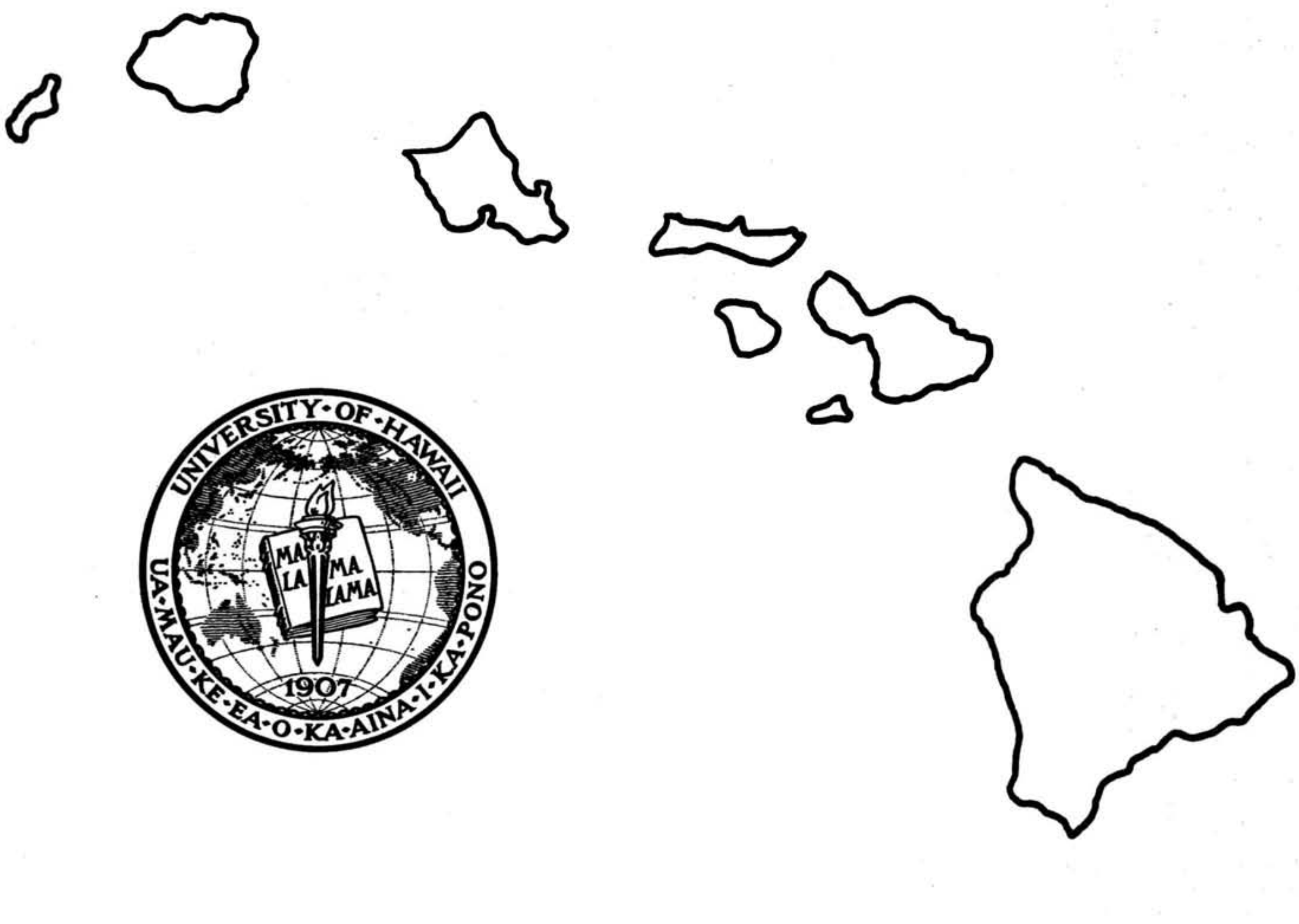
THE HAWAII GEOTHERMAL PROJECT

QUARTERLY PROGRESS REPORT NO. 1

JUNE 1, 1973 THROUGH AUGUST 31, 1973



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SUPPORT FOR PROJECT PROVIDED BY:

National Science Foundation
State of Hawaii
County of Hawaii

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University of Hawaii
Holmes Hall 240 - 2540 Dole Street
Honolulu, Hawaii 96822

HAWAII GEOTHERMAL PROJECT
PROGRESS REPORT I
June 1, 1973 through August 31, 1973

The Hawaii Geothermal Project (HGP) was organized to focus the resources of the University, the State, and the County of Hawaii on the identification, generation, and utilization of geothermal energy on the Big Island of Hawaii. The proposed research program involved an interdisciplinary team of fifty-four researchers from throughout the University system which, in collaboration with a distinguished group of advisers and consultants, was to engage in thirty-eight separate research tasks related to geothermal resources. (Refer to Table I.) These scientific investigations were grouped in the three programs: a) Geophysical, b) Engineering, and c) Environmental-Socioeconomic, and included short-range exploratory and applied technology tasks to assist in the early development of geothermal power in Hawaii, as well as long-range research studies of a more basic nature. The funding required to undertake this ambitious program came to $4,988,000 over a two-year period, which included the location and drilling of a deep test hole and initial planning for the construction of a 10-MW prototype geothermal power plant.

Rather than two-year funding at a $4,988,000 level, the HGP was successful in identifying only $452,000 for the first year's activity. $252,000 came from the NSF-RANN Program, with the State and County of Hawaii each furnishing an additional $100,000. This drastic reduction in funding necessitated a revision in program planning, so that rather than initiating all of the research tasks during the first year, only those tasks with highest priority on identification and utilization of the geothermal resource were selected. Table II summarizes those tasks included in Phase I, along with budget allocations for the various programs.

A separate budget was assigned to each of the three research programs, in order to establish technical and fiscal authority and accountability. Dr. Augustine S. Furumoto, Professor of Geophysics, is co-P.I. and Director of the Geophysical Program; Dr. Paul C. Yuen, Professor of Electrical Engineering, is co-P.I. and Director of the Engineering Program; and Dr. Robert M. Kamins, Professor of Economics, is co-P.I. and Director of the Environmental and Socioeconomic Program. Dr. John W. Shupe, Dean of Engineering, is P.I. and Director of the HGP. Assisting in planning and administration are Dr. George P. Woollard, Director of the Hawaii Institute of Geophysics, who will work closely with the Geophysical Program, and Dr. John P. Craven, Dean of Marine Programs and Director of Marine Affairs of the State of Hawaii, who will provide input to the Environmental and Socioeconomic Program. These six men constitute the Executive Committee for the HGP and meet regularly to establish overall policy and program direction.

Invitations were sent to ten potential members to serve on the National Liaison Board and eighteen potential members for the Hawaii Advisory Committee. The National Liaison Board will consist of project leaders of other RANN-supported geothermal programs, along with additional national experts in geothermal research and development. This Board will meet annually in Hawaii to review program progress, to exchange current information on geothermal science and technology, and to advise on future planning and implementation for the project. The initial meeting of the Liaison Board is tentatively scheduled for February 1974. The Hawaii Advisory Committee will provide interaction with key individuals from industry, government, citizen groups, labor, and the scientific community, whose support is essential to the introduction of geothermal power in Hawaii. The Advisory Committee will meet semi-annually, with the initial meeting tentatively scheduled for October 1973.

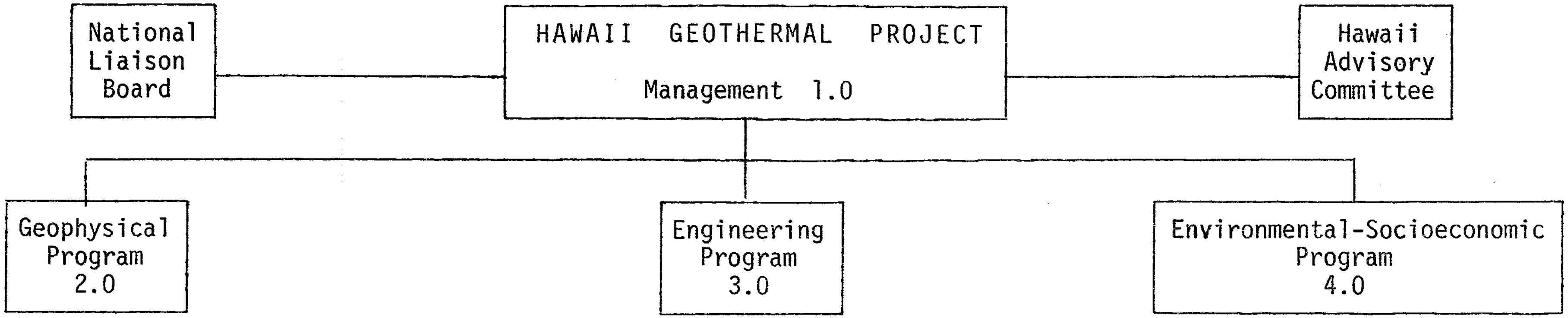
For all practical purposes the HGP got underway around June 1, 1973, and this date has been established as the beginning of the first quarter. Attached are progress reports prepared by each of the three program directors, with the page coding corresponding to the program identification appearing in Table I: 2.0 - Geophysical, 3.0 - Engineering, and 4.0 - Environmental and Socioeconomic. Subsequent progress reports will be more consistent and systematic regarding task deadlines and progress.

In addition to the activity described by the program directors, the HGP followed closely the work of Dr. George Keller, also funded by NSF-RANN, who drilled a 4,137-ft. test hole in Kilauea National Park to obtain scientific data on an apparent geothermal anomaly which he had identified through electrical resistivity measurements. The data from Dr. Keller's program is available and will assist the HGP in site selection for the deep hole.

In addition to NSF, constructive meetings have been held with such organizations as the United States Geological Survey, various groups within the Atomic Energy Commission, NASA-Ames, the State Department of Land and Natural Resources, the Attorney General's Office, the Department of Planning and Economic Development, the County of Hawaii Department of Research and Development, the Hawaiian Electric Company, and the geothermal group at Stanford University. The degree of cooperation, enthusiasm, and support from all segments of public and private interests has been most gratifying; and we retain our initial optimism that the HGP will make a significant contribution to the development of geothermal power in Hawaii.

John W. Shupe

John W. Shupe, Director
Hawaii Geothermal Project



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HAWAII GEOTHERMAL PROJECT ORGANIZATION CHART

HAWAII GEOTHERMAL PROJECT

PHASE I

BUDGET DISTRIBUTION BY PROGRAM AND TASK

	NSF	COUNTY	STATE	TOTAL
MANAGEMENT - Shupe				
1.0 Coordination	$ 25,965	$ 7,800	$ 18,100	$ 51,865
GEOPHYSICS - Furumoto				
2.0 Coordination	35,260	10,010	--	45,270
2.1 Photogeologic	23,900	--	--	23,900
2.2 & 2.4 Magnetic & Electromagnetic	51,826	10,800	--	62,626
2.3 Resistivity	14,871	30,000	--	44,871
2.5 Microseismic	20,635	8,500	50,000	79,135
TOTAL	146,492	59,310	50,000	255,802
ENGINEERING - Yuen				
3.0 Coordination	11,680	2,606	600	14,886
3.1 Well Test	20,021	--	2,273	22,294
3.2 G-H Lens	21,757	873	--	22,630
3.6 Energy from Brine	26,085	5,721	6,727	38,533
TOTAL	79,543	9,200	9,600	98,343
ENVIRONMENTAL AND SOCIOECONOMIC - Kamins				
4.0 & 4.6 Coordination & Economic Analysis	--	14,390	22,300	36,690
4.3 & 4.5 Legal & Planning	--	9,300	--	9,300
TOTAL	--	23,690	22,300	45,990
PROJECT TOTALS	$252,000	$100,000	$100,000	$452,000

HAWAII GEOTHERMAL PROJECT

QUARTERLY PROGRESS REPORT ON THE GEOPHYSICAL PROGRAM OF THE GEOTHERMAL PROJECT, NATIONAL SCIENCE FOUNDATION GRANT GI38319 AND GRANTS FROM THE COUNTY OF HAWAII AND FROM THE STATE OF HAWAII

The geophysical program of the Hawaii Geothermal Project commenced as soon as funds from the National Science Foundation, under Grant GI38319, were obtained in April 1973. The geophysical program itself is subdivided into the following tasks:

Task 2.0	Coordination of the geophysical program
Task 2.1	Photogeologic survey
Tasks 2.2 & 2.4	Magnetic and electromagnetic surveys
Task 2.3	Electrical resistivity survey
Task 2.5	Microseismic and microearthquake survey.

The present report will take into account progress up to the date of August 24, 1973.

Task 2.0 Coordination of the Geophysical Program

Task Investigator: A. S. Furumoto

The purpose of this task is to coordinate the efforts of the various other tasks in the geophysical program, including travel schedules of the various investigators, the purchasing of equipment so as to avoid duplication, the setting up of field offices and operational headquarters on the Island of Hawaii, and gathering data in one central place to expedite interpretation and evaluation.

Under the task, Mr. Carroll Dodd was hired as Electronics and Field Technician for the geothermal program. His duties include a wide range, varying from ordering and purchasing equipment and components, testing the components, assembling the various components and instruments to make a working geophysical system in the field.

Mrs. Carol Yasui was hired as Administrative Assistant and Stenographer for the geophysics program. Her duties include the processing of purchase orders, travel requests, editing the reports, establishing contact with various segments of the University and the community in regards to the project.

Another portion of the task is to set up field offices and an operational headquarters on the Island of Hawaii. As most of the field surveys during the first phase of the program will take place on the Island of Hawaii, it was found necessary to set up headquarters on the Island of Hawaii. For that purpose, an apartment in the Adult Student Housing on the campus of the University in Hilo was rented. While in Hilo, the investigators will reside at the apartment and also use the apartment as an administrative office. A telephone was installed to expedite matters.

For the actual field work, it was necessary to set up an on-site temporary field office as the Island of Hawaii is rather large and even commuting from the headquarters in Hilo to the field sites did become a time-consuming process. For a field office, a trailer was purchased in Honolulu and equipped to house equipment, desk and file cabinets. After outfitting and meeting of safety requirements, the trailer was shipped to the Island of Hawaii. It is now in full operation.

A. S. Furumoto undertook a few trips for consulting purposes. On May 17, 18, and 19, about 10 faculty members of the engineering program of the geothermal project traveled to Stanford University and to the geothermal area of Geyser 90 miles north of San Francisco. Furumoto joined the group and traveled with them. At Stanford University the group heard several presentations on reservoir engineering and on geothermal power production, using a two-phase closed system. At Geyser a field trip was undertaken to examine and look over the power plant operated by Union Oil Company and by Pacific Gas and Electric Company. The following remarks are made as an evaluation of the trip:

> The presentations at Stanford and the tour of the Geysers were interesting. The program was directed to the engineers and, as such, was of limited utility to the geophysical program. Inquiries during the presentation and tour led me to conclude that for the immediate future the geophysical program needs only to maintain the present level of contacts with the Stanford group.

Another trip undertaken by A. S. Furumoto was one to Japan. This was an extended part of a trip to the Southwest Pacific in connection with a project by the Office of Naval Research; hence, the travel funds sought for this trip was an additional $100 for air fare and per diem for about 8 days.

In Tokyo, contact was again reestablished with Japanese volcanologists. Further plans were advanced in promoting the U.S.-Japan joint seminar on the "Utilization of Volcano Energy." Detailed discussions were held with Drs. Takeshi Minakami and Kozo Yuhara on the contents of the proposed seminar.

In the city of Fukuoka, A. S. Furumoto discussed geothermal problems with Drs. Onodera and Yamasaki of Kyushu University. These two professors have been involved with the development of the geothermal power plant in Otake in Kyushu. Discrepancies of results between geological and geophysical surveys were discussed and interesting points were made. The association of geothermal sources with faults, especially normal faults, were emphasized; also, the association of geothermal sources with the basement rock, especially in andesitic areas, was discussed. The discussions were very fruitful and useful for the geophysical program in Hawaii.

Through the kindness of the Kyushu Power Company and Mitsubishi Heavy Industries, Ltd., a side trip was undertaken to visit the Otake geothermal power plant. The geological formations were explained by the people involved and the association of geological faults with geothermal sources was very evident. Faults near the geothermal sources were apparent as escarpments. The geothermal power plant in Otake is in reality only a pilot plant. As the pressure of the geothermal source is relatively low, the plant was designed as a test facility to try flashing techniques to generate electricity. The output of the power plant is only 10 megawatts and does not constitute much to the overall power requirements of Kyushu Island, which is heavily industrialized. As the power plant has proved successful in extracting electrical power from a low pressure system, the power authorities involved are now constructing a 50-megawatt plant. This new plant will use a double flash system. When the geothermal hot water reaches the ground surface, it is allowed to flash into steam at atmospheric pressure. Then the steam and water combination is allowed to travel through conduits to the power plant. At the power plant the steam part will be sent through turbines and the hot water is sent to another chamber to flash again into a partial vacuum. The double flash system will provide 25% more power than a single flash system.

The conclusions and interpretations drawn by A. S. Furumoto from these two trips are the following:

> The existing geothermal power plants in the United States utilize geothermal steam that is dry, under high pressure, and has a high rate of flow. Little refinement is needed to harness the available steam to drive turbines. The field at Geyser is a very favored geothermal field, but such convenient fields are not found so often in the world.
>
> On the other hand, the Otake geothermal field in Kyushu, Japan produces low pressure wet steam with a rather low rate of flow. A lot of thought went into designing a plant to exploit the field: the double flash system is a consideration to overcome the difficulties.
>
> The faculty at Kyushu University worked closely with the power companies in the development of the geothermal field. The geological and geophysical surveys that preceded the development and the monitoring of the field after the installation of the power plants were done by the faculty.
>
> The conclusion is that as we expect a low pressure wet steam field with a low rate of flow in Hawaii, the geophysical program should arrange a formal working relationship with the faculty of Kyushu University. A cooperative program of exchange of personnel involving joint seminars and joint field projects will be ideal. Talks along this line should be initiated in January 1974.

Task 2.1 Photogeologic Surveys
Task Investigator: Agatin T. Abbott

This section of the report was prepared by Agatin T. Abbott. The field work for Task 2.1 was accomplished between July 27 and August 4, 1973. Field work consisted of establishment of ground control stations to direct lines of flight for the aerial survey and the execution of the flight plans.

The imagery used in this investigation is infrared scanning conducted by the firm of Daedalus Enterprises, Inc. of Ann Arbor, Michigan that specializes in infrared scanning procedures. The Executive Vice President of the company and developer of this instrument, Mr. Carl Miller, accompanied the equipment to Hawaii to conduct the survey. The arrangements with Daedalus and the contract for completion of the project was negotiated with R. M. Towill Corporation of Honolulu. Towill Corporation provided the airplane and navigator for the infrared scanning flights. The flights were accomplished during times of darkness, preferably a number of hours after the sun had set, in order to minimize the effect of the sun's heat on the rocks. It is for this reason of night time flying that good ground control must be established. Students were located at key ground points along the flight paths with light sources so that the plane's navigator could guide the aircraft along the course determined by the investigator in charge.

Three principal flight paths were included in the original contract, as well as two optional flight paths which would be completed provided sufficient time remained after finishing the three principal lines. The first of three principal flight paths consisted of two parallel lines, each about 20 miles in length, along the Puna rift zone of Kilauea Volcano. The flight paths traversed the area from the National Park boundary, East of Makaopuhi Crater, to Cape Kumakahi. The second principal flight path, which is approximately 18 miles in length, began at the intersection of the National Park boundary with the highway between Volcano and Naalehu and followed the trend of the southwest rift zone of Kilauea. The line terminated at the coastline at a point two miles east of Punaluu. The third flight line was on the slopes of Mauna Loa on the southwest rift zone and consisted of a line approximately 24 miles in length which followed the southwest rift zone to the tip of South Point.

Because the principal lines were flown within the designated time, Dr. Abbott decided to exercise the options and fly two additional paths. The first of these is a path following the northwest rift zone of Hualalai Volcano. The flight path was approximately 14 miles in length and continued along the northwest rift from the summit of Hualalai to the coast line. The second optional line extended from a point about a mile to the west of the village of Kamuela and continued in a westerly direction to the coast line in the area of Kawaihae. The length of this flight path is approximately 8 miles.

The field work for this phase of the aerial photographic survey of the geothermal project is essentially complete. The data are at the present time being analyzed and plotted on topographic maps. The photographs are being developed and will be available for study in the near future.

Other than the personnel of Daedalus Corporation and Towill Corporation, three student assistants and Dr. Abbott were the only other personnel involved in this phase of the program operation.

It should also be stated here that the infrared scanning surveys made earlier in this year by Dr. George Keller in connection with a NSF program have been made available for the current project. Where applicable, Dr. Keller's infrared scanning surveys will be integrated with those of the current project.

Tasks 2.2 and 2.4 Magnetic and Electromagnetic Surveys

Task Investigator: Douglas Klein

The personnel involved in Tasks 2.2 and 2.4 are the following: Douglas Klein as Task Investigator, Gary McMurtry, and James Kauahikaua as graduate research assistants. The salaries of all the personnel are budgeted from the NSF Grant GI 38319.

Aeromagnetic surveys have been carried out over the Island of Hawaii by other projects. Some of the data have not been processed because of a lack of urgency to publish them. The data, however, are relevant to the geothermal project and so negotiations are underway to make the data available to the geothermal project.

Electromagnetic surveys use a source of electromagnetic radiation to penetrate the subsurface of the ground and a receiver at some distance away to monitor the variations of the electromagnetic radiation which are caused by changes in electric conductivity of the subsurface material. There is an inherent limitation in this type of survey in that the ground penetration is usually about several hundred feet. For greater depth penetration, a variation in the survey was introduced. Instead of a large loop as a source, a dipole set of electrodes was used as the source and electrical current was sent through the electrodes. The dipole source is a copy of the source used in the electrical resistivity surveys. The mobile receiver, however, was left unchanged.

Difficulties encountered in this task was the purchasing and assembling of proper instruments. As delivery days by the manufacturers were slow, the schedule of the task was postponed several times. The instruments were eventually assembled and field tested on the Island of Oahu. Field tests in Oahu were not satisfactory because of the large amount of high voltage transmission lines in a small island.

The personnel with their equipment moved to the Island of Hawaii on August 6, 1973. There the instruments were field tested in remote areas and bugs were eliminated. After that, surveying began in earnest. At the time this manuscript was prepared, several areas have been surveyed and data are now being processed.

Task 2.3 Electrical Resistivity Survey

Task Investigators: Robert Harvey, George Keller

As there was no faculty member in the Hawaii Institute of Geophysics who was willing to take on the task of electrical resistivity surveys for the geothermal project, the survey was subcontracted to Dr. George Keller of the Colorado School of Mines. The contract was drawn up in May, 1973, signed by Dr. Keller and by the representatives of the Research Corporation of the University of Hawaii. It was agreed that the electrical resistivity survey would be reconnaissance in nature and cover the Southeast section of the Island of Hawaii and a small section near Kawaihae in the Northwestern section of the Island.

The resistivity survey was commenced as soon as the contract was drawn up. Sixty working days were agreed to in the contract. By August 1973 the surveys were completed and by the middle of August the final report was submitted by Dr. Keller to the Research Corporation of the University of Hawaii.

The general area surveyed by the resistivity reconnaissance survey is given in the accompanying figure. Areas of anomalies of low resistivities were found along the East Puna rift. As the electrical resistivity surveys were reconnaissance in nature, no detailed depth profiling was done over the anomalous area. Depth profiling will be done by Task 2.2 and Task 2.4.

Task 2.5 Microearthquake and Microseismic Surveys

Task Investigator: Augustine S. Furumoto

The purpose of this survey is to set up seismic monitoring system over areas known to be of low resistivity anomalies or suspected areas of geothermal sources. It is suspected that a geothermal source will generate microearthquake and ground noises quite different from other ambient ground noises.

The difficulty encountered by this task has been the purchasing of seismic instruments. Many of the instrument factories have asked for 90 to 120 days of delivery time. The project has not been able to proceed as these delivery times will put the project back into the months of November and December. Using whatever seismic instrumentation gear available at the present time at the University of Hawaii, a preliminary microearthquake was carried out over one of the areas that was suspected to be of a geothermal source. Geophones were set up in a triangle form, with recording done on tape at one central location. Five days of observations were done and data are now being processed.

The present prospect for this task is that the field work will be done in November and December 1973 and interpretation in January 1974. We should be completed with the work in due time for writing the new proposal.

Augustine S. Furumoto

Augustine S. Furumoto

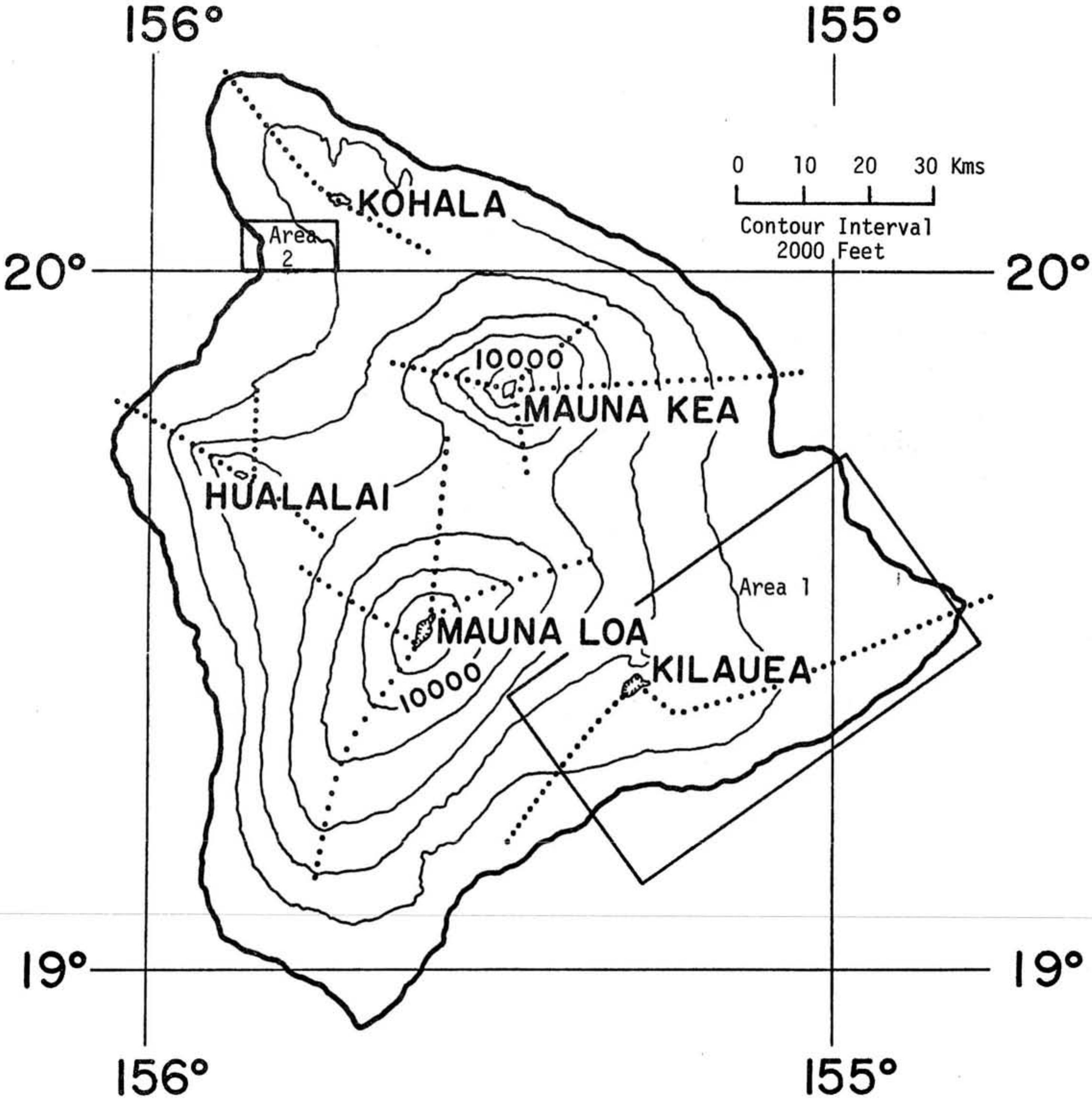

FIGURE 1. Map of the County of Hawaii showing the areas where electrical surveys were carried out. Area 1 covers the Kilauea shield in the Kau and Puna districts, while Area 2 is in the South Kohala district. Elevation contours are in feet.

HAWAII GEOTHERMAL PROJECT

Engineering Program

Quarterly Report No. 1

Summary:

The objectives of the Engineering Program are (1) applied research in problem areas related to the extraction of energy from geothermal resources, and (2) planning, design, and specification of a research-oriented, environmentally-acceptable geothermal power plant. Work is progressing currently on four of the tasks originally proposed:

Task 3.1	Well Test Analysis
Task 3.2	Ghyben-Herzberg Lens Dynamics
Task 3.6.1	Heat Exchanger and Binary-Fluid Cycle Design
Task 3.6.2	Optimal Hot Brine Plant Design

This report summarizes the milestones (A) for each task, the progress made to date (B), and the future work planned (C).

Paul C. Yuen

Task 3.1

Well Test Analysis

A. Milestones

May 19, 1973	1. Research on gas and petroleum well test analysis
June-July-August, 1973	1. Research on the nature of a geothermal reservoir and geothermal well testing
July-August, 1973	1. Initiation of an international survey on the state of Geothermal Reservoir Engineering
August 31, 1973	1. Further research on reservoir and well test analysis 2. Preliminary analysis of international survey
December 31, 1973	1. Research on the construction of a geothermal reservoir model 2. Preliminary system design of a physical model 3. Further research on geothermal reservoirs and well testing (with Geophysics) 4. Investigation to determine whether a typical Hawaii geothermal reservoir is an open or a closed system 5. Completion of analysis on international survey
December 31, 1974	1. Completion of initial phase of the fabrication of the physical model and initiation of laboratory simulation studies 2. Selection of necessary software and hardware for geothermal reservoir engineering 3. Development of a method of two-phase flow analysis
December 31, 1975	1. Analysis of laboratory simulation runs and correlation with computer model 2. Modification of physical model 3. Purchase of hardware necessary for well testing and depending on the availability of a geothermal well possibly run tests 4. Test software methods associated with well test analysis
December 31, 1976	1. Analysis of well test data 2. Projection of reservoir performance

Task 3.1
Well Test Analysis

B. Progress to Date

This task will computer model an evolving geothermal system to test the open or closed nature of a geothermal reservoir. Extensions of this initial model will be made to predict reservoir locations and well performance. The knowledge of the nature of a reservoir is necessary for a more confident and accurate prediction of well performance.

While studies are being undertaken to determine the nature of a geothermal reservoir, parallel work will be accomplished in physically modelling a geothermal reservoir and in assessing the availability of hardware and software required for well testing and analysis. Equipment and techniques will be assayed for vapor, hot-water and two-phase flow.

The parameters requiring measurement in a geothermal reservoir engineering study are:

1. Permeability-not of the microscopic rock, but of the macroscopic system; that is, fractures will most probably dominate over vesicular or layer formations in determining permeability,
2. Temperature,
3. Pressure,
4. Fluid Composition,
5. Flow rate,
6. Porosity-to obtain fluid volume,
7. Other downhole data (casing condition, scaling, etc.).

The literature abounds with descriptions of the hardware necessary for measuring these parameters. At this time it appears that the most recommended hardware includes a clockwork mechanism Amerada RPG gauge for pressure, geothermograph for temperature, and a separator with orifice meters for two-phase flow measurements. Injection rate is measured for permeability, and laboratory analysis can determine fluid composition and porosity.

With the following statement Alex Muraszen perhaps best captures the state-of-the-art of geothermal reservoir engineering : "....with the present state-of-the-art; neither the capacity of the reservoir nor its longevity can be accurately predicted." Although the methods of analysis used in the petroleum and gas industries cannot be naively applied to geothermal systems, the principles of petroleum reservoir engineering for single-phase liquid flow can be applied with certain modifications to hot water geothermal reservoirs. In the same manner, there is a kind of one-to-one analogy for the gas industry and vapor dominated wells. Unfortunately, it is appearing that the majority of the geothermal reservoirs, including those projected for Hawaii, will be steam flashed, or two-phase. Two-phase well analysis is an extremely challenging and fruitful area for research.

In summary, the types of ongoing software analytical work include:

1. Estimation of subsurface flows and permeabilities from temperature, pressure and flow data ,
2. Reservoir simulation ,
3. Well log analysis ,
4. Prediction of downhole conditions through geochemical methods .

C. Future Work

During the next quarterly period the following work is planned:

1. Completion of literature surveys on geothermal reservoir engineering and physical modelling of a geothermal resource ,
2. Initiation of a program to produce a physical model of a geothermal reservoir .

Task 3.2

Ghyben-Herzberg Lens Dynamics

A. Milestones

August 15, 1973	1. Survey of literature on the Ghyben-Herzberg lens dynamics with emphasis on coning and steady flow with heat source below 2. Survey of literature on building a physical model to simulate the Ghyben-Herzberg lens system
December 31, 1973	1. Formulation of the convection problem for a rectangular porous region 2. Finite Difference solution of the convection problem for a rectangular region 3. Formulation of the coning problem 4. Completion of a preliminary design of the physical model to simulate the Ghyben-Herzberg lens
December 31, 1974	1. Completion of the solution of the coning problem 2. Completion of the finite element solution of the convection problem for an irregular region 3. Completion of the fabrication of the physical model 4. Formulation of the problem with source and sink with heating from below
December 31, 1975	1. Completion of the solution of the problem with source and sink with heating from below 2. Completion of laboratory simulation of the geothermal process with source and sink 3. Completion of the laboratory simulation of the coning problem

Task 3.2

Ghyben-Herzberg Lens Dynamics

B. Progress to Date

The aim of the task is to predict the performance of geothermal wells under different operating conditions and to study the environmental impact of the geothermal system, especially the stability of the Ghyben-Herzberg fresh water lens when it is perturbed by the extraction of the brine below it. The results of these studies will aid in the selection of a suitable well site. Specifically, we shall address ourselves to obtaining answers to the following questions:

1. What are the heat transfer and fluid flow characteristics of geothermal systems on the island of Hawaii?
2. What is the life span of a geothermal well under different operating conditions?
3. What is the capacity of a particular well?
4. What must be the minimum depth of a geothermal well so that fresh water will not cone downwards to the well?
5. What is the effect of recharge on the performance of a well?

During this past quarter, an extensive survey of pertinent literature has been conducted. We have begun work on solving the following two problems first:

1. Free convection in a coastal aquifer with geothermal heating from below,
2. Coning of fresh water into the salt water in a coastal aquifer.

The mathematical formulation of the first problem has been completed by taking a simplified model for the coastal aquifer.

The formulation of the second problem is now in progress.

C. Future Work

During the next quarterly period we expect to complete the computer solution for free convection in a coastal aquifer with geothermal heating from below using the simplified model. The model will then be expanded so as to more closely represent the actual geological conditions existing on Hawaii. The formulation of the coning problem will be completed.

Task 3.6.1

Heat Transfer and Binary-Fluid Cycle Design

A. Milestones

September 30, 1973

1. Heat Exchanger Research-literature search and survey of state of the art
2. Binary-Fluid Cycle Research-literature search and survey of the art (acquisition of tables of properties of likely candidate secondary fluids)

December 31, 1973

1. Heat Exchanger Research-decisions as to characteristics of heat exchanger to be studied in detail
   a. heat exchanger configuration (shell and tube, cross flow, long tube counter flow, or reboiler)
   b. tube orientation (vertical or horizontal)
   c. tube arrangement (in-line or staggered)
   d. kind of tube (bare or finner)
   e. whether hot brine or secondary fluid is to be circulated inside the tubes
2. Binary-Fluid Cycle Research-identification of the principal parameters to be considered

March 30, 1974

1. Heat Exchanger Research-detailed design of a test heat exchanger and ordering of equipment
2. Binary-Fluid Research-completion of digital computer programming

June 30, 1974

1. Heat Exchanger Research-initiation of construction of heat exchanger and test set-up
2. Binary-Fluid Cycle Research-update program as heat exchanger specifications are made more detailed and study of effect of insertion of auxiliary equipment on cycle efficiency with an eye toward improving cycle efficiency

Task 3.6.1

Heat Transfer and Binary-Fluid Cycle Design

B. Progress to Date

During the first quarter efforts were directed toward a survey and review of the pertinent literature covering the last fifteen years in order to ascertain the current state of the art of power generation using secondary (low boiling point) fluids. The particular categories of interest surveyed were:

1. Thermodynamic and transport properties of candidate fluids
   These properties and the means of computing them are generally available in the open literature. However, as most of these fluids are manufactured for use in refrigeration cycles, properties at the higher pressures and temperatures are sketchy. Empirical equations of state have been proposed and correlate fairly well but the stability of these fluids at high pressures and temperatures must be scrutinized more closely.
2. Heat transfer and pressure drop characteristics of heat exchangers
   Much of the research on boiling reports in the open literature is confined to heat transfer from single tubes. Of more direct applicability would be boiling heat transfer from tube bundles but it appears that much of this desired information is proprietary to to firms manufacturing heat exchanger equipment. In applying these single tube correlation equations to bundles of vertical tubes, the diameter of a single tube will be replaced by the equivalent hydraulic diameter of the cross-sectional area of flow outside the tubes. When horizontal tube bundles are considered, it is more difficult to apply single tube correlation equations. The effects of bubble agitation and bundle configuration (in-line or staggered) are not well known and correction factors to account for these parameters must be determined.
3. Scale formation: its effect on heat transfer and means of controlling
   Current practices in the control of scale formation are being studied; viz., the effect of various parameters such as pressure, temperature, fluid velocity, and concentration on the rate of scale deposition. A more intensive study will be made after preliminary analysis of well water composition becomes available.

4. Secondary fluid power cycles

   Motive power generation using a secondary fluid has seen limited application thus far. Among the better known examples are the Paratunka geothermal plant in Kamchatka, USSR, and the exhaust heat recovery system at the Japan Gas Chemical Mizushima plant. These are first generation, simple Rankine power cycles designed especially for a single specified heat source.

   Other theoretical analyses of simple Rankine cycles using different working fluids have been made and these show that ideal thermal efficiencies will probably be in the 20%-30% range. Of interest are the existence of minimum values as well as maximum values of efficiencies for various turbine inlet conditions. While these analyses indicate general trends, there is a need for a more systematic analysis of means of improving cycle efficiencies. Among these possibilities are the use of a reboiler and the flashing of the available hot brine before using it to vaporize the secondary fluid.

C. Future Work

Based on the background information studied thus far, during the coming quarter, broad design information will be obtained on the following subjects:

1. Hot brine circulated inside or outside tubes ,
2. Bare or finned heat exchanger tubes ,
3. Spacing and configuration of tubes (vertical or horizontal, in-line or staggered arrangement) within a bundle ,
4. Effect of agitation by bubbles on heat transfer and pressure drop on upper rows of tubes if horizontal configuration is used ,
5. Means of calculating average heat transfer coefficient and pressure drop in the event multiple boiling mechanisms (nucleate, film, annular, mist boiling) are present in the tube bundle ,
6. Use of modifications of the basic Rankine cycle as various combinations of brine temperatures and working fluids are used ,
7. Specification of pressures and temperatures within modified Rankine cycles .

Task 3.6.2

Optimal Hot Brine Plant Design

A. Milestones

December 31, 1973	1. Compilation of a list of characteristics of the major components of power plants, thermal properties of fluids 2. Completion of heat balances
April 30, 1974	1. Completion of specification of engineering data required for well site location
December 31, 1975	1. Completion of a conceptual design of a prototype research plant and assist a mechanical engineering contractor to complete the final design

Task 3.6.2

Optimal Hot Brine Plant Design

B. Progress to Date

The convecting fluids which carry heat from geothermal reservoirs to the surface usually consist of steam, liquid water, various dissolved solids and gases in a wide range of temperature and pressure. Because of non-uniformity of the fluid, the methods of using geothermal energy for power production differ from one plant to another. The current methods have been surveyed:

1. Non-condensing steam plant (Fig. 1). Steam from wells is sent through a cyclone separator and admitted to the turbines which exhaust to the atmosphere ,
2. Condensing steam plant (Fig.2). This type of plant is suitable for steam with gas content up to 8 to 10 per cent. At the Geysers, California, the natural steam contains about 1 per cent gases ,
3. Condensing plant using secondary steam (Fig. 3). The steam is used to heat the secondary steam in a heat exchanger, and the secondary steam operates in a closed cycle for power generation ,
4. Condensing turbines using flash steam (Fig. 4). The liquid-dominated field is filled with compressed hot water that does not become steam until the pressure is released ,
5. Binary-fluid cycle plant (Fig. 5). The possibility of using a secondary fluid such as Freon or isobutane as the working fluid has been well explored and small Freon plants have been built in Japan. San Diego Gas and Electric Company is testing a 9 mn isobutane plant at Imperial Valley, California.

C. Future Work

The collection of information on currently operating geothermal plants will be continued. Special emphasis will be placed on areas and characteristics which are applicable to Hawaii. Engineering data needed for making a decision on the selection of a well site will be obtained and will include information such as well diameter, casing, pumps, etc.

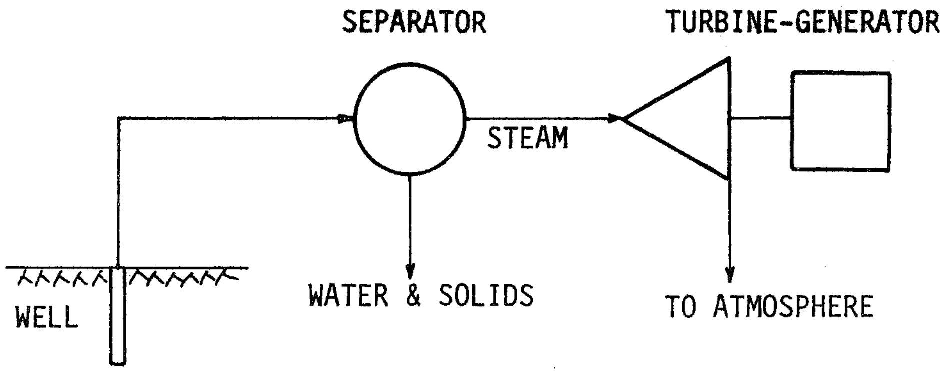

FIG. 1 NON-CONDENSING PLANT

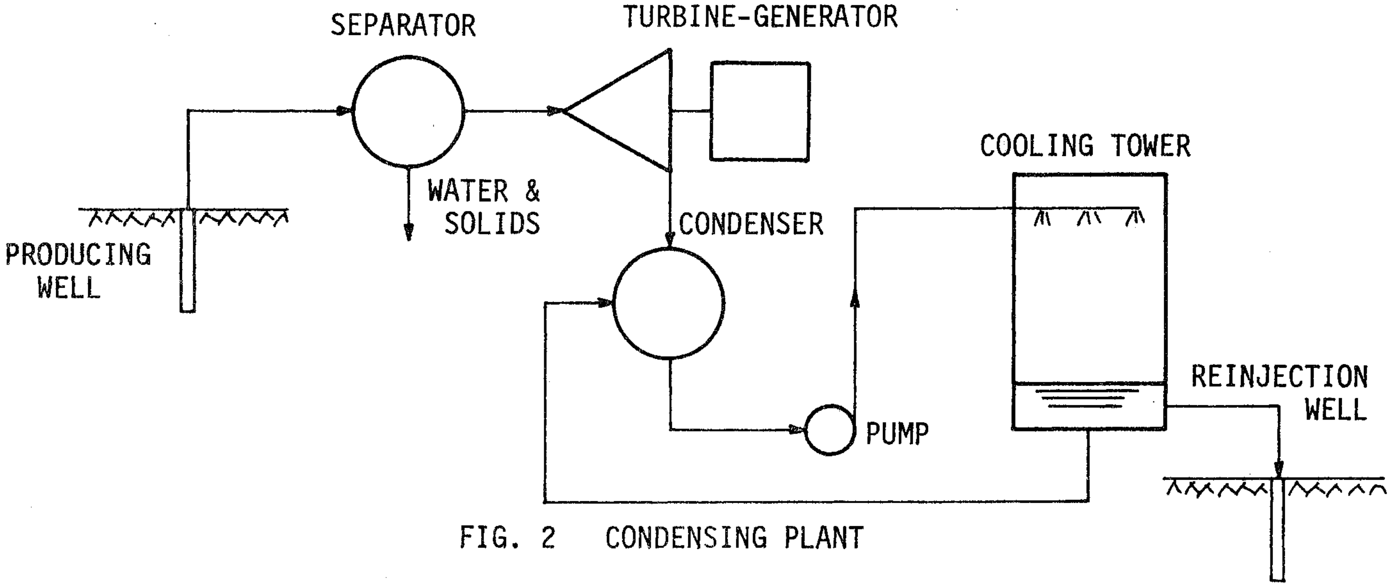

FIG. 2 CONDENSING PLANT

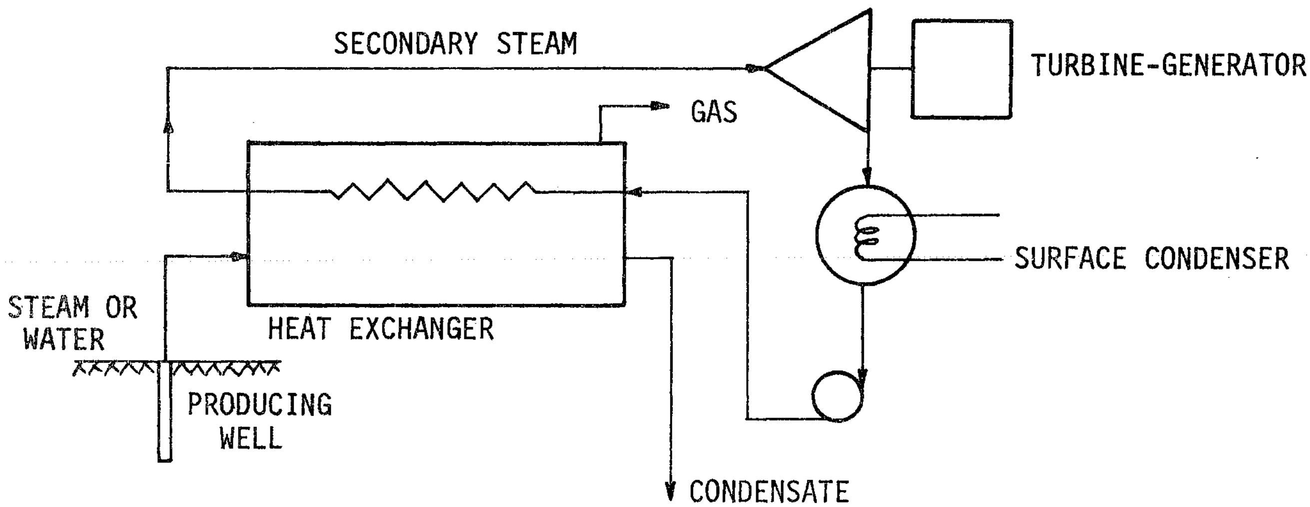

FIG. 3 CONDENSING PLANT USING SECONDARY STEAM

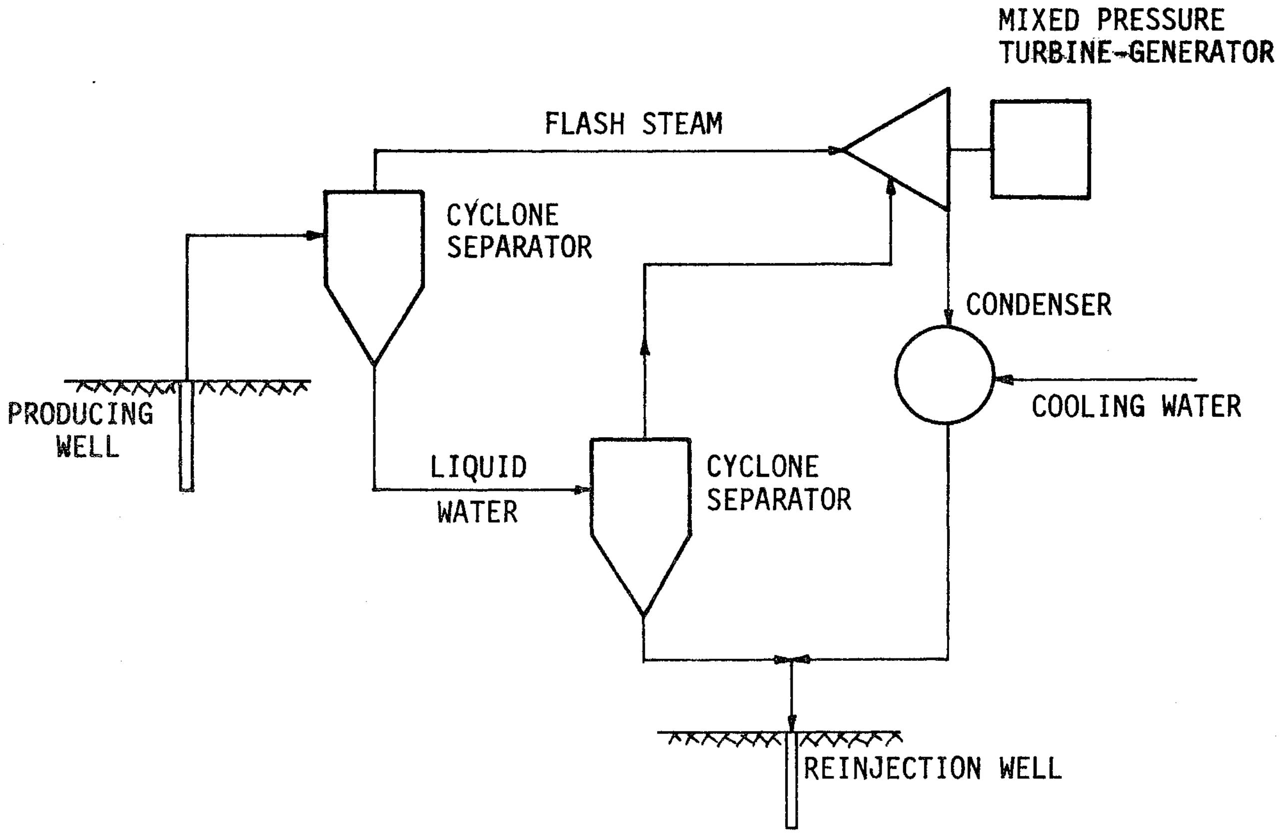

FIG. 4   CONDENSING TURBINES USING FLASH STEAM

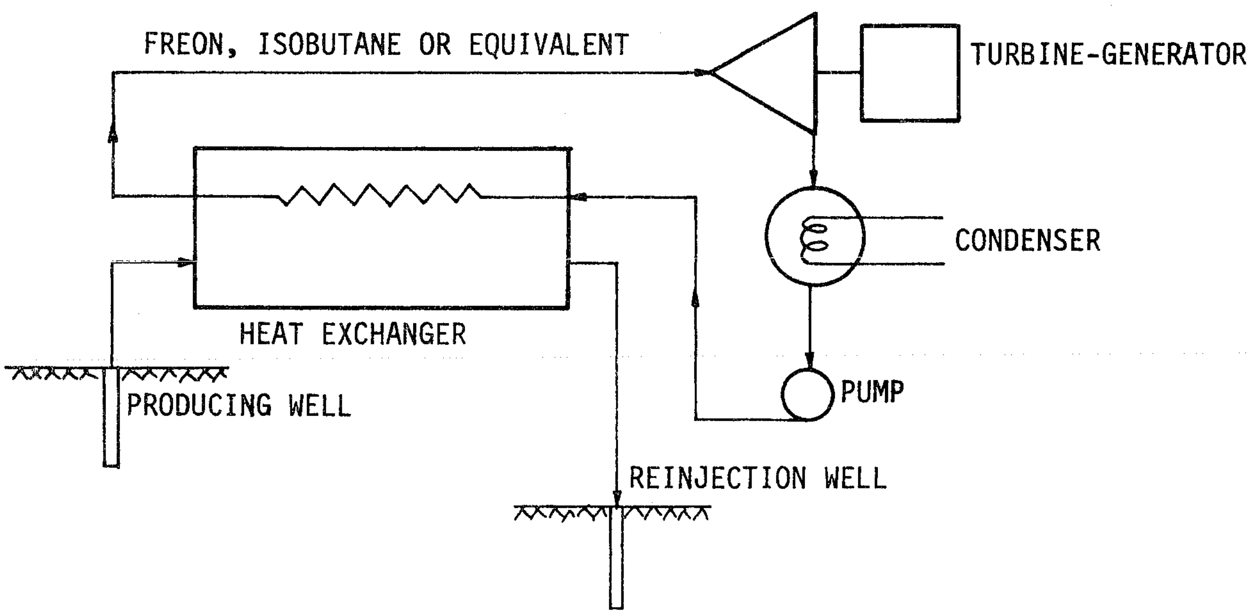

FIG. 5   BINARY CYCLE PLANT

ENVIRONMENTAL-SOCIOECONOMIC-LEGAL TASKS

The initial concentration has been on the legal aspects of geothermal energy resources in Hawaii, namely, investigation of the laws of the State which bear upon the ownership of the subterranean resources and the legal constraints on their exploitation, including regulation of commercial companies tapping geothermal energy for generating electrical power. To this end, we are consulting with the Office of the Attorney General of the State of Hawaii in the search of statute and case law which may be applicable to this new energy source.

A survey of the laws and regulations relating to geothermal power in force, or being promulgated, in the twelve Western states other than Hawaii is underway. To help analyze and apply to Hawaii the legal arrangements of mainland jurisdictions, the project has retained as a consultant David N. Anderson, Geothermal Officer in the Division of Oil and Gas in California, the first area in North America to experience the production of energy from geothermal sources on a commercial scale.

Initial contacts have been made with the Hawaii State Department of Land and Natural Resources, the agency with overall responsibility for developing and safeguarding both surface and subterranean resources throughout the State. The chairman of the departmental board recently extended us an invitation to work with the Divisions of Land Management and of Water and Land Development, the units most directly concerned, and we are now arranging for on-going consultations.

A close relationship has existed from the initiation of this project with the County of Hawaii, and particularly the Mayor and the Director of the Department of Research and Development. We are exploring ways of meeting a near-term problem the County may face, namely, how to deal with proposals to do speculative drilling for geothermal power, or to lease lands for this purpose, in advance of geological explorations and the enactment of laws or adoption of regulations establishing the rules of the game.

Economic research is beginning with data gathering. An array of statistics necessary for analyzing the economic potential for the County and the State of Hawaii have been identified and collection of data has begun. At the same time, we are preparing a questionnaire to be sent to the geothermal areas -- The Geysers, California; Larderello, Italy; Matsukawa, Japan; Wairakai, New Zealand; Cerro Prieto, Mexico -- where electricity has been produced to ascertain costs of production and value of output. The sample is small, but the data, hitherto not gathered, may be informative to economic analysis.

No funding has been provided for studies of the environmental effects of geothermal energy use in Hawaii. However, in the past few months there has been a growing feeling of urgency that base-line measurements be made of the quality of water and air in the areas most likely to be affected by the development of this new power source. We are therefore looking for resources to begin these measurements in good time, should there be an attempt to move precipitously toward geothermal development on private lands.

TASK SCHEDULE FOR LAST QUARTER OF 1973:

Task 4.3
Legal Aspects

- Lay out alternative approaches to the law governing geothermal resources: analogous to water? to minerals? *sui generis*?
- Complete survey of Hawaii law relating to geothermal resources.
- Analyze legal/regulatory provisions of mainland states relating to geothermal resources.
- Draft interim provisions for dealing with proposals for developing geothermal energy.

Task 4.6
Economic Aspects

- Obtain, collate, and begin analysis of economic data of County and State of Hawaii relevant to geothermal development.
- Obtain, collate, and analyze economic data from areas of world where geothermal production is operative.
- Adopt existing input/output and econometric models of Hawaii economy to application for projecting impact of geothermal power in hypothetical quantities and costs.

Task 4.1
Environmental Aspects

- Attempt to find resources to establish base-line conditions for air and water in areas of probable geothermal exploration.

Task 4.0

Management Aspects

- Support and coordinate the activities of the six persons engaged in the foregoing tasks; keep in communication with appropriate State and County agencies; brief State and County executive officers, legislators, and other interest public officials of progress of Task, of legal problems posed, and public policy issues raised.

Robert M. Kamins

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