative Environmental Assessment Record - Environmental Analysis - Environmental Impact Report, as well as a Program for Collection of Environmental Baseline Data and an Environmental Summary Document.

East Mesa, California

WELL DATA

Well Name	Well 5-1	Well 6-1
Total Depth	6016 ft	8030 ft
T_{max}(time)	242°F (7 hr)	255°F (drilling)
Casing	13-3/8" @ 617 m	9-5/8" @ 7292 m
Bit at TD	10-5/8"	8-1/2"
Tests	-	Logs, flow, P, T
G_t, Equilibrium	-	396°F-8030 ft, 73.2°C/km
Surface Faults	N10°W, active	N10°W, active
Geol. Features	Sands and siltstones	Brawley formations, quaternary
Surface Deposit	Lake bed	Lake Coahuila deposit (Ancient Salton Sea)
Elevation	-	36 ft
Mean Surface T.	73°F	73°F
Well Flow	-	2 liter/sec
Water Table	-	30 ft
Well P, D	-	28 psi, 0 ft 1887 psi shut-in pressure @ 4474 ft
Salinity, ppm	2950, log	26,300
Prod. Interval	1000 ft 305 m	-
Sonic Porosity, ϕ_a	0.29	-
Density ϕ, Frac.	0.27	-
Neutron ϕ, Frac.	0.24	-
Average Porosity	0.27	-
Reservoir Rock	Sand and siltstone	Sand and siltstone
Flow Rate, ton/hr	55.6	22.7 (100 GPM)
Permeability, md	6	

Well Name	Well 6-2	Well 8-1	Well 31-1
Total Depth	6008 ft	6205 ft	6230 ft
T_{max} (time)	248°F (4 hr)	-	250°F (8 hr)
Casing	11-3/4" @ 306 m	13-3/8" @ 1000 m	13-3/8" @ 309 m
Bit at TD	10-5/8"	10-5/8"	10-5/8"
Tests	Logs	Logs, Flow, T	-
G_t, Equilibrium	66.4°C/km	60.1°C/km	60.8°C/km
Surface Faults	N10°W, active	N10°W, active	-
Fracturing	-	-	30° dip S50°W fault at 5500; normal 10° dip S60°W
Surface Deposit	Lake bed	Lake bed sands	-
Elevation	24 ft	50 ft	35 ft
Mean Surface T.	73°F	73°F	73°F
Well Flow	9.5 liter/sec		
Water Table	30 ft 9.2 m		
Well P, D	12 psi, 0 ft 2664 psi, 5515-5625 ft		
Salinity, ppm	5000	1600	2900
Prod. Interval	654 ft 199 m	1050 ft 320 m	755 ft 230 m
Sonic Porosity, ϕ_a	0.24	0.31	0.39
Density ϕ, Frac.	0.25	0.24	0.27
Neutron ϕ, Frac.	0.21	0.27	0.30
Average Porosity	0.23	0.27	0.29
Reservoir Rock	Sand & siltstone	Sand & siltstone	Sand & siltstone
Flow Rate, ton/hr	34.2 @ psi surface pressure	97.6	127
Permeability, md	28 (calc)	14	-
Peculiarities	-	-	Slickensides in cuttings

Well Name	Well 16-30	Well 38-30
Total Depth	8000'	9009'
Prod. Interval	Slotted liner 6403'-8000'	Slotted liner 6368'-8897'
Casing Configuration	13-3/8"-1480', 8-5/8"-5900', 6 5/8"-8000'	13 3/8"-1197', 9-5/8"-5104', 7" 4897'-8898'
Max. Temp °F	363	353
Pressure (psig)	2110 @ 5000'	2257 @ 5500'
Tests	Logs, T, P, flow	Logs, P, T, flow
Flow Rate, lb/hr	305,000	450,000
Water TDS, ppm	<2000	1850
Geological (Prod. Interval)	Predominately unconsolidated sand, silt and clay estimated to 20,000 feet	
Avg. Porosity	0.23	0.28
Avg. Permeability	76 D-ft (air)	388 D-ft (air)
Net Sand	983	550

Well Name	Well 56-30	Well 58-30
Total Depth	7520'	7305'
Prod. Interval	Slotted liner 5296'-7520'	Perforated liner 4952'-720
Casing Configuration	13-3/8"-1503', 8-5/8"-5320', 6-5/8"-7520'	16"-1962', 10-3/4"-1732'-5476', 7-5/8"-5276'-7260'
Max. Temp. °F	331	341
Pressure (psig)	2697 @ 6500'	2669 @ 6500'
Tests	Logs, T, P, flow	Core, logs, T, P, flow
Flow rate, lb/hr	850,000 (pumped)	150,000
Water TDS, ppm	1720	2050
Geological (Prod. Interval)	Predominately unconsolidated sand, silt and clay estimated to 20,000 feet.	
Avg. Porosity	0.24	0.19
Avg. Permeability	143 D-ft (air)	65.8 D-ft (air)
Net Sand	1257	1355

Well Name	Well 78-30RD	Well 18-28
Total Depth	7220'	8001'
Prod. Interval	Perforated liner 5295'-7197'	Perforated liner 5111'-5286', slotted liner 6440'-8000'
Casing Configuration	13-3/8"-1491', 8-5/8"-5227', 6-5/8"-7442'	13-3/8"-1285', 9-5/8" 5020', 7"-8000'
Max. Temp °F	354	313
Pressure (psig)	2061 @ 5000'	1838 @ 4353'
Tests	Core, logs, T, P, flow	Logs, T, P, flow
Flow rate, lb/hr	320,000	650,000
Water TDS, ppm	<2000	1880
Geological (Prod. Interval)	Predominately unconsolidated sand, silt and clay estimated to 20,000 feet.	
Avg. Porosity	0.25	0.29
Avg. Permeability	76.1 D-ft (air)	1137 D-ft (air)
Net Sand	1023'	1208'

Well Name	Well 16-29	Well 52-29
Total Depth	8021'	4524'
Prod. Interval	Perforated liner 6413'-7996'	Slotted liner 1438'-4524'
Casing Configuration	16"-2049' 11-3/4"-4550' 8-5/8"-7996'	16"-2470' 11-3/4"-3382' 8-5/8"-4524'
Max. Temp °F	357	258
Pressure (psig)	2041 @ 5000'	1897 @ 4500'
Tests	Logs, T, P, flow	Logs, T, P, flow
Flow Rate, lb/hr	430,000 (pumped)	1,100,000
Water TDS, ppm	2050	2240
Geological (Prod. Interval)	Predominately unconsolidated sand, silt and clay estimated to 20,000 feet	
Avg. Porosity	0.22	0.27
Avg. Permeability	37 D-ft (air)	317 D-ft (air)
Net Sand	765'	1288'

EAST MESA, CALIFORNIA
FLUID DATA

	Well 6-1	Well 6-2	Well 8-1	Well 31-1
BORON (MG/L)	9.75	7.45	1.6	2.5
SILICA	320	269	389	274
BICARBONATE	202	560	417	845
CARBONATE	0.0	0.0	0.0	0.0
SULFIDE	3.0	1.5	1.0	0.3
SULFATE	42.8	156	173	183
TDS	26,300	5,000	1,600	2,900
pH	5.45	6.12	6.27	6.27

(BUREAU OF RECLAMATION '77)

	Well 38-30	Well 56-30	Well 78-30	Well 16-29
BORON (MG/L)	1.8	1.4	2.1	3.4
SILICA	193	192	196	240
BICARBONATE / CARBONATE	550	320	472	548
SULFATE	152	169	170	167
POTASSIUM	25	38	28	24
TDS	1,851	1,720	1,537	2,040

DEVELOPMENT STATUS AND ACTIVITY

The Westmorland geothermal reservoir is located south of the Salton Sea area of the Imperial Valley, California. Drilling activities commenced in the Westmorland area in February 1976 and the first well was drilled by Republic Geothermal, Inc. to a depth of approximately 7,500 feet. The Westmorland prospect appears to be a unique and distinct geothermal field, separate from all other fields in the Imperial Valley. By May 1977, a total of six wells had been drilled in the area. Of the six wells, four are capable of producing geothermal fluids and two were drilled for injection purposes. Measured subsurface temperatures range from approximately 205°C to 260°C at a depth of 7,500 feet. The reservoir fluids tested ranged from 14,700 to 72,100 ppm in total dissolved solids. Noncondensable gas content, predominantly carbon dioxide, is as high as 2% of the total flow from the production wells.

In July 1979, the Department of Energy approved a $29 million loan guarantee to develop geothermal resources for the commercial production of electricity in the Westmorland field. Westmorland Geothermal Associates (a general partnership of Republic Geothermal, Inc. and MAPCO-Geothermal, Inc.) is the operator of the field and plans to drill about 19 wells in the area to produce geothermal energy sufficient to generate 55 megawatts of electricity. Development drilling activity resumed in November 1979.

MAJOR DEVELOPMENT PROBLEMS

1. Commercial development requires that the scaling in the producers, pipelines, injection pumps, and injection wells be controlled to permit continuous operation.

2. The possibility of subsidence is a lesser concern. Nevertheless, regional monitoring must be carried out and adequate injection at the proper formation depth and location is required.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Westmorland prospect area is located in the Imperial Valley, California, on privately-owned lands. The area is characterized by very flat, intensively irrigated agricultural land. Those lands not actually being farmed are dedicated to agricultural support facilities. The New River runs through the middle of the Westmorland prospect area. Groundwaters are saline. The climate of the Imperial Valley is one of hot, dry summers and mild winters with very low annual precipitation. The nearest towns are Westmorland (1,417) and Brawley (14,010). Currently there are four completed production wells and two completed injection wells drilled on the MAPCO Geothermal, Inc.-Republic Geothermal, Inc. leases.

Two Environmental Impact Reports have been prepared in accordance with the California Environmental Quality Act. One Environmental Impact Assessment has been prepared for the U.S. Department of Energy in accordance with the National Environmental Policy Act.

WESTMORLAND, CALIFORNIA

ESTIMATES OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (°C)	Range: 175-260 Best Estimate: 220
Total Dissolved Solids (PPM)	70,000 Av.
Electric Energy Potential (MWe 30 Yrs.)	500+
Overlying Rock	Shale-siltstone caprock atop arkosic sand
Depth to Top of Reservoir (Meters)	1,000
Land Status (approx.)	
Total KGRA acres	95,824
Total federal acres	18,644
Total state and private acres	76,370

Geothermal fluids produced from Westmorland wells range from 15,000-70,000 mg/liter Total Dissolved Solids (TDS), so mitigation measures to prevent contamination of the ground water are necessary. No gaseous components in deleterious quantities have yet been detected in the geothermal fluid. Surveys have been conducted for cultural resources. No threatened or endangered species have been observed in the prospect area, although several wildlife species of concern are known to occur in the nearby Salton Sea wildlife areas. All wells are tied-in with the valley-wide subsidence network. A regional seismic monitoring program is in existence. An ambient air monitoring program is also in existence in the Imperial Valley.

All well operations have been conducted under Conditional Use Permits approved by Imperial County, Notices of Intent approved by the California Division of Oil and Gas, Waste Discharge Orders approved by the California Regional Water Quality Control Board, and Authority to Construct permits approved by the Imperial County Air Pollution Control District. The Conditions of Approval of these permits must continue to be observed. No further permitting will be required for well stimulation operations, although the D.O.G. requests that a history of the operations be filed with their office. A stimulation project in this area does not appear to present a concern.

WESTMORLAND, CALIFORNIA

WELL DATA

Well Name	Landers 3	Kalin Farms 1
Total Depth	4650'	8490'
T. Max. Depth	259°/3114' Flowing BHT	389°/5000' Flowing BHT
Casing	13-3/8"-105', 9-5/8"-3114' 7" 3013'-4640'	13-3/8"-100' 9-5/8"-546', 7"-5355' 5-1/2" 5090'-8490'
Bit @ T.D.	8-3/4" @ 4650'	6-1/4" @ 8490'
Prod. Interval	Slotted liner 3013'-4640'	Slotted liner 5090'-8490'
Tests	T, P, logs, flow	T, P, logs, flow
Flow Rate, lbs/hr	413,000	254,900
TDS, ppm	25,308	48,894
Geological (Prod. Int.)	Predominately unconsolidated sand, silt and clay to an estimated 20,000 ft.	
H_2S	None	None
Av. Porosity	.2657	.24
Av. Permeability	45.57 md	34.60 md
Core Data:		
Av. Perm.	201.85 md (air)	10.93 md
Av. Porosity	31.34%	12.86%

Well Name	Landers 1	Landers 2
Total Depth	7000'	7507'
Temp. Max. Depth	486°/7500 static temp	467°/7507' static temp
Casing	13-3/8" 0-2005'; 8-5/8" 1810'-5100'; 6-5/8" 4808'-6998'	13-5/8" 0-1140; 9-5/8" 869'-5947'; 7" 5886'-7507'
Bit @ T.D.	7-7/8" @ 7000'	8-3/4" @ 7507'
Tests	T, P, flow, logs	T, P, flow, logs
Geological Features	Predominately unconsolidated sand, silt and clay to an estimated 20,000 ft.	
H_2S	None	None
TDS, ppm	72,083	57,657
Prod. Interval	Slotted liner 5100'-6998'	Slotted liner 5886'-7507'
Av. Porosity	19% (.17% Redrill)	.15%
Perm., Md.	18.47 md	11.33 md
Flow Rate, lbs/hr	214,600	217,600
Core Data:		
Air Perm. Av.	10.26 md	
Porosity Av.	16.82% (25.17% Redrill)	

Well Name	Dearborn 1	Dearborn 2
Total Depth	8000'	4582'
T. Max. Depth	420°/7900' Compl. data	269°/4400' Static temp.
Casing	13-3/8"-1939' 8-5/8" 1805'-4995' 6-5/8" 4798'-8000'	13-3/8"-150' 9-5/8"-3087', 7" 2882'-4582'
Bit @ T.D.	7-5/8" @ 8000'	8-3/4" @ 4564'
Tests	T, P, logs, flow	T, P, logs, flow
Geological Features	Predominately unconsolidated sand, silt and clay to an estimated 20,000 ft.	
Max. Prod. T.	334°/4750' flowing BHT	
H_2S	None	None
TDS, ppm	14,652	21,910
Prod. Interval	Slotted liner 5351'-8000'	Slotted liner 2882'-4582'
Av. Porosity	.22	.25
Reservoir Rock	Siltstone	
Av. Permeability	17.85 md	40.16 md
Flow Rate, lbs/hr	103,000	426,000
Core Data:		
Air Perm.	3.89 md	
Porosity	16.87%	

VALLES CALDERA/BACA, NEW MEXICO

ESTIMATES OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (°C)	Range: 240-315 Best Estimate: 280
Total Dissolved Solids (PPM)	6,000
Electric Energy Potential (MWe 30 Years)	400 (minimum)
Overlying Rock	Extrusive igneous rocks
Depth to Top of Reservoir (Meters)	1,000
Land Status	
Total KGRA acres	168,761
Total federal acres	29,375
Federal acres leased	20,000
Total state and private acres	138,386
State and private acres leased	90,000

DEVELOPMENT STATUS AND ACTIVITY

In the Jemez Mountains of north-central New Mexico, Union Oil of California is developing a geothermal field to supply steam to a proposed 50 MW power plant. The reservoir, underlying the Baca Ranch, was first discovered in the 1960s during exploratory drilling for oil and gas. Union has drilled approximately 18 wells to date.

Located at a depth of 6000 ft., the reservoir is estimated to contain 60 cubic miles of hot water with temperatures ranging from 500°F to 600°F. The area under development is near the center of the Valles Caldera, a volcanic structure that collapsed into itself forming a circular depression roughly 10 miles in diameter. A large hot magma chamber is believed to exist beneath the caldera.

Construction on the proposed plant, which will use a double-flash conversion cycle, is expected to begin in early 1980. When completed in 1982, 15 to 17 producing wells will be on line to supply the facility. Wells in the area are capable of producing 200,000 lbs of geothermal fluid per hour in a two-phase mixture of 65 percent water and 35 percent steam. High pressure separators will separate water from the steam. Approximately 70 to 75 percent of the total fluids produced will be reinjected into the reservoir.

Test data indicates the reservoir has a minimum potential of 400 MW for 30 years based only on the heat content of the water. Total energy available would be considerably higher if the heat content of the reservoir rock could be recovered through injection (Maddox, 1978).

Public Service Company of New Mexico will construct the plant facilities and transmission lines necessary to connect the plant with the company's existing transmission network. Under the agreement with Public Service, Union will drill the wells and construct and operate all pipelines, separators and other surface facilities necessary to provide the 50 MW facility with sufficient quantities of clean geothermal fluid. Total cost of the project is estimated at $140 million with approximately 50 percent of the funding being provided by the Department of Energy.

Los Alamos Scientific Laboratory has been conducting a hot dry rock experiment at Fenton Hill to the west of the Caldera. Two deep holes have been successfully connected by hydraulic fracture and water has been circulated between them. Two additional deep wells are being drilled.

MAJOR DEVELOPMENT PROBLEMS

Based on current knowledge of the site, there appears to be no critical technological problems which would impede the plant development. However, the low permeability of fractured volcanic rock may present difficulties for fluid disposal. Commercial development requires that the scaling in the pipelines, production wells, injection pumps and injection wells be controlled to permit continuous operation.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Valles Caldera prospect area is located in Sandoval County, New Mexico, on privately-owned lands mostly leased by Union. The prospect area is in the heart of a caldera approximately twelve miles in diameter. Major habitat types are grassland meadows, wetland meadows and brush chaparral. A wide range of the small mammals and a large variety of birds are present in the area. Air quality is generally good. Redondo Creek is located in the canyon area. While the water quality is very good, this creek is too small to support fish. The water does feed a major fishery downstream. The nearest population centers are Los Alamos (15,000), 10.5 miles to the east, and Jemez Springs (300), 8 miles to the southwest.

A Draft Environmental Impact Statement, prepared by the U.S. Department of Energy in accordance with the National Environmental Policy Act, is scheduled to be released for public review on July 9, 1979. This DEIS discusses the Valles Caldera environment and evaluates the proposed 50 MW power plant and all attendant wells, access roads, transmission lines and pipelines.

The Jemez Mountain Salamander, designated by the State of New Mexico as an endangered species, is known to occur in abundant numbers in the meadow and mountain areas. Union has a mitigation program to avoid habitat of this species which has been approved by the state. Other threatened and endangered species have been observed in the area, the most notable example being the peregrine falcon.

While the geothermal leases are all on privately-owned land, surrounding lands are administered by the federal government and are primarily used for recreational purposes. A potential environmental conflict exists between these recreational land uses and geothermal development, particularly regarding visibility of the operations. Another environmental concern is the potential hydrogen sulfide emissions, although during testing operations the New Mexico Environmental Improvement Board's standard of 3 ppm has not been exceeded. There are also natural sources of hydrogen sulfide from hot springs in the area.

All air and water quality permits necessary for operations have been obtained. The county has not taken an active role in permitting the geothermal operations. No further permitting for well stimulation operations would be required unless surface area greater than the existing 1-1/2 to 2-acre pad sizes is necessary. Increased surface disturbance may present permitting problems. Union also has an agreement with the DOE to suspend all activities until the EIS is complete. The final EIS is anticipated by February, 1980; should well stimulation operations commence before that date, the DOE must be consulted. Because these operations would take place on already existing wells and location pads, this would most likely not present a major obstacle.

WELL DRILLING DATA

WELL NAME	-	COMPANY	-	DEPTH	-	COMP. DATE
Baca 1	-	Baca Land & Cattle	-		-	1963
Baca 2	-	Baca Land & Cattle	-		-	1964
Baca 3	-	Baca Land & Cattle	-		-	1964
Baca 4	-	Baca Land & Cattle	-		-	1970
Baca 5	-	Union Oil Co.	-		-	1971
Baca 5A	-	Union Oil Co.	-	6973'	-	1971
Baca 6	-	Union Oil Co.	-		-	1972
Baca 7	-	Union Oil Co.	-		-	1972
Baca 8	-	Union Oil Co.	-		-	1973
Baca 9	-	Union Oil Co.	-		-	1972
Baca 10	-	Union Oil Co.	-	6001'	-	1973
Baca 11	-	Union Oil Co.	-	6929'	-	1973
Baca 12	-	Union Oil Co.	-	9212'	-	1974
Baca 13	-	Union Oil Co.	-	8228	-	1974
Baca 14	-	Union Oil Co.	-	6824'	-	1975
Baca 15(P)	-	Union Oil Co.	-	5505'	-	1975
Baca 16(A)*	-	Union Oil Co.	-	7001'	-	1975
Bond #1	-	Westates Petroleum	-	3652'	-	

(SMITH 76, SMITH 78C, WITHAM 76, HOT LINE 74D)

REMARKS:
- (P) = PRODUCIBLE
- (S) = SUSPENDED
- (A)*= ABANDONED TEMPORARILY
- (O) = OBSERVATION
- (I) = INJECTION

NOTE: UNION OIL COMPANY WELL AND FLUID DATA BECOME AVAILABLE AS PART OF GEOTHERMAL DEMONSTRATION POWER PLANT PROJECT.

BRAWLEY, CALIFORNIA

ESTIMATES OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (C°)	Range: 200-300 Best Estimate: 260
Total Dissolved Solids (PPM)	100,000
Electric Energy Potential (MWe 30 years)	1,000
Overlying Rock	Sediment, siltstone, sandstone
Depth to Top of Reservoir (Meters)	1,500
Land Status	
Total KGRA acres	28,855
Total federal acres	0
Federal acres leased	0
Total state and private acres	28,885
State and private acres leased	No data

DEVELOPMENT STATUS AND ACTIVITY

By the end of 1979 Union Oil Company of California had drilled ten wells and three wells had been drilled by Chevron and McCulloch.

In 1980 Union plans to put a 10 MW, single-flash power plant on line at its Brawley site. The field was first identified in the late 1960s by University of California (Riverside) field studies. Development of the field, contained in the 29,000-acre Brawley KGRA, began in 1975.

Reservoir temperature of the hot-water dominated system is about 500°F. The salinity of the geothermal brine is approximately 100,000 ppm. Spent fluids will be reinjected. Of the ten producing wells drilled in the field, four will supply hot brine to the initial plant. The remaining wells will power future generating units. The power plant will be operated by Southern California Edison and will require about 700,000 lbs of fluid per hour. Electricity generated by the plant will be used by the Imperial Irrigation District.

MAJOR DEVELOPMENT PROBLEMS

1. Commercial development requires that the scaling in the pipelines, injection pumps, and injection wells be controlled to permit continuous operation.

2. The possibility of subsidence is a lesser concern. Nevertheless, regional monitoring must be carried out and adequate injection at the proper formation depth and location is required.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Brawley prospect area is located in the Imperial Valley, California, on privately-owned lands. The area is characterized by very flat, intensively irrigated agricultural land. Those lands not actually being farmed are dedicated to agricultural support facilities. The climate of the Imperial Valley is one of hot, dry summers and mild winters with very low annual precipitation. Both the New and the Alamo Rivers flow through the Brawley KGRA. Groundwaters are saline. The nearest towns are Brawley (14,010) to the south and Calipatria (2,074) to the north of the KGRA. Union is the main operator in the Brawley area.

A total of twenty-three Environmental Impact Reports has been prepared in accordance with the California Environmental Quality Act for geothermal operations in the Brawley prospect. One major Environmental Impact Report is currently being prepared for Union's proposed 10 MWe geothermal power plant.

Geothermal fluids produced from Brawley wells are moderately saline, so mitigation measures to prevent contamination of the ground water are necessary. No gaseous components in deleterious quantities have yet been detected in the geothermal fluid. Site-specific surveys have been conducted for cultural resources. No threatened or endangered species have been observed in the prospect area although several wildlife species of concern are known to occur in nearby Salton Sea wildlife areas. Imperial County

requires that all wells be tied-in with the valley-wide subsidence network. A regional seismic monitoring program is in existence. An ambient air monitoring program is also in existence in the Imperial Valley.

All well operations have been conducted under Conditional Use Permits approved by Imperial County, Notices of Intent approved by the California Division of Oil and Gas, Waste Discharge Orders approved by the California Regional Water Quality Control Board, and Authority to Construct permits approved by the Imperial County Air Pollution Control District. The Conditions of Approval of these permits must continue to be observed. No further permitting will be required for well stimulation operations although the D.O.G. requests that a history of the operations be filed with their office. A stimulation project in this area does not appear to present a concern.

WELL DRILLING DATA
BRAWLEY, CALIFORNIA

COMPANY	WELL	DEPTH	DATE COMPLETED	STATUS	CASING
Union Oil	Cox 1	9609'	5/5/77	Shut-in	20"-94', 13-3/8"-1220' 9-5/8" 1018'-5202', 7"-9600' 10-3/4" tie back from surface-1018'
Union Oil	Veysey 1	8385'	6/23/75	Workover	13-3/8"-1217, 9-5/8"-5222'
Union Oil	Kruger 1	6793'	4/16/76	Shut-in	20"-78', 13-3/8"-1210', 9-5/8"-1021'-4000', 7"-6793'
Union Oil	Veysey 2	5921'	6/23/75	Shut-in	20"-118', 13-3/8"-1069', 7"-5893'
Standard Oil	Wilson 1	13,443'	7/20/63	Plugged & abandoned	No casing info.
Union Oil	Jiminez 1	9618'	7/15/76	Shut-in	20"-105', 13-3/8"-1255', 9-5/8" tie back from surface-1078', 9-5/8" 1078'-5145', 7" 4986'-9602'
Union Oil	H. B. Tow	5031'	6/16/75	Shut-in	20"-100', 13-3/8"-1018', 9-5/8"-3995'
McCulloch	Mercer #1-28*	13,381'		Shut-in	Perforated liner to 12,910'
			*Flow data:	75000 lb/m steam 14,900 BPD brine at	WHT=422°F WHP=307 psig

WELL DRILLING DATA (cont.)

COMPANY	WELL NAME	DEPTH	COMP. DATE
Chevron Oil	Rutherford #1	2417 M	1977
Union Oil	Veysey	2714 M	
Phillips Petroleum	East Brawley Strat Test 2	610 M	
Chevron USA Inc.	Brandt	3048 M	
Union Oil	Slater	2166 M	

RAFT RIVER, IDAHO

ESTIMATES OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (C°)	Range: ∿ 145 Best Estimate: 140
Total Dissolved Solids (PPM)	2,000
Electric Energy Potential (MWe 30 years)	100 MWe
Overlying Rock	Alluvium tuffs, schists and quartzites with a quartz monzanite basement
Depth to Top of Reservoir (Meters)	1,500
Land Status	
Total KGRA acres	30,209
Total federal acres	25,110
Federal acres leased	None
Total state and private acres	5,099
State and private acres leased	No data

DEVELOPMENT STATUS AND ACTIVITY

The Department of Energy (DOE) has drilled five deep production wells (and two injection wells), one of which extends to 1,830 meters (6,000) feet. Since 1975, testing and evaluation of the reservoir for application of binary cycle power generation has taken place. A 5 MWe binary cycle power plant is now under construction. Pilot development of heat-exchanger facilities and possible additional drilling are planned. Also, DOE is considering modifying the experimental binary facility to verify efficiency increases obtainable from allowing condensing temperature to drop when ambient temperatures drop.

MAJOR DEVELOPMENT PROBLEMS

Based on the subsurface fluid temperature, the economics of this prospect for electrical production appear marginally attractive. All major technological problems should be resolved by the time the first plant postulated at Raft River is completed.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Raft River prospect area is located in Cassia County, Idaho, on both privately owned and federally administered lands. The prospect area is a sparsely populated region. Land use is primarily agricultural and recreational. Habitat in the areas not farmed is that of the cold desert, dominated by sagebrush and greasewood. There is a large variety of small mammals and birds present, with extensive use of the geothermal area in fall and winter months by birds of prey. Climatic conditions are typical of the cold desert, semi-arid characteristics of southern Idaho, and the ambient air quality is very good. The Raft River is the only perennial surface water in the area; other surface waters are intermittent streams. The fish population in the Raft River is limited. The quality of the ground water is generally good. The existing geothermal wells are drilled to depths greater than 3000 feet and the total dissolved solids content of the fluid range from 1,200 to 6,000 mg/liter.

Three environmental documents have been prepared to date in accordance with the National Environmental Policy Act: one for wells which have since been drilled, one for withdrawal of land from administration by the U.S. Bureau of Land Management, and one for the proposed 5 MW power plant.

Since geothermal operations are being conducted not under a federal geothermal lease but on withdrawn lands, no permits or approvals need to be acquired from the U.S. Geological Survey (as is usual on federally administered lands). The state agency with major responsibility for permitting on privately-owned lands is the Idaho Department of Water Resources, and an agreement has been reached with this agency whereby no permits are required but compliance with the intent of the law is necessary. Whenever operations are conducted, both the Water Resources Department and BLM must be notified by EG&G. No county permits or air quality permits have been required for the project.

The major environmental concern regards communications between shallow and intermediate ground water aquifers and the geothermal system. It is thought that these aquifers, which have been developed for irrigation and domestic water supplies, could be contaminated as a result of seepage from the reserve pit, by seepage into zones around the uncased portion of the geothermal wells or from injection of waste geothermal fluid. This concern was intensified following the heavy use of NaCl to kill a well in June 1978. A four-part water quality monitoring program has been implemented in response to this environmental concern.

A well stimulation project in this area appears not to present a permitting concern, but special attention must be given to potential water quality problems, especially as related to injection operations.

RAFT RIVER, IDAHO

WELL DATA

Well Name	RRGE-1	RRGE-2
Total Depth	4989'	6543'
Prod. Interval	Open hole 3623'-4989'	Open hole 4227'-6543'
Casing Configuration	20" 0-901' 13-3/8" 0-3623'	20" 0-904' 13-3/8" 0-4227'
Max. Temperature	296°F	294°F
Pressure, psig	150 wellhead	150 wellhead
Tests	Flow, core P, T, logs	Flow, P, T, logs, cores
Flow Rate	800 gpm	540 gpm
Water TDS (Prin. Const.)	1560 ppm ($Cl-Ma-SIO_3$)	1267 ppm ($Cl-Na-SIO_3$)
Geological Data	820'-4595' Salt Lake FM 4595'-4708' Metamorphosed zone 4708'-4928' Elba quartz 4928'-TD quartz Monzonite	1050'-4664' Salt Lake 4664'-4752' metamorphosed zone 4752'-4988' elba quartz 4988'-TD quartz monzonite
Avg. Porosity	.30	.17
Avg. Permeability- Thickness	>100 D - ft k = 25 - 165 md	49 D - ft k = 25 md
Core Data	Ø = .162 k= 5 md @ 4506' Tuffaceous siltstone	Ø = .155 k= .04 md @ 4227' k= .0022 md @ 4372' (shale)

Well Name	RRGE-3	RRGP-4
Total Depth	5900' approx.	5099'
Prod. Interval	Open hole (3 legs)	Open hole 3526'-5115' (leg B)
Casing Configuration	20" 0-120' 13-3/8" 0-1386' 9-5/8" 1188'-4241' 3 legs all open hole to 5900' approx.	20" 0-400' 13-3/8" 0-1901' 9-5/8" 1512'-3526'
Max. Temperature	298°F	240°F @ 2900' approx.
Pressure, psig	112 @ wellhead	120 @ wellhead
Tests	Logs, P, T, flow	Cores, logs, P, T, flow
Flow rate	540 gal/min	Non-commercial
Water TDS (Principle Const.)	4130 ppm (Cl-Na)	<2,000 ppm (Cl-Na)
Geological Data	Slight variations on legs 2 & 3 1270'-5300' Metamorphosed zone 5300'-5780' Elba quartzite, 5780'-5842' Quartz monzonite	4600'-5099' quartz, schist, elba quartzite quartz monzonite w/fractures
Avg. Porosity	-	-
Avg. Permeability- Thickness	6.7 D-ft	26 D - ft @ 2840 ft (RRGI-4)
Core Data	Ø = .228 k= .04 md @ 3366' Tuff k= 100 md @ 3365' Tuff	Ø = .245 k= 60 md @ 1900'
Peculiarities	Three legs open to production	Leg A filled with cuttings or bridged

Well Name	RRGP-5B	RRGI-6
Total Depth	4925' approx.	3858'
Prod. Interval	Open hole 3408'-4925'	Injection well Open hole 1698'
Casing Configuration	20" 0-1500' 13-3/8" 0-1510' 9-5/8" 1284'-3408' First leg cemented Second leg open hole to 4925'	20" 0-120' 13-3/8" 0-1698'
Max. Temperature	274°F	209°F
Pressure, psig	-	-
Tests	Logs, cores, P, T, flow	Cores, logs, P, T, flow
Flow Rate	(1095 gpm leg A) 700 gpm leg B (damaged)	1500 gpm injection
Water TDS (Principle Const.)	1618 ppm ($Cl-SIO_3$)	6286 ppm (Cl-Na)
Geological Data	Siltstone, quartzite schist, elba quartzite, quartz monozonite	-
Avg. Porosity	.17-.30	
Avg. Permeability	25-165 md	
Peculiarities	Leg A cemented, leg B near wellbore may be cemented in fractures	Skin damage suspected

Well Name	RRGI-7
Total Depth	3888'
Prod. Interval	Injection well Open hole 2044'-3888'
Casing Configuration	20" 0-150 13-3/8" 0-2044'
Max. Temperature	-
Pressure, psig	65 @ wellhead
Tests	Logs, cores, P, T, flow
Flow Rate	840 gpm injection
Water TDS (Principle Const.)	< 2,000 ppm (Cl-Na-Ca)
Geological Data	Fractured metamorphics above elba quartzite
Avg. Porosity	.17-.30
Avg. Permeability	25-165 md
Core Data	-

Available Chemical Analyses of Raft River Geothermal Water
(in mg/liters unless otherwise noted)

	RRGE-1	RRGE-2	RRGE-3	RRGP-4	RRGP-5	RRGI-6	RRGI-7
Ca	53.5	35.3	193	150	40	157	315
K	31.3	33.4	97.2	28	---	---	---
Li	1.5	1.2	3.1	3.1	---	---	---
Mg	2.4	0.6	0.6	0.2	---	---	1.6
Na	445	416	1185	1525	---	---	2100
Si	57	61	74	51	67	---	39
Sr	1.6	1.0	6.7	6.5	---	---	---
Cl	776	708	2170	2575	900	3150	4085
F	6.3	8.3	4.6	4.5	8.4	8.5	5.0
HCO_3	64	41	44	24	---	37	26
NO_3	<0.2	<0.2	<0.2	---	---	---	---
$S^{=}$	---	0.3	---	---	---	---	---
$SO^{=}_4$	60	54	53	61	---	---	64
pH	8.4	7.6	7.3	7.4	8.1	7.3	---
Conductivity (umhos/cm)	3370	2740	9530	7280	2150	10,500	12,000
TDS	1560	1270	4130	4470	---	---	---

ROOSEVELT HOT SPRINGS, UTAH

ESTIMATES OF RESOURCE CHARACTERISTICS

Resource Characteristic		Estimate
Subsurface Fluid Temperature (°C)	Range:	204-260
	Best Estimate:	230
Total Dissolved Solids (PPM)		7,800
Electric Energy Potential (MWe 30 years)		1,000
Overlying Rock		Sediments, metamorphics, and volcanics
Land Status		
Total KGRA acres		29,791
Total federal acres		24,592
Federal acres leased		24,592
Total state and private acres		5,199
State and private acres leased		No Data

DEVELOPMENT STATUS AND ACTIVITY

Thermal Power Company, a subsidiary of Natomas Company, has completed a joint-venture well which was drilled to 382 meters (1254 ft.). Preliminary testing demonstrated a wellhead pressure of 25 kg/cm^2 (355 psi) and temperature of 222°C (432°F). The projected total mass flow capability of the well is 450,000 kg/hr of steam and hot water.

Phillips Petroleum Company reports that an 823-840 meter (2700-2800 ft.) test well had an initial flow rate of 90,700 kg/hr (200,000 lb/hr) of steam at 204°C (400°F). Phillips has completed 7 wells, and has held negotiations with several organizations interested in utilization including Utah Power and Light Company. In addition to a hydrothermal electric generating plant, possible applications include a hybrid coal-geothermal electric plant and process heat uses.

Thermal Power Company plans to build a larger test facility to determine more precisely the electric generating potential. Thermal Power holds options to drill on an additional three sections of geothermal leaseholds in the Roosevelt fields. Two wells drilled in 1976, at the site of a significant new field discovery the year before, were both successful producers. One was 1860 meters (6100 ft.) deep and the other only 380 meters (1250 ft.) deep. The latter produced steam at 100 meters, 210 meters, and 360 meters, with a total mass flow of about 450,000 kg/hr (1,000,000 lb/hr).

MAJOR DEVELOPMENT PROBLEMS

No major development problems are currently evident at the Roosevelt Hot Springs hydrothermal site. However, technological areas which could entail a moderate risk include:

- wellbore scaling
- fluid disposal
- high silica content of brine
- cooling water availability/subsidence

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Roosevelt Hot Springs prospect area is located in the Escalante Desert, Beaver County, Utah. The majority of the lands are administered by the federal government and leased to Phillips Petroleum, with the exception of several sections of land administured by Utah Stade and leased to Thermal Power Company and O'Brien Resources. The two major habitat types are the big sage brush community in the lower elevations and the juniper-pinon pine community in the foothills of the Mineral Mountains.

Climatic conditions are typical of the high desert, semi-arid characteristics of the area and the ambient air quality is very good. Surface waters are lacking, appearing intermittently in normally dry washes during intense rainstorms. The groundwater table is being depleted as recharge does not equal use. The nearest town is Milford (1,400), located approximately eighteen air km southwest of Roosevelt Hot Springs.

Eleven Environmental Analyses have been prepared by the U.S. Geological Survey in accordance with the National Environmental Policy Act to evaluate operations proposed by Phillips in the Roosevelt Hot Springs area. Phillips has also submitted a Program to Collect Environmental Baseline Data to the USGS.

No major environmental concerns have been raised during the above-mentioned reviews. The geothermal resource at Roosevelt is characterized by reasonably clean geothermal fluid and low concentrations of noncondensable gases. Site-specific surveys have been conducted for cultural resources. A baseline environmental monitoring program, including air quality, water quality, biological data, noise, subsidence and seismicity, is currently proposed. Implementation will occur as development progresses to utilization of the resource.

All well operations have been conducted under Plans of Operation approved by the U.S. Geological Survey and Bureau of Land Management. Well stimulation operations can be carried out under the plans already approved, but a Sundry Notice describing the details of the operation must be approved by the USGS prior to commencing operations. Preparation and approval of the Sundry Notice should require approximately one month, and a stimulation project in this area does not appear to present a concern.

WELL DRILLING DATA

WELL NAME	COMPANY	DEPTH	COMP. DATE
U-27386 12-35(P)	Phillips Petroleum		10/01/75
U-27386 54-3(P)	Phillips Petroleum		08/28/75
U-27386 55-3	Phillips Petroleum		05/24/75
U-27386 82-33(I)	Phillips Petroleum		12/23/75
U-27388 9-1(S)	Phillips Petroleum		04/08/75
U-27389 OB.2	Phillips Petroleum		02/15/75
U-27389 13-10(P)	Phillips Petroleum		11/04/75
U-27390 OB.1	Phillips Petroleum		03/12/75
#42-9(S)	Phillips Petroleum	2099 M	1975
#25-15(P)	Phillips Petroleum	2290 M	1976
Utah State #3-1(P)	Phillips Petroleum		
Utah State #14-2(P)	Thermal Power	1862 M	1976
Utah State #72-16(P)	Thermal Power	382 M	1976
Utah State #24-36(S)	Thermal Power	1861 M	1977
Utah State #52-21	Getty Oil Co.	2281 M	
UU #76 SC(3 HF)	University of Utah	1954 M	
UU #76-1	University of Utah		
UU #1A	University of Utah		
UU #76 BS(1 HF)	Universtiy of Utah	2193 M	
KGRA #52-21	Getty Oil Co.	2273 M	

(SMITH 76, SMITH 77B, SMITH 78C, WITHAM 76)
(NIELSON 78, LETTER FROM J.W. WOFFINGTON, DEC 78)

REMARKS:
- (P) = PRODUCIBLE
- (S) = SUSPENDED
- (A) = ABANDONED
- (O) = OBSERVATION
- (I) = INJECTION

ROOSEVELT HOT SPRINGS, UTAH
WELL DATA

Well Name	Well 9-1
Total Depth	6885 ft
T_{max}	377°F (14-1/2 hr)
P. Casing	15-1/2", 1280 m
Bit at TD	8-1/2"
Tests	logs, T, mud log
G_t, Equilibrium	102.6°C/km
Sedim. Base	710 ft
Fracturing	N20E @ 3600 & 5800 ft
Geol. Features	Granodiorite batholith
Surface Deposit	Escalante Valley: Quaternary sands, Well 9-1 2900 feet from prod. well (250,000 lb/hr) warm spring 3 miles away
Elevation	5828 ft
Mean Surface T.	52°F
Well Flow	
Salinity, ppm	22,000 by SP
Prod. Interval	Open hole
Sonic Porosity, Ø a	0.05 in fractures
Density Ø, frac.	0.019 in fractures
Average Porosity	0.02
Reservoir Rock	Granodiroite
Fractures	Inflow @ 3572-3604 ft
Permeability, md	<1
Peculiarities	No flow on test; possible fault at 5800 ft altered zone at 4070 ft.

Well Name	72-16	14-2
Total Depth	1254'	6100'
T. Max	468.8° F @ 1229'	517.8° F @ 6091'
Casing	20"-85', 13 7/8"-550'; 9-5/8" - 1098'; open hole completion	20"-79', 13 7/8"-645'; 9-5/8"-1805'; open hole completion
Bit @ T.D.	17 1/2"	8 1/2"
Tests	4/4-5/77 flow test, P & T surveys	P & T surveys, flow test, prod. log, acoustic televiewer
Geological Features	Alluvium w/zones of hydrothermal alterations 0'-290', conglomerate 290'-425' granite, (fractured 425'-1254' T.D. Geo. a TD = 9-15 Mybp	Alluvium 0'-200', Granite 200'-6100' Geo. Age @ TD = Est. 9-15 Mybp
H_2S	Trace	Trace
pH		6.1
TDS, ppm	6955'-7000'	6400'-6700'
Prod. Interval	1098'-1254' (T.D.) open hole	1805'-6100' open hole
Average Porosity	Very low 2%	Very low 2%
Reservoir Rock	Granodionite	Granodionite
Permeability, md	Very low <1md	Very low <1md
Flow Rate	1,300,000 lb/hr	483,000 lb/hr
Peculiarities	Fracture production	large noncondensible gas production (CO_2) Fracture production

Well Name	52-21
Total Depth	7500'
Prod. Interval	Open hole - 8-1/2"
Casing Configuration	30" - 30'; 20"-182'; 13-3/8" - 765'; 9 5/8" - 2039'
T. Max, °F	398 u
Pressure (psig)	2965 @ TD
Tests	Nonproductive
Flow Rate	-
Water - TDS	-
Geological	Granodiorite
Avg. Porosity	Very low
Avg. Permeability	Very low

THE GEYSERS, CALIFORNIA

RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Vapor Temperature (°C)	240
Electric Energy Potential (MWe 30 yrs)	2200
Overlying Rock	Medium-Hard
Depth to Top of Reservoir (Meters)	1000

DEVELOPMENT STATUS AND ACTIVITY

The Geysers geothermal area, located in the Mayacmas Mountains of northern California, is currently the world's largest producer of electrical energy from a geothermal source (663 MW from thirteen units). Over 200 wells have been drilled in the area, representing one of the few areas known to be composed of a vapor-dominated hydrothermal system. Early wells were drilled adjacent to natural steam vents, tapping the vapor-dominated reservoir at depths of less than 1000 ft. Steam production from these wells ranged from 40,000 to 80,000 lbs per hour. Higher flow rates and greater pressures are now being attained from wells penetrating steam zones between 4900 and 9800 ft. Maximum well depths reach approximately 11,000 ft.

Dry steam is produced from near-vertical fractures occurring in a hard, dense sandstone of the Franciscan formation. The average initial per-well production is 150,000 lbs of 355°F steam per hour with bottom hole pressure at 450-500 psi. As the steam flows to the surface it expands and cools, reducing pressure at the wellhead to 125 psi.

Over one million lbs of steam, at a constant enthalpy of 1200-1205 Btus per lb, are required per hour to generate about 55 MW of electricity. Depending on production capabilities, seven to ten wells are on line for each 55 MW unit, with one or two additional wells on standby. New wells are drilled and added to the gathering system as well production declines. Sufficient productive acreage must be reserved adjacent to the producing area for each generating unit to provide an adequate steam supply over the life of the units. Approximately 20% of the total condensed steam is reinjected into the producing reservoir.

Thirteen units are now in operation at The Geysers, ranging in capacity from 11 MW to 106 MW. Units 1 through 10 were constructed two to a site, but new units are located in individual power houses. Units 12 and 15 came into service in 1979 and have rated capacities of 106 MW and 55 MW, respectively. Union-Magma-Thermal holdings will supply steam to all units except 15, which is supplied by Thermogenics, Inc. It is also the first unit to employ a surface condenser and the Stretford process for H_2S abatement.

Construction on Unit 13 is nearing completion with the unit projected to be operational by early 1980. The 135 MW turbine generator will be the largest geothermal unit in the world and the first to be constructed in Lake County. Aminoil will be the steam supplier.

Unit 14, rated at 110 MW, is also under construction and is projected to go on line in August, 1980. Union-Magma-Thermal will provide the steam. Units 16, 17 and 18 are in the regulatory approval process with 17 and 18 scheduled for commercial operation in July and October of 1982, respectively. Commercial operation of Unit 16 is projected for early 1983. When all units are operations, The Geysers will have a net installed capacity of 1248 MW.

Preliminary design plans and permitting procedures, involving three other California utilities, are under way in the northern part of the field.

After 20 years of field development, the full potential of The Geysers is unknown. The proven capacity of the field is now between 1600-1700 MW and its future potential may be 2200 MW.

MAJOR DEVELOPMENT PROBLEMS

No serious long-range technological problems are anticipated. The Department of Energy is sponsoring several programs (under Environmental Control Technology and Research) which have as their goal the control of hydrogen sulfide. The levels of H_2S emitted at The Geysers (H_2S constitutes two to seven percent of the total noncondensable gases by weight) are not a threat to health or safety. The principal objection is to the odor nuisance. Pacific Gas & Electric has plans for control techniques to be incorporated in all newly established plants, and retrofitted to existing plants. These abatement methods include the iron catalyst, use of direct contact condensers and the Stretford process.

Available subsurface data indicate that steam production in The Geysers region is largely from fracture zones in Franciscan graywacke. Given the presence of suitable reservoir rocks at any of several levels, the structural conditions determining the presence of steam would appear to depend upon: (1) the presence of channel ways such as faults, fractures, or bedding planes that allow percolation of meteoric water to some depth and provide an adequate but not excessive supply of water to the system; (2) the presence of structural traps for steam accumulation; and (3) a potent heat source.

At The Geysers, drilling site preparation costs are high because of the rough terrain and inaccessible location. This has led to the practice of drilling multiple deviated wells from a common site. Experience at The Geysers has indicated that five wells can be drilled from a common location, and one well may not be commercial even though it is only 30-40 m from a

commercial producer (Overton and Hanold, 1977). Stimulation attempts using hydraulic fracturing have not been successful, as the formation accepts the fluid without a sufficient pressure rise to even attempt propping the natural or induced fractures. In at least some of these stimulation experiments, the conditions for successful hydraulic fracturing of the producing formation have been far from ideal; e.g., in wells with only partial casing, attempts were made to pressurize long segments of the uncased well, and fluid loss could have occurred in formations other than those in the steam-producing region where the stimulation was desired.

The DOE is currently supporting explosive fracturing experiments in cooperation with Union Oil Company in The Geysers.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Geysers geothermal field is located in Sonoma and Lake Counties, California, predominantly on privately-owned land. The Geysers is a dry steam reservoir, unlike the other prospects being considered. Because the field has been producing commercial electricity for many years, a vast wealth of environmental information exists.

Briefly, The Geysers field is located in steep, mountainous terrain. Major habitat types are the oak woodland, California chaparral and riparian communities. The climate is mild. The area is remote from population centers. Major environmental concerns focus on air quality, especially hydrogen sulfide emissions; water quality, particularly erosion, sedimentation and trace metals; subsidence and seismicity; and noise from well operations.

The following agencies have the main responsibilities for permitting in The Geysers: Sonoma and Lake County, Conditional Use Permits; California Division of Oil and Gas, Notices of Intent; California Regional Water Quality Control Board, Waste Discharge Orders; and Lake and Sonoma County Air Pollution Control Districts, Authority to Construct and Permit to Operate. Conditions of approval of these permits must continue to be observed while conducting well stimulation operations. No further permitting should be required for well stimulation, although the D.O.G. requests that a history of the operations be filed with their office.

Although a stimulation project in this area does not appear to present a concern, the area is one of higher environmental sensitivity so that environmental mitigation measures may need to be carefully considered.

GASES AND SOLIDS IN GEYSERS AREA STEAM (PPM)

	GEYSERS RANGE OF CONC. MEASURED		GEYSERS AVERAGE	OTTOBONI STATE WELLS	CASTLE ROCK SPRINGS
	LOW	HIGH			
CO_2	290	30600	3260	4123	216
H_2S	5	1600	222	277	96
CH_4	13	1447	194	146	3.6
NH_3	9.4	1060	194	176	140
N_2	6	638	52	47	2.2
H_2	11	218	56	57	1.0
C_2H_6	3	19	NEG		0.03
C_3H_8					0.06
AS	0.002	0.050	0.019		
B	2.1	39	16		
HG	0.00031	0.018	0.005		

(WERES 77)

THE GEYSERS, CALIFORNIA*
WELL DATA

COMPANY	WELL	DEPTH	COMPLETED	CASING
Union	Thermal 7 Flow Rate-206,000 lb/hr Wellhead Press 44psi	5070'	12/12/67	13-3/8"-325' 9-5/8"-2020' prod. int. 2020'-4208' dry steam
Union	Thermal 8 Flow Rate-140,000 lb/hr	5590'	2/19/69	13-3/8"-370', 9-5/8"-1020' prod. int. 1020'-5590' dry steam
Union	Thermal 9	775'	8/17/59	
Union	Thermal 10	936'	3/09/59	
Geothermal Kinetics, Inc.	Rorobaugh 1 Flow Rate 100,000 lb/hr Dry Steam	7200'	9/11/73	20"-150', 13-3/8" 2500', 9-5/8" 2267'-4404', prod. int. 4404'-7200'
Thermogenics, Inc.	Filley 1 Flow Rate 215,000 lb/hr Dry Steam	6898'	10/24/74	29"-149', 13-3/8"-2403', 9-5/8" 2156'-5526'
Thermogenics, Inc.	Rorobaugh 1 Flow Rate 117,000 lb/hr Dry Steam	6676'	3/19/69	13-3/8"-950', 9-5/8" 893-2450', prod. int. 2450'-6676'
Thermogenics, Inc.	Rorobaugh 2 Redrill #1 2408'-4290' #2 3800'-5077' #3 4500'-7215' #4 4307'-6730'	7215'	6/24/68	13-3/8"-1665' 9-5/8"-4255' prod. int. 4255'-6730'

*Abridged list of wells.

DESERT PEAK/BRADY HOT SPRINGS, NEVADA

ESTIMATE OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (°C)	Range: 200-230
	Best Estimate: 214
Total Dissolved Solids (PPM)	2,450
Electric Energy Potential (MWe 30 years)	1,000
Overlying Rock	Basalt and alluvium
Depth to Top of Reservoir (Meters)	500
Land Status	
Total KGRA acres	98,508
Total federal acres	59,358
Federal acres leased	26,049
Total state and private acres	39,150
State and private acres leased	No Data

DEVELOPMENT STATUS AND ACTIVITY

Several companies have been drilling in the area since 1959. Magma Power Company drilled several shallow wells between 1959 and 1961. Earth Energy, Inc. drilled a well to 1,519 meters (5,062 ft.) in 1964. By August 1975, Phillips Petroleum Company and Union Oil Company had drilled deeper than 2,100 meters (7,000 ft.) and Magma had drilled two wells, one to 1,050 meters (3,500 ft.) and the other to 1,350 meters (4,500 ft.) near the old holes. One 1,500 meter (4,900 ft.) well had a temperature of 214°C and a high flow rate. Phillips has new high-flow-rate wells east of the old Brady Magma wells.

In 1977, ERDA (now part of DOE) approved an application for $3.46 million in loan guaranties for Geofood Products, Inc., to build a plant to use heat from the Brady geothermal resource for dehydration of food products.

MAJOR DEVELOPMENT PROBLEMS

There do not appear to be any severe technological problems at Desert Peak/Brady Hot Springs. However, the following determinations must be made:

1. Whether or not brine production may lead to severe scaling

2. What the noncondensable gas content is, as this may affect the choice of conversion technology

Also, injection feasibility must be demonstrated, and the maintenance of production flow must be demonstrated in formations having low permeabilities.

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Desert Peak prospect area is located in Churchill County, Nevada. Although Phillips Petroleum drilled the existing wells on privately-owned lands, the company has formed a unit of their federal and private leased acreage. Habitat types of the Desert Peak area are desert sagebrush community in the foothills and alkali sink-scrub in the flatlands. There are no surface waters in the area of operations. The area is remote from population centers. Currently, Phillips has completed three wells and is in the process of drilling a fourth well. The geothermal resource at Desert Peak is characterized by reasonably clean geothermal fluid and low non-condensible gas content.

Because of unitization with lands leased from the federal government, all operations in the unit must be permitted through federal processes even if they are on private land. An Environmental Analysis has been prepared and Phillips has an approved Plan of Operation for the well now being drilled. A Sundry Notice must be approved by the USGS prior to commencement of well stimulation operations. Approximately one month should be allowed for permitting, and a stimulation project in this area does not appear to present a concern.

DESERT PEAK/BRADY HOT SPRINGS, NEVADA

WELL DATA

COMPANY	WELL	DEPTH	DATE COMPLETED	STATUS	CASING
Magma Energy, Inc.	SP Brady 2	4446'	3/28/75	Shut-in	13-3/8" - 1186'; 8-5/8" 1080' - 4446', slotted
Union Oil & Magma Energy, Inc.	SP Brady 1	7275'	6/12/74	Suspended	20"-117', 13-3/8"-1044', 9-5/8" tie back liner; surface 900' 8-5/8" 900'-3998'
Earth Energy, Inc.	Brady Prospect 1	1758'	1965	-	-
Magma Energy, Inc.	SP Brady 8	3469'	4/11/75	Shut-in	13-3/8" - 1151'; 8-5/8"-3469' slotted
Magma Power	Brady 1	700'	1959	-	-
Magma Power	Brady 3	610'	1961	-	-
Magma Power	Brady 4	723'	1961	-	-
Phillips Petroleum	Desert Peak B 21-1	4000'	12/23/76	Suspended	9-5/8" casing set; open-hole prod.
Phillips Petroleum	Desert Peak 21-2	3500'	1/7/77	Suspended	9-5/8" casing set; open-hole prod.
Phillips Petroleum	Desert Peak 29-1	7662'	5/13/74	Shut-in	Did not produce

CHANDLER, ARIZONA

ESTIMATE OF RESOURCE CHARACTERISTICS

Resource Characteristic	Estimate
Subsurface Fluid Temperature (C°)	Range: No data Best Estimate: 178
Total Dissolved Solids (PPM)	62,000
Electric Energy Potential (MWe 30 years)	200
Overlying Rock	Alluvium, evaporite other sedimentary, volcanics
Depth to Top of Reservoir (Meters)	2,500
Land Status	
Total KGRA acres	KGRA not defined

DEVELOPMENT STATUS AND ACTIVITY

Two deep wells by Geothermal Kinetics were completed by August 1975. The deeper well was 3,200 meters (10,450 ft.). Neither well was a good producer when completed with slotted or perforated liner and deep-well pumps. No other known drilling activity has taken place.

MAJOR DEVELOPMENT PROBLEMS

Reservoir characteristics have not yet been established. Early exploratory drilling has not revealed the existence of a viable reservoir. Initial findings of further concern include hard drilling and well completion problems; low permeabilities of the formation (flow rates less than 2000 gpm); problems of drilling mud sealing off the geothermal production formations; and measured dissolved solids as high as 62,000 ppm (with a contamination from drilling fluids suspected).

ENVIRONMENTAL AND INSTITUTIONAL EVALUATION

The Chandler Valley prospect area is located in Maricopa County, Arizona, on privately-owned lands. Land use in the area is primarily agricultural. Climatic conditions are those of an arid desert environment. The closest town is Chandler, and the prospect area is approximately twenty-five miles from the major urban area of Phoenix. Currently there are two completed wells being considered for the stimulation project.

No environmental documents have been prepared to date for geothermal operations in Chandler Valley. Permitting is primarily through the Arizona Division of Oil and Gas. No other county or state permits have been acquired. A permit for re-entry into the well should be required by the D.O.G. for well stimulation operations, and this should take approximately one to two weeks.

It appears that permitting would not present a concern in Chandler Valley, but a question does arise regarding the fact that DOE funds would be used for a project where no environmental reviews have taken place.

CHANDLER, ARIZONA

WELL DATA

Well Name	Power Ranch #1	Power Ranch #2
Total Depth	9207 ft	10,454
T_{max}	352°F @ 9065 ft	352°F
G_tc/km	49.2	47.4
Casing	9-5/8" @ 1648 m	13-3/8" @ 823m, 7" Liner @ 3119 m
Bit at TD	8-3/4"	8-1/2"
Tests	Logs,T,drill stem test,prod.	Logs,T
Sedim. Base	5410 ft	4760 ft
Metam. Base		10,250 ft
Surface Faults	Recent 40m x 1m wide N25°E 5 miles south of well, 10m deep	
Geol. Features	Basin & range lowlands P intrusions, lake bed	Quaternary/tertiary basin & range lowlands, Central Ariz., Salt River Valley
Surface Deposit	Lake sand and clay to 1000 ft, quaternary/tertiary	
TDS, ppm	26,700	29,700
Elevation	1338 ft	1336 ft
Mean Surface T.	80°F	80°F
Water Table	400 ft	
Well P, D	3893 psi @ 9180 ft (pressure bomb)	
Salinity, ppm,	27,300 by SP	3650 by SP
Prod. Interval	7830-9207 ft	
Sonic Porosity, ϕ_a	0.22	0.13
Average Porosity		0.05 (TRW measured)
Reservoir Rock	Volcanic	Volcanic
Flow Rate	150 gal/min	150 gal/min (max)
Permeability, md	0.16 - 0.4 core (0.3 test)	0.16 - 0.4 core
Peculiarities	Est. 850 ton/hr initially (Blew 207°F mist while air assisted.)	Water different from #1

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