UCID- 16721

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California

THE LLL GEOTHERMAL ENERGY DEVELOPMENT PROGRAM

Status Report

January, 1974 - January, 1975

A. L. Austin

February 14, 1975

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

kb

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

THE LLL GEOTHERMAL ENERGY DEVELOPMENT PROGRAM

PREFACE

The LLL Geothermal Energy Development Program was initiated in January, 1974. Quarterly Progress Reports have been prepared for the purpose of describing the program activities during the respective reporting periods. We have decided to broaden the scope of this quarterly report to give readers a better understanding of the continuity and long-term goals of the program.

This report includes significant events during the year as well as the activities during the preceding quarter, and is intended to serve as a status report.

I. INTRODUCTION

The major goal of the LLL Geothermal Program is to develop systems for the recovery and conversion of the energy stored in hot water deposits with particular emphasis on those containing $> 3\%$ total dissolved solids (TDS). The current interest in conversion machines and systems designed uniquely for these resources is stimulated mainly because: hot water resources are abundant, economic conditions require development of high efficiency machines to minimize costs, and the range of chemical conditions in the high salinity deposits will require new approaches. Currently, the Flashed Steam system and the Binary Cycle systems are under consideration for application to the low salinity resources, but problems of precipitation, corrosion, and scale formation may limit their applicability to the high saline resources.

The LLL program is directed toward development of an entirely new approach called the Total flow concept. This, in principle, consists of expanding the total wellhead brine-steam mixture directly through a mixed-phase expander to drive an electrical generator. Among the candidate expanders are tangential, axial and radial flow impulse turbines, reaction devices, and positive displacement devices such as the helical screw expander.

Thermodynamically, the Total Flow process is the simplest, and it can be shown that it provides the upper bound on cycle efficiency. A detailed analysis indicates that about a 60% increase in power output could be achieved by successful development of the Total Flow concept. As shown in Figure 1, this advantage exists over the expected range of reservoir temperatures. The implication is that although the program is focussed on utilization of the high temperature/high saline resources, the concept, once developed, will find application for all hydrothermal resources.

*Work performed under the auspices of the U.S. E.R.D.A.

Development of any conversion system for use with high saline brines must include resolution of the technical problems of precipitation and scale control, corrosion, erosion, and brine management, i.e., handling and disposal. This requires extensive chemical and materials application development work, both in the laboratory and field. Final system design must be preceded by field testing of materials and components in actual brines under representative operating conditions. Consequently, a major portion of the program effort is devoted to characterizing the precipitation kinetics, scale formation and control methods, and materials behavior coupled with development and testing of brine tolerant expander concepts.

Since there is a clear national need to provide alternate commercial energy sources, the program goal is to establish technical feasibility in time to stimulate commercialization within the decade of the eighties. This will require development and testing of a complete system of at least 5-10MW capacity to demonstrate and prove the technology. Concurrent investigations of the resource location and magnitude, productive capacity and lifetime of reservoirs, and environmental impacts must be included to evaluate the reliability of long-term power production. Consequently, the LLL program consists of three basic activities: resource assessment, brine chemistry and materials technology, and energy conversion and system engineering. A generalized program plan is shown in Figure 2 illustrating the interaction between these three subprograms. The following describes detailed status of each.

II. ENERGY CONVERSION SUBPROGRAM

In order to introduce greater flexibility in the utilization of geothermal fluids, particularly those with high salinities, the emphasis (see Section II-A-2) is on development of the single stage impulse turbine. In this device the entire wellhead product is expanded through converging-diverging nozzles to convert fluid enthalpy into kinetic energy in the form of low-temperature, high velocity streams of fluid. These jets are used to drive an impulse turbine of special design, but similar to conventional hydraulic devices. Two promising candidates are tangential and axial flow devices. The former is shown in Figure 3.

The efficiency of these devices is dependent on many factors, but we can define the turbine requirements in a general way as follows. For a fluid mass flow rate, $\dot{m}$, the power output is given by:

$$P = \dot{m} \frac{V^2}{2} e_w \dots \dots (1)$$

where V is the composite fluid velocity at the nozzle outlet before entering the blading and e_w is the wheel efficiency for conversion of the kinetic energy to shaft work. The outlet velocity V is obtained from the isentropic enthalpy drop Δh_s through the nozzle. Hence, the velocity is given by:

$$V^2 = 2 \Delta h_s \eta^2 \dots \dots (2)$$

where η^2 is the nozzle efficiency for conversion of fluid enthalpy to kinetic energy, i.e., η is usually called the nozzle velocity coefficient. Substituting (2) into (1) the actual power output is:

$$P = (\dot{m} \Delta h_g) \eta^2 e_w \dots \dots \dots (3)$$

Since the critical design parameters are η and e_w , the main emphasis of the conversion subprogram is to design systems which have $\eta > .9$ and $e_w > .9$. If this can be achieved, then the turbine, or engine, efficiency $\eta^2 e_w$ will be greater than 70% which will yield the advantages noted in Figure 1. Both η and e_w are dependent upon many factors which interact in a very complex manner. The following describes current research directed toward development of nozzle and turbine designs for efficient conversion of the energy in the two-phase mixture of brine and vapor produced from geothermal wells.

To accomplish this, the conversion program is divided into laboratory development work and field testing of conversion systems. The following will describe those activities and plans.

A. Laboratory Activities - Conversion Systems

1. Geothermal Test Facility (GTF)

The resource assessment and brine chemistry subprograms are by their nature constrained to field activities. Energy conversion work can accomplish a great deal in less hostile environments in preparation for later joining the resolved problems of chemistry and materials in a brine-tolerant design for a complete system as illustrated in Figure 2.

In order to provide a basic laboratory tool for gathering mechanical performance data on turbine concepts, design information for components such as nozzles and turbine blading, and for fundamental investigations into the mechanics of two-phase flow, a geothermal test facility has been constructed and is now operational. The facility is shown in Figure 4. It consists of a water heater capable of producing about 1.5 lb/sec of water at 1000 psia and 550°F. By flashing through a throttling valve, a wide range of typical wellhead thermodynamic states can be reproduced. The facility includes condensing equipment to provide exhaust conditions down to about 1.7 psia Hg (120°F). This allows experiments to be performed under representative flow conditions. As shown in Figure 4, the facility includes fully instrumented chambers for component testing as well as performance testing of turbines up to 100 Kw capacity. Figure 5 is a photograph of the exterior of the facility.

Additional capabilities are currently in preparation. These include a spin pit for turbine testing, a test bed for instrumentation development, facilities to allow performance testing of special turbines developed by industry, and apparatus for erosion testing of candidate materials.

2. Turbine Development

a) Design Concepts

Considerable thought and analysis has been directed toward selection of turbine candidates for development. Turbine configurations investigated include radial, tangential, and axial flow impulse turbines, pure reaction devices and positive displacement devices. We have concluded that tangential and axial flow impulse turbines are most promising for use with geothermal brines in a Total Flow process and are now subjects for detailed investigations. Although the relative advantages and disadvantages of both have yet to be precisely determined, we have recently decided to accelerate development of the single stage axial flow impulse machine. The major factors influencing this decision are: (1) reduced turbine speed, (2) simpler construction and blade geometry, (3) higher power output for a given size and width of turbine disk, and (4) possible advantages in transferring the momentum of the liquid droplets in the two-phase flow to the wheel.

Final design of the first experimental unit is underway. It has a vertical axis of rotation with downward fluid flow. The wheel diameter is about 1 meter, utilizing a single nozzle to give about 50 kW output at 8000 rpm. The unit is expected to be ready for test in the test facility by the end of FY 75. The unit can produce higher power outputs by addition of nozzles to produce higher flow rates. If laboratory tests produce satisfactory performance characteristics the unit will be field tested at higher power outputs approaching 1 MW if a source of relatively clean geothermal fluid is available.

Although erosion is a fundamental problem, this first unit will not be designed with erosion-proof materials. In the interests of accelerating turbine performance work, the unit will be fabricated from 7075-T6 aluminum alloy even though erosion is expected. The total testing time for a single design is less than 100 hours; hence, the amount of blade erosion over this time period will not significantly affect the mechanical performance.

b) Analytical Efforts

The following briefly describes the analytical tools developed or used to date for design and development of total flow turbines.

ASME Steam Tables (Equation of State for Water)

The two-phase equation of state in the form of the ASME Steam Tables is now available on our computer.

Isentropic Nozzle Design Code

A small one-dimensional code which calls the equation of a state as a subroutine is available for specifying area ratios on the basis of isentropic nozzle design in the two-phase region. The code assumes that there is no difference between the liquid and vapor phase velocities. This code is being used for preliminary design of test nozzles.

Two-Phase Single Component Nozzle Flow Code

This is a one-dimensional flow model including boundary layer corrections, originally developed by the Jet Propulsion Laboratory for liquid metal MHD studies. The code solves continuity, momentum, and energy plus equation of state including mass, momentum, and energy exchange between phases. All processes are assumed to be equilibrium. Droplet breakup is based on an empirically derived critical Weber number criteria. Also, increases in entropy resulting from friction are considered. This code allows us to calculate both liquid and vapor fields in one-dimensional geometry. This code is used, along with experimental data, for initial design studies of nozzles for use with the turbine wheel. This code has an inherent error, however, in definition of the variable "quality" which affects the accuracy in the region of low quality and high phase-velocity differences.

Rather than changing this code, we have started work on a two-dimensional code which will find direct application in design of both nozzles and turbine blades.

Two-dimensional Droplet Flow Model

In order to estimate droplet trajectories around cylindrically curved surfaces the Lagrangian equations of motion for a droplet in a vapor field were written and solved numerically. The present model assumes the the vapor velocity is always tangential to the surface, constant in magnitude across the blade passage, and unperturbed by the droplet. Mass and energy exchange between phases is not yet accounted for; the droplet is assumed to be of constant radius. Momentum exchange between the vapor and the droplets is accounted for by assuming that the droplets are rigid spheres and using an appropriate drag coefficient based on the droplet Reynolds number, calculable from the relative velocity of vapor to droplet. This code has been completed and is now used for studies of droplet motion through turbine blade passages. The purpose is to determine the effects of inlet fluid conditions such as slip, droplet size, nozzle angle, etc. on droplet trajectories relative to the moving blade. The calculations indicate that droplets of less than 5 μ diameter can be carried through the curved blade passage by the vapor drag.

Normal and Oblique Shock Solutions

Estimates of normal and oblique shock conditions can be made for an arbitrary equation of state (in this case water) using numerical methods for simultaneous solution of the equations of continuity, momentum, energy and state. Presently; the two phase solution assumes no slip before or after the shock between phases, and for oblique shocks, the droplets are assumed to be small enough to follow the vapor streamlines.

Multivariable Constrained Optimization Techniques

Numerical optimization techniques were used to compare various ideas in the initial stages of conceptual design. These techniques will be used throughout the program for specialized equation solution as, for example, the normal and oblique shock solutions, and for design optimization once sufficiently complete numerical models have been developed.

Finite Element Analysis

In order to evaluate the stresses associated with both blade attachment and turbine wheel hub design, two-dimensional finite element analysis has been employed. We have used an LLL program, DTVIS2, which can predict stresses resulting from static as well as dynamic conditions of loading and include heat transfer and thermal effects. This code is currently in use for design of the first turbine test unit.

3. Turbine Component Development

a) Nozzle Development and Testing

As mentioned earlier, the nozzle coefficient, η , is a critical design parameter, and that the research goal is to achieve coefficients $> .9$. Very little is known about nozzle performance for expansion of low quality steam (i.e., mass vapor/total mass $< 30\%$), particularly when the flow is supersonic. There exists only a small range of back pressures for any given inlet condition over which the nozzle coefficient is a maximum. Optimizing the nozzle configuration will require extensive analytical and experimental work. Consequently, we have initiated a series of nozzle tests in the Geothermal Test Facility.

The first test series have been completed. The nozzles tested were simple conical converging-diverging as shown in Figure 6 which includes a rubber mold of the nozzle interior to show the configuration. The tests were performed to compare performance with previous data obtained by others in 1962, and to locate the optimum operating condition and to compare this with theoretical calculations. Excellent agreement between our test and past data was obtained.

Additional tests were run by holding inlet conditions constant at 400 psia and 12% quality while varying back pressure from 14.5 psia down to 2.30 psia. The results indicate, as expected, shock waves at the exit for $p_b > 6.7$ psia which results in an increase in exit pressure. At 6.73 psia an almost ideal expansion occurs (all in the nozzle), and below this value additional expansion occurs after the nozzle. Figure 7 and 8 illustrate these two cases. Figure 7 is the near ideal expansion, and Figure 8 shows the additional expansion occurring after the nozzle exit.

For each test run the nozzle thrust was measured in order to calculate thrust coefficient at each back pressure. This coefficient can be interpreted as equal to the nozzle coefficient for the range of test conditions.

The results are summarized in Figure 9 which shows a maximum at the optimum back pressure of 6.7 psia for this nozzle. This results are very encouraging since the peak value is about .93. It should be noted, however, that this is the first test series run on our Geothermal Test Facility. Many more tests will be required to establish complete confidence in reproducibility. Additional tests of these nozzles are in progress.

b) Turbine Blading Studies

The most recent and interesting experiment performed for turbine blade development demonstrates two major characteristics of the flow of high velocity two-phase fluid over blades: (1) separation of the phases as the flow proceeds around the curve of the blade, and (2) erosion of the edge of the blade.

Figure 10 shows the initial set-up, an aluminum blade with a sharp edge is exposed to the nozzle flow (left). The blade shown is not intended to be precisely representative of a turbine blade, but is used to investigate the problems of turning the flow for momentum transfer. Figure 11 is a view of the nozzle and blade during a typical run, which demonstrates that partial separation of the liquid from the two-phase flow has occurred; note the thin spray exiting the lower edge of the blade. Finally, Figure 12 shows the erosion that has taken place on the blade during a 40 minute run. (Velocities of impingement of the flow on a moving blade in a turbine will be considerably lower than encountered here.) A similar piece of aluminum with a heavy anodized coating sustained approximately the same erosion damage as shown here, but with more than twice the exposure time. These preliminary tests illustrate the nature of the erosion problem and similar tests are in preparation to evaluate various candidate materials and coatings ranging from steels to carbides and nitrides.

4. Field Testing

In order to accelerate development of energy conversion systems, the next step after laboratory testing will be to carry out field tests in an environment not dominated by severe chemistry problems. Hence, plans have been formulated for testing the first laboratory turbine unit at higher flow rates on a low salinity well. This will allow evaluation of turbine concepts at power levels up to 1MW, and provide early identification of field test problems. The most important point, however, is that this work is preparation for later joining the resolved problems of chemistry and materials to produce a brine tolerant design for testing on a high salinity well. By such parallel development efforts, the program will not be paced by progress in any single subprogram area.

Negotiations with Union Oil Company have been started for arrangements to use a well in their New Mexico development. These wells are generally high temperature/low salinity, and are suited for field testing. To support this work, we are designing a mobile test unit with instrumentations and

apparatus for measuring flow rate and quality. The capability for condensing and cooling to provide sub-atmospheric exhaust conditions will be added. All of this preliminary work is paced to allow field testing by mid FY 76.

5. Participation with Industry

In an effort to work more closely with those companies having equipment that might be suitable in a geothermal environment, we have initiated joint programs and contacts with a number of organizations.

- Terry Corporation - Contacts have been made and one partially modified turbine, to accept saturated steam, has been purchased for experimentation.
- Elliot Corporation - Contacts have been made, but lack of interest on the part of the manufacturer has terminated further discussions.
- Keller Corporation - Discussions have taken place, but as yet the Keller Corporation does not have a machine suitable for testing.
- Rotoflow Corporation - A request for quotation has been sent and received relative to a 100 KW machine that can be evaluated in the laboratory. Delivery will take one year from the placement of order.
- Hydrothermal Power Co., Ltd. - An agreement has been reached between the company and LLL to lease an existing piece of machinery, (helical screw expander) for laboratory evaluation. The testing will take place in early spring of this year. NOTE: This unit has been field tested in a low salinity environment.

III. CHEMISTRY AND MATERIALS SUBPROGRAM

One of the major problems in the development of the HT/HS resource is the control of precipitation and scale formation in surface equipment. The high temperature brines underlying the area near the Salton Sea contain as much as 26% by weight of total dissolved solids, with chlorides as the major constituents. However, the minor constituents such as silica, iron and lead are found to be the main source of scale formation as the fluid is cooled in the process of energy extraction. Both the chemistry of the brines and the mechanisms of precipitation and scale formation are very complex and not yet understood. Hence, a significant effort is underway to characterize these processes by a laboratory and field test program.

The Chemistry subprogram consists primarily of investigations into the kinetics of precipitation, brine composition, and scale formation. The goal is to use the results of these activities to develop means of precipitation and scale control for use in Total Flow conversion systems.

Since corrosion and erosion of components also pose serious problems, a second component of the chemistry subprogram consists of materials testing and selection for brine tolerant turbine components and ultimately development of economical fabrication techniques. These activities will be carried on concurrently with conversion system development, and the results of both will be combined to produce a brine tolerant conversion system.

Since the brines cannot be adequately synthesized in the laboratory, the chemistry and materials subprogram must be carried out in the field using brines under representative well flow conditions. Consequently, a research agreement has been established with the consortium of Southern Pacific Land Company, Phillips Petroleum, and Southern California Edison Company. The agreement allows LLL access to the Sinclair #4 well located in the Salton Sea Geothermal field. This is a high temperature/high salinity well, and is operated by the consortium as part of their geothermal research activities. Access to this well was started in May 1974, and has provided an early opportunity to begin our research investigations under field conditions.

A. Field Activities

1. Material Tests

One of the major advantages of the Total Flow concept is that it allows design flexibility for incorporation of scale control techniques. Since all of the pressure (and temperature) drop occurs in the nozzle of the impulse turbine, and since the transit time for passage of the fluid through the machine is in the millisecond range, precipitation and scaling may be localized or controllable both in terms of rate or location. Consequently, the first test series consisted of flowing brines through nozzles and over simulated turbine blades, or wear plates. The purpose was to provide a materials screening by post test inspection.

A wide variety of materials were tested including metals and plastics. Most either scaled or eroded, but Teflon (PFA) showed promising performance after over 100 hours of exposure to flowing brine. The two wear plates of Teflon (TFE) and Teflon (PFA) were subjected to detailed visual inspection. The TFE plate was somewhat warped with a distinct valley eroded into the plate where the stream impinged. This valley then partially filled with scale. The PFA wear plate was somewhat roughened, but suffered little erosion. Microscopic examination showed the TFE surface to be chipped in appearance with considerable debris imbedded in deep cracks and crevices. Fine hair-like projections above the surface could be seen. On the other hand, the PFA surface was smoother, appearing like rolling countryside, but with some semiburied debris. The teflon TFE hairs were examined with the Scanning Electron Microscope which revealed very fine hairs even at 1500X magnification. Crystalline growth (scaling) appeared to be taking place on some hairs. This development of a rough surface with extending hair-like structures during exposure could account for the rather poor showing of Teflon TFE, compared to the PFA.

These results are preliminary, and more testing is needed. The implications, however, are that flexible, low modulus, materials may be most suitable for producing nozzles and turbine blades resistant to erosion and scale.

Considerable field experience was gained from this first test series, and a complete redesign of the equipment has been completed and installed at the Sinclair #4 site. The new installation is shown in Figure 13 with a closeup view of the nozzle/wearplate assembly shown in Figure 14. The well has been shut-in since November and is not scheduled for operation by the consortium until March for LLL's exclusive use for completion of the second series of nozzle/wear plate tests. During March we also expect to accomplish the following:

a) Well Flow Characterization

Measure pressure, temperature, and velocity as a function of distance from the wellhead and under varying well flow rates. In order to adequately instrument the horizontal pipe, two or three more taps may have to be added. The time needed for measurements will depend on the time it takes for the well to stabilize after changing the flow rate. To cover all the flow rates of interest might take several days.

b) Brine Characterization

Using a "portable" calorimeter measure the total enthalpy of the brine. This will have to be repeated several times to determine sampling errors.

Conduct a statistical brine sampling program to determine variations in brine chemistry and their cause -- are they a result of sampling technique or does the chemistry change with time. This will be the first part of a long range program.

c) Nozzle Performance

Photograph the two-phase brine as it expands through a series of nozzles to compare the expansion of brine with that of pure H₂O at the same temperature and pressure. Here we will be using framing cameras capable of 44,000 frames/second to examine droplet size and velocity, and boundary layer behavior.

2. Brine Analysis

Three brine samples were taken on October 23, 1974 to determine the CO₂ content of the brine and to indicate the problem of sampling the two-phase flow. The samples were taken from two ports about 8.5 m from the wellhead. Samples #1 and #2 were taken from a port on the side of the brine line, while sample #3 was taken from a port on the top of the brine line. Samples #1 and #3 were quenched with water during sampling. Sample #2 was not quenched with water during sampling.

Assays for Na, Ca, and K from the October samples and earlier samples are given in Table I. The September 19 sample appears to have been contaminated with NaCl precipitation. The analysis of the October 23 sample #3 indicates it was predominately condensed steam. These results illustrate the problems associated with brine sampling.

TABLE I

Date	Sample No.	Na* x10 ³	Ca* x10 ³	K* x10 ³	Na/Ca	Ca/K
July	1	53.8	26.3	18.0	2.05	1.46
Sept. 19	1	52.0	20.2	13.3	2.57	1.52
Oct. 23	1	46.6	22.2	12.4	2.10	1.79
Oct. 23	2	52.5	23.4	13.7	2.24	1.71
Oct. 23	3	0.33	0.15	---	2.2	---

*PPM by weight

The noncondensable gases over the brine in the October samples were analyzed by mass spectrometry. The results shown in Table II indicate that the gas is primarily CO₂. Although the mass spectrometer is relatively insensitive to H₂S, it was detected in sample #3. The valves on these sample bottles were not designed for gas sampling; therefore, the pressure, volumes, and weights of CO₂ given in Table II are not reliable quantitative data.

TABLE II
Gas Analysis* of October 23 Samples

PVT Analysis

Sample No.	Liquid Volume (cm ³)	Gas Volume (cm ³)	Gas Pressure (Pa at 21.9°C)	Total Gas (cm ³ at STP)	CO ₂ (cm ³ at STP)	CO ₂ (grams)
1	800	454	10.4×10^5	4,350	4,210	8.27
2	250	1004	5.4×10^5	4,930	4,810	9.45
3	280	971	3.9×10^5	3,470	3,390	6.66

Mass Spectrometric Analysis**

Sample No.	CO ₂	N ₂	CH ₄	H ₂	H ₂ S
1	97.1	0.42	1.88	0.57	N.D.
2	97.6	0.33	1.45	0.42	N.D.
3	97.9	0.35	1.31	0.35	0.01

* Refer to gas phase only. Does not include dissolved gases.

** Percent by volume.

When the brine was drained from the sample bottles, it contained small amounts of suspended solids which appeared black in sample #1 and #2, and light grey in sample #3. Upon exposure to air an additional yellow-brown precipitate was formed, as noted in the September 19 sample.

The bottles containing samples #1 and #2 were cut open and inspected after the brine was removed. A thin layer of scale was found in each bottle which appeared as a black precipitate when removed. A total of 34.8 mg and 44.3 mg were recovered from bottle #1 and #2, respectively, which was predominately metal sulfides.

The change in pH reported in last quarter's report is now thought to be due to the evolution of CO_2 -- not the precipitation of silicic acid as reported then.

3. Scale Morphology

We have examined the scale which formed in a stainless steel nozzle during a five-day test on Sinclair #4. When the nozzle was removed from the test stand a piece of well debris was found in the throat of the nozzle, restricting its flow. The inside of the nozzle on the expansion side was coated with about 3 mm of scale. The high pressure side had a very thin coat of scale < .1 mm.

Figure 15 shows a cross section of the nozzle and scale at a magnification of 10:1. The arrow indicates the direction of brine flow. The bright areas which are pointing "upstream" in the flowing brine are metallic phases.

Figure 16 is a photomicrograph of one of these "bumps" as seen using bright field illumination. Figure 17 is the same area as seen with dark field illumination. The bright phase appears to be a dendritic growth growing into the flowing brine. The dark field illumination permits us to see the growth beneath the surface of the specimen (through the SiO_2).

Figure 18 is a scanning electron micrograph of the banded region in Figures 16 and 17. The micrograph is a 2400:1 magnification, and shows at least three phases. As can be seen by the analysis, the bright phase is predominately metal, with the SiO_2 filling in the interstices. We postulate that the metallic phase is growing in the fast flowing super-saturated brine, while the SiO_2 is being deposited out of liquid in the interstices.

The metallic phases in the scale seem to be deposited by a nucleation and growth mechanism. The initial layers next to the nozzle wall are growing perpendicular to the wall and are fairly uniform in length. We believe that the banded region was deposited when the well flow conditions were changed (the well was being operated by Southern Pacific Land Co. at that time, and we have no record of any changes they might have made). After the banded region was deposited, the large dendritic growth began to grow further, thus, changing the brine flow pattern along the nozzle wall. Finally, the metallic phases were covered with a coating of SiO_2 . We believe this final coating was deposited during the time the nozzle flow was restricted with the well debris.

B. LABORATORY ACTIVITIES

1. Materials Testing

A rather sizeable number of materials have been evaluated in 300°C hot (synthetic) brine test using stainless bombs. Some were fabricated by molding, etc., from commercial "raw" materials, and others were purchased or obtained in plate or cylinder form from cooperative manufacturers.

Among the first examined were the polyimides. Their excellent high temperature performance has aroused much interest, and at least seven polyimides, differing somewhat in type, are available at least semicommercially at relatively attractive prices. Samples of four types were tested: Dixon Meldin, DuPont NR-150, Monsanto Skybond 700, and DuPont Vespel. All either dissolved or became porous and brittle within one to three days at 300°C in brine. They will be tested for the lower temperature applications in turbine or condenser construction. A few filament-wound wear plates and nozzles have been made with the NR-150 polyimide and carbon fiber. Nozzles with different fiber orientation will be tested to allow study of this variable.

A summary of the laboratory data is shown in the attached Table III. The materials tested at 300°C are listed in two columns; those showing a loss of more than 10% in 72 hours, and those showing less than 10%. The most stable in each category are at the top of each column. The large weight gains are the result of salts which remained behind in porous structures following vacuum drying. They could not be easily washed out. Results with most of the better polymers are plotted in the graph, Figure 19.

In addition to these, PPQ and phenolic show promise. An inadvertent temperature rise to 430°C for 16 hours in one bomb test gave some interesting results. H resin and one of the Dienite Butadiene resins survived, while Teflon TFE, PBI, and another Dienite did not. Three tests have been run at about 250°C with the expected decrease in severity.

In an early field test, PPQ/carbon fiber composite samples, PPQ neat, and a polyimide sample were lowered to the bottom of a brine well in a perforated pipe along with many other materials for three months. The PPQ survived, some delamination occurred with the composite, and the polyimide became very friable, which is consistent with laboratory findings.

2. Computer Simulation of Brine Equilibria

A Fortran IV version of H. C. Helgeson's PATHCAL code is being adapted for use on LLL computers. Our version is called GEOCAL. Considerable debugging has already been done. Its present status is that it will compile, requiring about 0.6 minutes of machine time, and fits into the 7600 SCM. The controller that is generated is not able to read in all its data from a disc file, and begins output. We will be able to do trial computations soon.

TABLE III

Material Weight Losses at 72 hrs. in
300°C Synthetic Brine^{a)}

Materials Showing More Than 10% Loss
at 72 hours:

No.	Material	% Wt. Loss
33	Ryton polysulfone (40% glass)	Flowed
35	Ryton R4 neat	Flowed
3	Meldin polyimide	31
4	Epoxy/Thorne1 50S Fiber	43
1	Eckonol 900 polyester	69
2	Dexsil-201 carborane	82
7	NR150B polyimide	100
31	Skybond 700 polyimide	100
25	KS polyamide resin	100
28	NR150B polyimide	100
29	Vespe1 polyimide	100

Materials Showing Less Than 10% Loss
at 72 hours:

No.	Material	% Wt. Loss
9	Polybenzimidazole Foam	79 (gain)
8	Keramid 601/Thorne1 400 fiber	35 (gain) ^{b)}
13	HA-54 polyaromatic	6 (gain)
5	Carbon/C-fiber composite	4 (gain)
6	Teflon TFE	1 (Gain)
21	H-104 polyaromatic	0
32	Polyphenylquinoxaline/C-fiber	0
34	H-124 polyaromatic/graphite	0
22	HA-54 polyaromatic (stabilized)	1
20	Dienite X644 polybutadiene	2
27	Phenolic (Ferro Corp)	3
12	Dienite X644 Polybutadiene	5
11	Polybenzimidazole (PBI)	5
26	Dienite X556 polybutadiene	5
23	Imidite 2803 (PBI)	5
30	Dienite X643 polybutadiene	8
10	Dienite X555 polybutadiene	9
19	Dienite X555 polybutadiene	9

- a) Certain samples contained fillers which usually improve performance. This makes exact conclusions difficult, if one attempts to compare polymers where some are filled and others not. In this case, we are simply comparing materials.
- b) The 35% figure is misleading here because visual inspection showed that much of the Keramid binder was gone, leaving a porous materials capable of absorbing much salt-laden brine.

3. System Design

We have recently completed a draft of a preliminary design study of a condensing/cooling system uniquely suited for the Total Flow system. The concept involves cyclone separators downstream of the turbine to separate the vapor fraction from the high saline liquid fraction in order to limit salt carryover to the cooling tower. The vapor fraction is condensed in a barometric condenser with a wet tower for heat rejection. Only one special case has been analyzed, the results indicate that the capital investment costs may be about 45 \$/Kw for the entire unit including the cooling tower, and would add about 1 mill/kw-hr to the power sales price in order to achieve an internal rate of return of 15%. Additional work is planned to optimize the system.

IV. GEOLOGY SUBPROGRAM

A. GENERAL - HT/HS PROGRAM

1. Test Site Development

Currently, the LLL field activities are limited to work at Sinclair #4 on a non-interference basis through an agreement with the well owners. (see Chem. Sub-program) While this arrangement has been very helpful in providing an early opportunity for field work, there are limitations. The well has been shut down periodically for reasons out of our control, surface space is limited to accommodate future power plant development, scheduling of our research work is constrained by the schedule of the owners, and our research agreement must be renewed yearly. In order to broaden opportunities for accelerated field work and to prepare for the eventual construction of a 5-10 MW experimental power plant, we have surveyed the lease situation in the Imperial Valley in search of a location for an expanded test site to accommodate future program needs.

We have identified a location in the center of the Salton Sea Geothermal Field, and directly over known deposits of high temperature/high salinity brines. The site is marked on the map shown in Figure 20, which shows its relationship to the Known Geothermal Resource Areas (KGRA). The property contains 550 acres and an existing well known as State #1 which has produced brine and vapor at about 100 lb/sec with a TDS of about 22%. Other nearby geothermal wells such as IID 1, IID 2, Sinclair 4, Sinclair 3, and River Ranch have been flowed at comparable rates. This property and well site are currently leased by Imperial Thermal Products (Morton Salt Co.) from the State of California.

We are currently negotiating a contract with the help of AEC/SAN for assignment of this lease to LLL (or ERDA possibly).

The current version of the lease calls for LLL to have rights to the property for research purposes for up to 8 years. Annual rental for the property is expected to be about \$25,000. The well will cost \$50,000

per year for 5 years, and the total cost of the well could be as high as \$250,000. Estimated cost of a new well is around \$400,000. Both the annual installment for the charge for the wells and the annual rental are to be paid in advance for any given year. The agreement can be terminated by LLL (or ERDA) and the end of any year period.

In anticipation of construction of facilities for LLL at this site, a contract has been let with Design Sciences, Inc., of El Centro, California, to prepare a topographic survey of the lease. This information will be used in cost estimates for holding ponds, work pads, and roads. Preliminary plans have been set out for the construction that would actually take place when the lease is obtained.

2. Salton Sea Geothermal Field Resource Assessment

A new terminology for resource assessment has been adopted based on recommendations of the U. S. Geological Survey and the U. S. Bureau of Mines. In brief, certain key words have been defined which reflect: a) confidence in understanding of the geologic parameters which describe the resource and, b) economic feasibility of schemes to exploit the resource. Opinions about geology and economic feasibility vary a great deal, owing to lack of geologic data and to lack of specific experience bearing on economic feasibility, and LLL has also had to accept these inadequacies in making resource estimates for the Salton Trough.

To date, LLL has carried out two series of resource evaluations. These are summarized in Figure 21 and 22. The identified, demonstrated and inferred, paramarginal subeconomic resource of the Salton Trough is estimated to be of the order of 100 GWY. This resource is roughly equal to 20 times the 1972 Southern California consumption of electrical energy. Under extreme assumptions regarding the existence and recovery of the resource, the resource could be as large as 1300 GWY (4×10^{17} BTU).

In Figure 22 the recoverable energy is plotted vs. reservoir volume and volumetric energy in the reservoir, Q_r , and on the fraction E , of what energy which can be moved to the surface of the earth and converted to useful energy. The energy in the reservoir Salton Trough and on the average volumetric energy concentration, k . Volumetric energy concentration depends on the average porosity of the reservoir, specific heat of the included brine, and the difference between the average temperature of the brines of these reservoirs and the average "dump" temperature. Although the volume of the reservoirs is not known, it should not be greater than about 6000 cubic miles (which is roughly the volume of sediments in the Trough). A volumetric energy concentration of 5000 BTU/ft³ corresponds to a temperature drop. Assuming that one half the trough contains brine that could on average support a 400°F temperature drop, and further assuming E to be 0.20, the recoverable energy could be of the order of 10^{17} BTU as a maximum.

Work has begun on an LLL report explaining in detail the resource estimates that have been made to date. Resource assessments for the Salton Trough, for the Salton Sea KGRA, and for the SSGF will continue to be made as new data are acquired from other parts of the geologic program for instance, from geophysics work.

3. Proprietary and Well Data Acquisition

Proprietary data for wells drilled in the Salton Sea Geothermal Field which are data on file with the California Division of Oil and Gas ("DOG") have been collected and put in our files. Comprehensive data on well flow are not included in DOG material. However, we plan to obtain it as best we can directly from the groups who in the past operated wells in the field.

4. Subsurface Geologic Studies (and Land and Lease Ownership)

Maps on land and lease ownership have been prepared. A map showing the ownership of leases within the KGRA (cf. the field itself) is being assembled. (The major leaseholder in both settings is Southern Pacific Land Company.)

LLL has acquired a series of maps and cross-sections from Phillips Petroleum Company which show information on porosity, temperature, and certain other geologic data (e.g., depth to top of metamorphism) for most, but not all, of the Salton Sea Geothermal Field. Since maps such as these are the foundation of reliable, factually-based resource assessments, LLL has begun preparation of another series of maps showing an independent interpretation of original temperature data from the Salton Sea Geothermal field. These maps will cover a larger area than the Phillips maps. Whereas the Phillips maps show depth to a surface on which the temperature is chosen constant value, the new maps (Figure 23) will show the distribution of temperatures on surfaces at selected depths. Both series of maps should be consistent with one another, and thus the work planned will provide a check on the Phillips maps. Also, the new mapping lends itself to a different technique for making a resource assessment. This assessment will be compared with previous estimates.

Work on a map showing salinity of produced fluid, completed intervals, and total depth of wells has been started. Salinities from wells in the field range up to 330,000 ppm. No systematic variation in salinity has been observed.

5. Geochemistry

Work in geochemistry will emphasize understanding of the spatial distribution of chemical elements and mineralogical species which constitute the rocks of the reservoir, of the spatial distribution of the fluid of the reservoir, including its elemental and physical-chemical qualities, and the interaction of reservoir rock and reservoir fluid. The goal of this work is to be able to anticipate the quality of fluid that would be available to a power plant and also to anticipate any reservoir production problems owing to perturbation of the original physical-chemical environment of the reservoir (e.g., precipitation of minerals in the pore space adjacent to the well bore.)

We have only recently initiated work in this area and have defined a program in the areas of in-situ measurements of fluid properties; rock analysis including mineralogy, bulk chemical composition, and isotope chemistry; and reservoir petrology to understand the variation in reservoir chemistry and possible production problems.

6. Geophysics

Although there are many other geophysical techniques applicable to geothermal resource assessment, only refraction, temperature surveying and electrical surveying tasks are contemplated for this fiscal year. All three of these methods should yield information which will more specifically and more reliably define the resource present in the Salton Sea KGRA. There is little information on the "off-shore" part of the KGRA and special emphasis will be given to acquire data from there. Before long time power generation can become a reality, detailed investigations of this area need to be made to evaluate the viability of this resource. We have initiated a geophysical program to collect the following information.

a. Seismic Refraction Data

The purpose of this work is primarily to define the surface of the basement, and perhaps of any stocks within the sedimentary package above the basement. Contact has been made with Professor Shawn Biehler (UC/Riverside), who is to provide equipment and some personnel to run northwest and east profiles across the SSGF. No contract has been drawn up yet, however.

b. Temperature Gradients Surveys

A plan for carrying out temperature gradient surveying has been set out. Fifteen holes to depths of 200 to 500 feet are planned. Cost is expected to run in the neighborhood of \$2,000 per hole. Two firms which provide these surveys have been contacted. It is expected that a contract will be let with one of these first during the third quarter FY 75.

c. Electrical Surveys

Most explorers for geothermal resources regard electrical surveying as the best geophysical method for defining geothermal resources. Owing to the known high salinity-high temperature quality of the Salton Sea resource, special problems associated with unusually low resistivity values within the earth are expected. Consequently, plans have been made to work with Geonomics, Inc., of Berkeley, California, whose principal technical person (T. Meidav) is the only person known to have experience in the Salton Sea area. LLL is planning a contract with Geonomics, Inc., for both onshore and offshore surveying. It is expected that this contract will be let within the next six weeks.

7. Reservoir Engineering

The culmination of all earth sciences tasks is the reasonable assurance that brine of certain quality can be provided to a power plant at acceptable rates and for a given minimum period of time (e.g., 20 years). Reservoir engineering concerns: 1) the design of system of wells to provide brine to the plant, 2) an assessment of specific properties of the fluid (e.g., viscosity) and of the rock (e.g., permeability) which control fluid flow in porous media, and 3) the modeling of the transport of brine from points within the earth to the well bores. Modeling (or "simulation") of this transport system using those parameters which in fact apply to the field is the only activity planned for this fiscal year. This work consists of two parts: 1) review of the literature geothermal reservoir and engineering and 2) evaluation and use of available computer programs which can serve to model geothermal brine transport.

8. Legal and Regulatory Aspects

Regulations exist which are designed to protect the safety of workers and the general public, to assure the sensible exploitation of natural resources, and to protect the environment. Tasks associated with regulation are being handled by the Environmental Sciences Group at LLL.

Progress to date include preparation of the following draft documents:

Cohen, J. J. et al. 1975, Regulatory Considerations in the Development and Geothermal Resources

"Regulatory Aspects of Geothermal Energy Development in the Salton Sea/Imperial Valley Area", K. Tonnessen, 1975, Proposed UCID in review.

Environmental Aspects of Geothermal Energy Development in the Salton Sea/Imperial Valley Area, K. Tonnesson, 1975.

Plans have also been set in motion for satisfying regulatory requirements for LLL's activities in the Salton Area. The first goal has been to compile four documents which will be used to explain LLL's plan for activity. The documents include: 1) plot of proposed construction activities 2) air photographs of the site, 3) schedule of LLL activities at the State No. 1 site and, 4) brief explanation of the LLL HT/HS program. When the lease situation regarding the State No. 1 property appears to have gelled, we will be in a position to work effectively with the various regulatory agencies.

9. Miscellaneous

LLL has accepted roles in several short term assignments. These include helping with the II United Nations Conference on Geothermal Resources and coordinating the CCMS Non-electrical Project and Small Power Plant Project.

a. II U.N. Conference

The Geothermal Geology Group is organizing and leading two trips to the Salton Trough in connection with the conference. Logistics for the trip are virtually taken care of at this time. A guide book is also being prepared. Contributions to the guidebook have been received from all but two solicited contributors.

b. CCMS Non-electrical Project

The main goal of the CCMS Non-electrical project is to assess the status of non-electrical uses of geothermal resources throughout the world. A report is being prepared in this connection. All but two sections of the report have been written, namely, the sections on residential uses and on economics. A meeting to recommend a future program direction will be held in May, 1975. At that time, the chapter "present problems and future possibilities" will also be written.

Two other reports of interest have also developed as a consequence of LLL's involvement in the CCMS Non-electrical Project. These are "Klamath Falls Hot Water Well Study" by G. C. Culver, John W. Lund, and L. S. Svanevik, all of Oregon Institute of Technology and "Analysis for Potential Non-electrical Applications of Geothermal Energy and Their Place in the National Economy" by G. M. Reistad of Oregon State University.

The Culver et al. report clearly emphasizes the utility of downhole heat exchangers and the economic value of co-operative well drilling. (see Figure 24). This report is being issued as UCRL 13614 by LLL. The report by Reistad is valuable planning document insofar as it shows that much of the energy used in the United States could be satisfied by geothermal if it were available where needed. The main points of Reistad's report are shown in Figures 25 and 26. This report has been reviewed and revised and should be printed during the third quarter.

A contract to evaluate the possible use of the geopressure resource in certain industries was awarded to DSS Engineers of Fort Lauderdale, Florida. Although interest in this project stemmed from involvement in the non-electrical project, that work is now being regarded a part of geopressure project (which is reported elsewhere in this quarterly).

c. Small Power Plant Project

LLL is acting as pilot coordinator to develop small power plants (SPP) under the CCMS program of the NATO alliance. A contract has been joined with Rogers Engineering to provide preliminary concept designs for SPP using all conventional energy conversion equipment. Contract negotiation and monitoring will be done by A. W. Lundberg of LLL, Project Engineer of the Energy Conversion Subprogram.

The next step will be to discuss these and other NATO proposals in late Spring of 1975. Ultimately, the goal is to build a plant of 5-10 MW capacity to be used as a pilot demonstration plant.

V. GEOPRESSURE FEASIBILITY STUDY

1. Preliminary Results of Concept Definitions Study

A. geopressure energy development concept definition study is in progress. The purpose of the study is to evaluate economic feasibility of electrical power and natural gas production from the resource. The calculations are essentially complete and the text is in preparation. We have based our analysis on three basic classes of geopressure reservoirs and have selected a representative well depth, and reservoir pressure and temperature for each class. The following table lists the values used.

TABLE IV

<u>Class</u>	<u>Geopressure Zone Depth (FT)</u>	<u>Reservoir Zone Depth (psi)</u>	<u>Reservoir Temperature (F°)</u>	<u>Production Well Depth (FT)</u>	<u>Injection Well Injection (FT)</u>
I	5000-10000	5100	200	8500	5000
II	10000-15000	9100	250	13000	6000
III	15000-20000	12800	300	16000	7500

The production well casing size used in the calculations was 7" o.d. (5.92" i.d.). the injection well casing size was 9 5/8" o.d. (8.75" i.d.). Net power output was calculated as a function of wellhead pressure. Power is produced from both the pressure and temperature content of the water at the surface. Positive power output is produced from hydraulic and steam turbines while power is consumed by the cooling tower system and injection pumps. Two operating points were selected for each type of well. They represent essentially the peak power output. One is for operation where injection (reinjection) is required and the other is for operation without injection, assuming that surface disposal is allowable. Table V lists the output of an array of 15 production wells and 15 injection wells (when they are used). Natural gas, when present in the reservoir water, is assumed to be at saturation levels. The plan in the study is to sell the natural gas produced and not consume any of it for electrical production.

TABLE V

(15 Production and 15 Injection Wells)

Class	Well Depth (FT)	Operation	Wellhead Pressure (psi)	Flowrate (Million BBL/Day)	Gas Production (Million SCF/Day)	Electrical Production (MW)
I	8500	Injection	1150	.45	8.3	5.6
I	8500	No injection	700	.72	13	11
II	13000	Injection	2400	.82	24	30
II	13000	No injection	1800	1.00	29	42
III	16000	Injection	3600	1.12	46	75
III	16000	No injection	2800	1.27	52	93

The profitability of a geopressure resource development depends upon the reservoir production potential and the future price of natural gas and electricity. For the purposes of this study the reservoir parameters were assumed to be: (1) an area of 300 square miles; (2) a thickness of 500 feet; (3) a porosity of 20 percent, and (4) a maximum recovery factor of 6 percent of the in-situ water. The production lifetime will then be at least 20 years at the specified flow rates.

The 200°F, 8500 ft. deep reservoir without injection would be profitable as a gas well at a price of \$2.00 per 1000 Scf for natural gas. Net electrical power generation is probably not feasible because of the low power production potential (~ 10 MW). The 250°F, 13,000 ft. deep and the 300°F, 16,000 ft. deep reservoirs would be profitable as net electrical producers at a natural gas price of \$2.00 per 1000 Scf and electrical rate of 25 mills per kW-hr. Only the 300°F reservoir without injection would be marginally profitable as a net electrical producer without the presence of natural gas in the water.

Work has been completed on the initial \$26,000 contract with the Bureau of Economic Geology at the University of Texas at Austin. A final report has been published (Report Number ORO-4766-1). This work delineated sand body distributions of the Frio formation in an area from Corpus Christi to the Mexican border. Two promising geothermal fairways were identified that merit a more detailed study to evaluate potential test sites.

A second contract for \$40,000 has been negotiated with the University of Texas to continue the Frio formation facies analysis in the middle Texas area from Corpus Christi to the Colorado River. This study will last five months and begin January, 1975. The next step will be to supplement these regional studies with detailed site specific investigations to determine locations for drilling wells for purposed of flow testing and reservoir characterization.

The results of these geologic investigations and the system engineering study will provide the necessary information to determine the scope and program plan for geopressured resource development. Hence, the end product will be a recommendation for a national program.

VI. REPORTS AND PUBLICATIONS

1. "The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits", A. L. Austin, G. H. Higgins, J. H. Howard, UCRL 51366, April 3, 1973
2. "The LLL Geothermal Energy Development Program", A. L. Austin, Presented at the AEC Conference on Geothermal Energy, U. C. Berkeley, June 18, 1974.
3. "Some Comments on the Total Flow Method for Conversion of the Energy in Geothermal Hot Water Deposits", A. L. Austin, Presented at the Conference on Research for Development of Geothermal Energy Resources, Sponsored by National Science Foundation, Calif. Instit. of Tech., Pasadena, Calif., September 23-25, 1974.
4. "A Comparison of Methods for Electric Generation from Geothermal Hot Water Deposits", A. L. Austin and A. W. Lundberg, LLL, Presented at the Winter Annual Meeting of A.S.M.E., November 1974, Preprint No. 74-WA/ENER-10.
5. "Materials Screening Program for the LLL Geothermal Energy Project", L. E. Lorenson, Proc. of the 14th Annual A.S.M.E. Symposium, Albuquerque, N.M., February 28 - March 1, 1974. pp. 105-113.
6. "Some Elements of the Northern Gulf of Mexico Basin Geopressure Energy Resource", B. Myers, R. Nelson, J. Howard, R. Austin, UCRL 74807, Rev. 1, March 18, 1974. Presented at the Meeting of the American Association of Petroleum Geologists, San Antonio, Texas, April 2, 1974.
7. "Klamath Falls Hot Water Well Study", G. C. Culver, Oregon Instit. of Tech., UCRL 13614.
8. "Analysis for Potential Non-electrical Applications of Geothermal Energy and their Place in the National Economy", G. M. Reistad, UCRL 51747 (currently being processed for printing).

COMPARISON OF GEOTHERMAL POWER SYSTEMS

Fig. 1

Fig. 2 LLL Geothermal Program Overview

FY	74	75	76	77	78	79	80
<u>I. Chemistry and Materials Subprogram</u>							
Field Tests for Brine Characterization, Scale Control, and Materials Evaluation	—	—	—				
Component Durability Field Tests		—	—	—	—		
<u>II. Energy Conversion Engineering Subprogram</u>							
Laboratory Development and Testing of 100 KW Turbines	—	—	—				
Brine Tolerant Turbine Development and Field Testing			—	—			
Brine Tolerant Field System - 1 MW				—	—	—	
Experimental Power Plant - 10 MW					—	—	—
<u>III. Earth Sciences Subprogram</u>							
Resource Assessment		—					
Site Selection and Development			—	—			
Reservoir Engineering				—	—	—	—

TANGENTIAL FLOW EXPERIMENTAL TURBINE FOR TOTAL FLOW GEOTHERMAL APPLICATION

Fig. 3

GEOHERMAL TEST FACILITY

GEOHERMAL TEST FACILITY

Figure 5

Figure 6

Figure 7

Figure 8

Fig. 9 Nozzle Coefficient For a Conical Converging-Diverging Test Nozzle.

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

AREA #1

Mounting
Plastic

Scale

Stainless
Steel
Nozzle

Bright Field

10X

FIGURE 15

Cross Section of the Scale formed in the expanding brine from
Sinclair #4

Bright Field

70X

FIGURE 16

Dendritic Growth in Area #1 of Figure 15

Banded Area

Mounting
Plastic

SiO₂

Metallic
Phases

Dark Field

70X

FIGURE 17

Same area as Figure 16 - Dark Field Illumination

Fe, Cu, Pb, S

Ag

SiO₂

2400X

FIGURE 18

Scanning Electron Micrograph of Banded Area in Figure 17

FIG. 19

Fig. 20

SALTON TROUGH TOTAL RESOURCES

Fig. 21 Salton Trough Resources. The scheme used here follows the recommendations of the U. S. Geological Survey and U. S. Bureau of Mines. Data from deep wells (to 8000') and from shallow (200-500') temperature gradient surveying holes identify a currently subeconomic paramarginal resource of the order of 100 GWY (3×10^{15} Btu.). The inferred/hypothetical subeconomic submarginal resource is of the order of 500 GWY up to 1300 GWY for the undiscovered resource.

Figure 22

TEMPERATURE CONTOUR-4500 ft. LEVEL

T. PALMER

NOV. 1974

Fig. 23

Fig. 24 Average annual Operation Costs for Various Forms of Home Space Heating in Klamath Falls, Oregon.

Fig. 25 Heating Energy Uses in the United States in 1968 in Selected 25°C Temperature Ranges.

Fig. 26 CUMULATIVE ENERGY USE AS A FUNCTION OF TEMPERATURE OF HEATING, SHOWN IN RELATION TO THE TOTAL ENERGY REQUIREMENTS IN THE U.S.

(Note: Almost 50% of the non-transportation energy use can be satisfied by heat at temperatures below 150°C .)

DISTRIBUTION

Internal

W. Arnold
S. Bishop
C. Calder
F. Fulton
W. Gieri
F. Holzer
J. Howard
O. Krause
A. Lundberg
E. Lafranchi
E. McClure
K. Street
T.I.D. L-9 (5)

External

W. Berge
Phillips Petroleum Company
Geothermal Operations
11526 Sorrento Valley Road
Del Mar, California 92014

D. Duval
San Francisco Operations Office
U. S. A. E. C.
1333 Broadway
Oakland, California 94612

R. C. Lindwall,
Supervisor, Planning & Valuation
Union International Oil Division
Union Oil Company of California
Union Oil Center
Los Angeles, California 90017

C. McCulloch
Southern Pacific Land Company
One Market Street
San Francisco, California 94105

L. T. Papay, ScD.
Southern California Edison Company
Director Research & Development
2244 Walunt Grove Avenue
Rosemead, California 91770

Dr. L. B. Werner
U. S. Energy Research and
Development Administration
1800 G Street, Rm. 1149-D
Washington, D. C. 20545

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."