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PROCEEDINGS
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GEOTHERMAL RESERVOIR ENGINEERING

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PROGRESS REPORT ON THE DOE/DGE/LBL RESERVOIR ENGINEERING AND SUBSIDENCE PROGRAMS

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THE GEOTHERMAL RESERVOIR ENGINEERING MANAGEMENT PROGRAM
(Including projects continued from the former NSF-RANN Geothermal Program)

Fiscal year 1978 was the second year of LBL's responsibility for the Geothermal Reservoir Engineering Management Program ("GREMP") on behalf of the Division of Geothermal Energy of the Department of Energy.

The history of this program through FY 1977 is explained in LBL's Earth Sciences Division Annual Report for 1978. Administrative highlights of the program in FY 1978 are as follows:

1. All projects started under the NSF-RANN program were continued. These include work done at Stanford University; Princeton University; Systems, Science and Software; University of California at Riverside; and the University of Colorado. All of these programs were further extended into FY 1979 with the exception of the University of Colorado who chose to conclude their program.

2. Seven new projects were started. These projects are indicated in Table 1.

3. The Division of Geothermal Energy re-emphasized its concern that all projects under the GREMP program clearly and directly relate to DGE's "power-on-line" mission. The Review Task Force originally constituted to overview the GREMP program was dissolved, and plans were made to assemble a new task force. LBL was urged to solicit industry to assure that there is Federal support of research to all reservoir engineering-related technical "hangups" to "power-on-line." LBL was requested to revise and update the original GREMP planning document (LBL-7000).

4. With the exceptions noted below, all project areas of the original GREMP plan have been addressed as have all known serious technical reservoir-related impediments to geothermal resource development,

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e.g., formation damage during drilling. Important projects that have not yet received this full measure of support are work on mass flow measurement techniques, on use of tracers, and on decline curve analysis, particularly enthalpy decline curve analysis. Also, in keeping with the recommendation of the Review Task Force, essentially nothing has been done on economics and on exploitation strategies.

5. A so-called GREMP publication series was started. Henceforth all reports prepared under GREMP contracts will be published or reprinted as part of this series. S^3's summary of the Wairakei field and Terra Tek's bibliographic review will be the first two publications of this series.

6. The program began issuing a "Newsletter." The first was issued Aug. 1, 1978; the second, Nov. 3. The purpose of the newsletter is to summarize the highlights of progress in research and to direct readers to new, complete reports on the research. The newsletter is available by requesting addition of one's name to the GREMP Newsletter mailing list.

7. A plan for support of new work in the GREMP program through FY 1980 has been developed. The plan is shown in Figure 1.

Technical and scientific progress accomplished during the year can be related to five work areas. These work areas and the contracts within them are shown in Table 1. Brief sketches of these contracts and their achievements are shown in Table 2.

Technical progress on the program has been very satisfactory. Worthy of special note are the following accomplishments:

1. Completion of a comprehensive bibliographic review of the literature pertaining to geothermal reservoir exploitation (Terra Tek).

2. Development of a quantitative model of a prototype geothermal resource, namely one dominated by a vertical fault (University of Colorado).

3. Compilation of the entire production history of an important liquid dominated geothermal reservoir, namely Wairakei (Systems, Science and Software).

4. Increasing awareness of the importance of lithology logging as a practical tool during drilling of geothermal wells (University of California at Riverside).

5. Meeting for the third time at the annual Stanford Geothermal Workshop. This Workshop has become the outstanding public forum for exchange of ideas and information in geothermal reservoir engineering.

Table 1. GREMP MAJOR PROGRAM AREAS AND CONTRACTS

PROGRAM AREAS	CONTRACTS
1. Status of Geothermal Reservoir Engineering	A. Terra Tek* - review of the literature in geothermal reservoir exploitation engineering.
2. Measurements of Interest to Exploitation Engineers	A. Measurement Analysis Corporation* - review of the status of instrumentation to make measurements of interest to reservoir engineers, e.g., temperature, mass flow rate, etc.
	B. UC/Riverside - use of mineral species as an indicator of reservoir temperatures; use of stable isotopes to determine temperatures and total fluid flux throughout the reservoir.
	C. Battelle Memorial Institute/Pacific Northwest Laboratory* - measurement of well head enthalpies on a real-time basis.
	D. Terra Tek* - measurement of non-condensable gases, particularly carbon dioxide, in the flow stream on a real-time basis.
	E. Stanford University - techniques for measuring saturation and relative permeability and for use of natural tracers (radon) in reservoir studies; rock to fluid heat transfer; thermal stress cracking.
3. Analytical Tools	A. Terra Tek* - analysis of near-bore formation damage as a consequence of mud-type, and drilling and completion practices.
	B. Republic Geothermal Incorporated* - analysis of calcium carbonate precipitation in the near bore area due to inappropriate pressure drawdowns there.
	C. Stanford University - development of parallelpiped models for use in well testing to obtain lumped reservoir properties; decline curve analysis; incorporation of high non-condensable gas content into analytical mathematical models.

* New contract in FY 1978.

Table 1 (continued)

PROGRAM AREAS	CONTRACTS
3. Analytical Tools (cont'd)	D. Intercomp* - development of analytical techniques for interpretation of wellhead temperature, pressure, and mass flow rate data when the reservoir is in part in two-phase flow.
4. Forecasting Reservoir Performance	A. Princeton University - codes for the simulation of mass and energy transport in fractured reservoirs.
	B. University of Colorado - analytical model for mass and energy transport in a half space characterized by a vertical conduit (i.e. fault).
5. Synthesis of Data and Applications of Forecasting and Analytical Tools	A. Systems, Science and Software - synthesis of data for the Wairakei geothermal field.
	B. Stanford University - synthesis and analysis of data from the Travale-Radicondoli field and the Bagnore field.
	C. Systems, Science and Software - analysis of production history of the Wairakei field.
	D. University of Colorado - application of analytical model to the East Mesa field.
	E. University of California at Riverside - synthesis of subsurface geology based on lithology logging at the Cerro Prieto field.

* New contract in FY 1978.

TABLE 2. GREMP CONTRACTS - STATUS AND RESULTS

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
1. Status of Geothermal Reservoir Engineering	A. Terra Tek - • The objectives of this contract have been to develop an annotated bibliography, narrative review and thesaurus of geothermal reservoir engineering in a broad sense. Literature in English, Russian Italian and Japanese has been searched using computer search services, abstracts, and index services. Topics include: analytical modeling, numerical modeling, physical modeling, formation evaluation (including well testing and case studies, but not well logging), exploitation strategies (including production-disposal strategies, stimulation, well spacing), and interpretation of production trends (including isotope analysis, heat and mass flux histories, and tracer injection techniques). • There has been a need to gather together and synthesize the literature pertaining to reservoir engineering in order to understand more clearly where this technology and science now stands and accordingly to plan more effectively for support of research in the future. • The contract has essentially been completed as of December 1, 1978 and a report (the second in the GREMP series) which includes thesaurus, annotated bibliographic entries, and short narrative review has been prepared.
2. Measurements of Interest to Exploitation Engineers	A. Measurement Analysis Corporation - • The objective of this project is to evaluate measurement needs and existent measurement methods for geothermal reservoir related parameters, including permeability, flow rate, particulate count, conductivity, density, void fraction, quality, pH and others. • There is a need to determine what measurements are sought and desired in the geothermal resource exploitation community and to evaluate the current capability to make those measurements reliably.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
2. Measurements of Interest to Exploitation Engineers (cont'd)	• To date the contract has reported high interest in detection and measurement of fractures and in a non-fouling temperature probe. Mass flow measurement and enthalpy measurement at the wellhead appear to be of lesser interest. B. UC/Riverside - • An objective of the program at UC/Riverside is to map mineral assemblages and other indices of temperatures in order to determine the maximum temperatures to which the strata in a geothermal reservoir have been subjected. • Although supported originally as a topic of basic research, this task of the UC/R program has turned out to have appreciable practical value as a guide to decisions regarding progress of drilling toward zones sufficiently hot to be interesting economically. • UC/R has reported its results in many publications among the most recent being publication of UCR/IGPP 78/8, 78/9 and 78/10 in the proceedings of the Hilo Geothermal Resources Council meeting in July 1978. C. Battelle Memorial Institute/Pacific Northwest Laboratories - • The objective of this study is to evaluate calorimetry systems that will permit economical, reliable and accurate measurement of enthalpy values at the geothermal wellhead. • The saleable product from a geothermal well is the energy contained in the wellhead fluid. The energy content per mass unit passing from the well should therefore be known. Furthermore for power plant design purposes it is important that enthalpy of the wellhead product be known as a function of time. • The project began November 1, 1978, and Phase 1 is to conclude on March 30, 1979.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
2. Measurements of Interest to Exploitation Engineers (cont'd)	D. Terra Tek - • The objective of this project is to develop a simple and convenient instrument to measure non-condensable gases on a real-time basis in geothermal discharges. • Information on the non-condensable content in the flow stream is needed in order to estimate the power potential of a well and reservoir and also to design power stations. • A draft final report on the instrument design has been written. Construction of the instrument should begin following design approval. Laboratory and field testing are scheduled for completion by September 1979. E. Stanford University - • Among the many objectives of this program is a project to better understand the petrophysics of rock/high salinity fluid systems including: - techniques for measuring liquid content in brine/steam systems using a capacitance probe. - effect of salinity on surface tension and related phenomena. - effect of temperature on permeability and relative permeability. • Also, a project to evaluate the utility of radon in understanding geothermal reservoir behavior and response during production. • Also a project to evaluate heat flux from collections of rock fragments of various shapes and sizes to geothermal fluids. • Also a project to evaluate thermal stress cracking in rocks of known geometry. • All these projects are necessary in order to understand the fundamental behavior of mass and energy distribution and transport in geothermal reservoirs.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
2. Measurements of Interest to Exploitation Engineers (cont'd)	E. Stanford University (cont'd) - • Stanford has issued annual reports and topical reports on their findings.
3. Analytical Tools	A. Terra Tek - • The objective of the project is to evaluate the consequences of mud-type and drilling and completion practices on the development of a "baked" skin around the well bore. • It has been proposed that several geothermal wells have been essentially non-producing because of formation damage in the near-bore area as a consequence of standard drilling and completion practice applied to very high temperature environments. • To date Terra Tek has acquired some core material, has begun evaluation of operating practices and choices for mud, and has begun conceptualization of a laboratory program to simulate formation damage in order to understand the factors controlling it.
	B. Republic Geothermal Incorporated - • The objective of this program is to empirically evaluate the consequence of pressure drop in the near bore area on the precipitation of carbonate minerals from calcium carbonate carbon dioxide rich geothermal fluids. Such fluids are to be flushed through core by a pressure differential. • Carbonate precipitation is well known as a fouling agent in geothermal wells and is suspected to be a cause of impaired permeability around well bores. • The contract is about to begin.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
3. Analytical Tools (cont'd)	C. Stanford University - • Among the many activities underway at Stanford is a project to develop analytical mathematical models for well response of wells drilled into a parallelpiped, the shapes of which can be suitably and quickly changed in order to approximate the geometry of all or part of a reservoir. • There is an advantage to reservoir analysts to have available to them a suite of rapidly solvable analytical mathematical solutions. Review of pressure signatures for well tests with respect to various choices of these models can lead quickly to perspective on the intrinsic parameters and the possible geometries a reservoir may have. • Stanford has used these models to analyze data from certain Italian fields. • Decline curve analysis and treatment of non-condensables in analytical mathematical models have also been addressed in the program. D. Intercomp - • The objectives of this project are to develop an understanding of well testing under situations where there is two-phase flow in the reservoir and to explain, if such is possible, how analysis based on single phase reservoir analysis need be modified to account for the presence of two phases in the reservoir. • The consequence of two-phases present in the reservoir need to be understood in order that they can be properly taken into account when estimating reservoir parameters. • The contract started at the beginning of the fiscal year.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
4. Forecasting Reservoir Performance	A. Princeton University - • There are multiple objectives to this project, the general objective of which is to improve the methodology for geothermal reservoir simulation. Particular objectives include: - development of non-isothermal three-dimensional, two-phase code for heat transport in fractured geothermal reservoirs. - investigate (using finite element techniques) the solution of transient partial differential equations of special importance to such a code. • There has been a great deal of interest in a capability to simulate and forecast geothermal reservoir performance, particularly for fractured reservoirs. • Princeton has made significant progress in the formulation of the theoretical basis for the code and has developed certain important codes and subroutines particularly those useful in solving non-linear coupled PDE's. B. University of Colorado - • The objective of this project has been to develop a semi-analytical model for naturally occurring mass and energy transport in a half space in which the system is charged at some depth within an imbedded vertical conduit (i.e., fault). The model has been applied to the East Mesa field, California. • There has been and continues to be interest in understanding prototype models of geothermal reservoirs. The project has developed one such model. • The project has ended with publication of a final report.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
5. Synthesis of Data and Applications of Forecasting and Analytical Tools	A. Systems, Science and Software ("S^3") – • The objective of this project was to compile all possible reservoir related data on the Wairakei field, New Zealand. • Interest in case histories for purposes of sharing experience and as opportunities for use in history matching with simulators, etc. has always been evident in the development of geothermal resources. • This project has been completed, and both a comprehensive report and executive summary report have been issued. B. Stanford University – • Among the objectives of the Stanford program are activities to synthesize certain data from the Larderello area, Italy. Stanford investigators have, for example, constructed for different times in the development of the field in the Larderello vicinity, pressure maps of the fields and graphs of reservoir static pressures vs masses produced. • Many people interested in vapor dominated reservoirs have also expressed interest in learning from the experiences in the Italian fields. • The project has issued quarterly reports as well as specific reports at the Italian/Larderello-1977 and Stanford-1976 and 1977 workshops. C. Systems, Science and Software ("S^3") – • The objective of this project of S^3, which is a continuation of their earlier work on data compilation at Wairakei, is to construct a geologic model of the field and to match production and subsidence history in the field from 1953 to 1976. S^3 will also forecast future production from the field under different assumptions for the imposed production rates.

Table 2 (continued)

SUBJECT AREA	CONTRACT AND STATUS AND RESULTS
5. Synthesis of Data and Applications of Forecasting and Analytical Tools (cont'd)	C. Systems, Science and Software ("S^3") (cont'd) - • Because of its exceptional data base, Wairakei offers an unusual opportunity for reservoir simulation. • This project was initiated in September 1978 and is to conclude in May 1979. D. University of Colorado - • The University of Colorado has applied an analytical model (described above) to the East Mesa reservoir in order to gain insight into the natural phenomena that may have lead to the occurrence of the geothermal resource there. • This project has been completed. E. University of California at Riverside - • An objective of the UC/R program is to develop an advanced model of the subsurface geology in the Cerro Prieto field, noting in particular the distribution of temperature, porosity and temperature related mineral assemblages. • This project is a significant part of the cooperative Mexican-U.S. project to elucidate the Cerro Prieto geothermal resource. • UC/R continues to issue reports on a regular basis.

Figure 1

PLANNED GREMP PROJECTS AND RFP SCHEDULE FY '79/80

GREMP CATEGORY	SUBJECT	RFP/CONTRACTOR	TYPE OF CONTRACT	FY 1979 1	FY 1979 2	FY 1979 3	FY 1979 4	FY 1980 1	FY 1980 2	FY 1980 3	FY 1980 4
New Contracts											
I. Well Testing	Decline curve analysis	FY 1979 RFP	Competitive (FP)	+ — •	——	——	——	——	——	Δ	
	Two-phase mass flow	FY 1979 RFP	Competitive (FP)				•	——	——	Δ	
II. Geochemical-technical	Tracers to follow flow	FY 1979 RFP	Competitive (FP)	+ — •	——	——	——	——	——	Δ	
	Trace element studies	FY 1978 RFP	Competitive (FP)	•	——	——	——	——	——	——	Δ
III. Properties of Materials	Permeability/porosity from cuttings	FY 1979 RFP	Competitive (FP)				•	——	——	——	Δ
IV. Numerical Modeling		FY 1979 RFP	Competitive (FP)			+ —	•	——	——	——	Δ
V. Site-Specific Studies		FY 1979 RFP	Competitive (FP)			+ —	•	——	——	——	Δ
VI. Fundamental Studies		FY 1979 RFP	Competitive (FP)			+ —	•	——	——	——	Δ
VII. Analytical Modeling		FY 1979 RFP	Competitive (FP)				+	——	——	——	——
VIII. Surface Geophysics		FY 1979 RFP	Competitive (FP)								
IX. Physical Modeling		FY 1979 RFP	Competitive (FP)				+	——	——	——	——
X. Economics		FY 1979 RFP	Competitive (FP)			+	——	•	——	——	Δ
XI. Exploitation Strategy		FY 1979 RFP	Competitive (FP)			+	——	•	——	——	Δ

Legend

- • Proposed start of project/task.
- + CBD announcement or existing qualified contractors list.
- Δ Anticipated report, project milestone, or termination.

THE SUBSIDENCE R&D MANAGEMENT PROGRAMS

A major consequence of development of a geothermal reservoir may be subsidence occurring due to withdrawal of voluminous amounts of fluids. Unexpected and uncontrolled subsidence can have detrimental social, environmental, and economic impact. In order to better understand subsidence, its causes and effects, Lawrence Berkeley Laboratory initiated the Geothermal Subsidence Research Program (GSRP).

The goals of the GSRP are to develop methods for assessing naturally occurring subsidence, for inferring a geothermal reservoir's compaction potential, and for minimizing potential subsidence effects during exploitation of a geothermal reservoir. Attainment of these goals is expected to provide the tools needed for geothermal developers to measure subsidence and to predict subsidence potential of a reservoir. For regulatory agencies, the program is expected to lead to guidance with which to recommend appropriate action to minimize impact of subsidence.

The GSRP is organized into four independent elements:

1. Subsidence Characterization - Subsidence characterization is concerned with studying examples of subsidence and subsidence effects. Research has been conducted to document cases of known subsidence in geographic areas having geological and physical environments representative of geothermal areas. Where data were available, i.e., Wairakei, New Zealand, and The Geysers, California, case histories have been written. Associated studies have also been conducted on the economic and environmental impact of subsidence. These studies indicated that there is an inadequacy of the latter data.

2. Subsidence Mensuration - Research has developed guidelines for surface monitoring surveys to establish background deformation rates and monitor possible deformation induced by geothermal development. Research to date has also assessed the state-of-the-art of well bore extensometers to directly measure vertical distances between points in the wellbore. Several suggestions for improved instrumentation that have resulted from this research will make substantial contributions toward creating direct measurement instrumentation for use in geothermal wells.

Indirect measurement methods, i.e., gravity, resistivity and microseismic, have promise as inexpensive, areal survey techniques. Research will be conducted to evaluate the ability of these methods to detect changes in the physical properties of a geothermal reservoir, and to relate these changes to reservoir compaction and subsidence.

3. Subsidence Prediction - Ultimately, the ability to predict subsidence is dependent upon an understanding of the response of geologic materials and systems to natural and man-made stress fields. To gain this understanding, the Geothermal Subsidence Research Program has initiated research to study the response of reservoir material to various stress field changes.

   Other research will assess various subsidence models, review their relative analytical merits, and, if necessary, make recommendations for new models. A related project will develop methods for physical modeling using a centrifuge. Predictions of subsidence made by numerical modeling can thus be evaluated by comparison with a centrifuge model.

   Out of these efforts may evolve better understanding of how geologic materials and systems respond to stress field changes, and enable earth scientists to more accurately predict subsidence over a given reservoir. A step toward greater predictive capability is the assessment of existing theory and its applicability to geothermal reservoirs. Most subsidence theories were developed to describe the compaction of oil and gas reservoirs or of relatively shallow unconsolidated aquifers. The applicability of these theories to deep, thermodynamically complex geothermal systems needs to be examined.

4. Reservoir Operating Policy - The final element in the GSRP is the development policies that minimize effects of subsidence. These policies are derived from the research results of the previous three elements and should provide regulators with:

   (a) the ability to distinguish naturally occurring subsidence from that possibly caused by geothermal operations, and

   (b) the basis to operate or control a geothermal field such that adverse subsidence effects are minimized or avoided.

ACCOMPLISHMENTS

Case Histories

Most documented subsidence has been due to extraction of hydrocarbons or ground water. Useful analogies may be drawn for the production of geothermal fluids. In some cases, deep extraction of fluids has produced little or no subsidence. A case history of the geologic and physical environments, the stress history, and the response or lack of response at land surface, has proved useful in making comparisons to similar potential geothermal systems.

Four case histories were completed by Systems Control, Inc. in the following areas: Wairakei, New Zealand; Chocolate Bayou, Texas; Geysers, California; and Raft River, Idaho. The four subsidence sites were selected on the basis of: (1) physical relevance of subsidence areas to high priority U.S. geothermal sites in terms of withdrawn geofluid type, reservoir depth, reservoir geology and rock characteristics, and overburden characteristics, and (2) data completeness, quality, and availability.

A review of potential geothermal sites was made in order to determine the physical relevance (i.e., analogies) of areas with past subsidence to the potential geothermal sites. These case histories may serve as models for developers and/or regulators in assessing comparable areas.

Surface Monitoring - Guidelines Manual

The fundamental objective of a monitoring program is to quantify the magnitude and direction of surface movements that may occur in a geothermal reservoir area immediately prior to, during, and immediately following the removal of geothermal fluids.

A geothermal development program must include monitoring of horizontal and vertical displacements at the surface and at depth before and during production. It should be possible to differentiate between subsidence caused by geothermal operations and that caused by other man-induced activities, or those occurring naturally.

Thus, guidelines need to be developed to obtain data directly related only to geothermal fluid production. These guidelines should consider the geologic structure, stratigraphy, and seismicity of the area, as well as the existing and proposed ground water, gas, and oil developments. The guidelines should also consider, if available, any known ground deformation characteristics of the region and any man-induced deformations of nearby fluid producing fields.

Woodward Clyde Consultants have produced a manual that reviews various surface monitoring methods and compares their installation, utilization, and accuracy. Utilization of these methods should enable planners and regulators to determine the natural rate of subsidence. In addition, such a manual can be used to ascertain induced subsidence during development and production of a geothermal field.

Direct Measurements of Changes in Vertical Distances in a Wellbore

Woodward Clyde Consultants have recommended hostile environment component testing for the following four tools: 1) induction coil with slip collar well casings, 2) reed switches with magnets emplaced in slip collars, 3) electromagnetic oscillators with magnets emplaced in slip collars, and 4) radioactive logging with tracers emplaced in either slip collars or directly into the formation.

The study reviewed instruments available for monitoring subsurface displacements, both vertical and horizontal. Techniques and materials for improving existing or developing new instruments were evaluated. Elements of sensor and signal technology with potential for high temperature monitoring of subsidence were identified.

Environmental and Economic Effects

A contract with EDAW/Earth Science Associates resulted in assessment of data available from areas that have experienced geothermal and non-geothermal subsidence. A detailed appraisal was made of areas with the most comprehensive data base. Areas studied included desert basins in central and southern Arizona; Baldwin Hills and Inglewood, California; Galveston, Texas; Las Vegas Valley, Nevada; Mexico City, Mexico; San Joaquin Valley, California; Santa Clara Valley, California; Wairakei, New Zealand; and Wilmington-Long Beach, California.

Final reports from all these contracts will be available as part of an LBL subsidence report series.

In FY 1978 and early in FY 1979 seven contracts were let. Four of these are near completion while three others are continuing into FY 1979. These contracts are summarized in Figure 2.

Programs scheduled for FY 1979 are summarized in Figure 3.

During the Subsidence Workshop held at Asilomar, October, 1978, recommendations for the revision of the Subsidence Management Plan were made. Figure 4 illustrates a suggested revision for the plan.

The Geothermal Subsidence Research Program is directly responsive to the DOE/DGE goal of "power-on-line." The subsidence risk of geothermal development can be reduced by utilization of techniques and tools developed through the GSRP. Operational methodology developed by the program can provide guidance to regulators and developers to prevent or minimize subsidence.

The first Subsidence Newsletter is scheduled to be issued on February 1, 1979. It will be sent to all who request it and to those who currently receive the GREMP Newsletter.

Figure 2

STATUS OF CURRENT SUBSIDENCE CONTRACTS

TITLE	CONTRACTOR	TYPE	MODE OF PROCUREMENT	STARTING DATE (ESTIMATED OR ACTUAL)	TERMINATION DATE (ESTIMATED OR ACTUAL)
Case Histories (Category 1)	Systems Control	FP	Competitive	10/7/77	10/31/78
Guidelines Manual (Category 2)	Woodward-Clyde	FP	Competitive	11/18/77	10/31/78
State-of-the-Art Assessment (Category 3)	Woodward-Clyde	FP	Competitive	8/29/77	10/31/78
Environmental and Economic Effects (Category 4)	EDAW - Earth Sciences	FP	Competitive	9/20/77	10/31/78
Subsidence Models (Category 8)	Golder Associates	CPFF	Competitive	6/19/78	9/30/79
Physical Processes (Category 5)	Colorado School of Mines	CPNF	Competitive	9/15/78	9/30/79
Physical Processes (Category 5)	Terra Tek, Inc.	CPFF	Competitive	11/5/78	12/31/79

FP - Fixed Price
CPFF - Cost Plus Fixed Fee
CPNF - Cost Plus No Fee

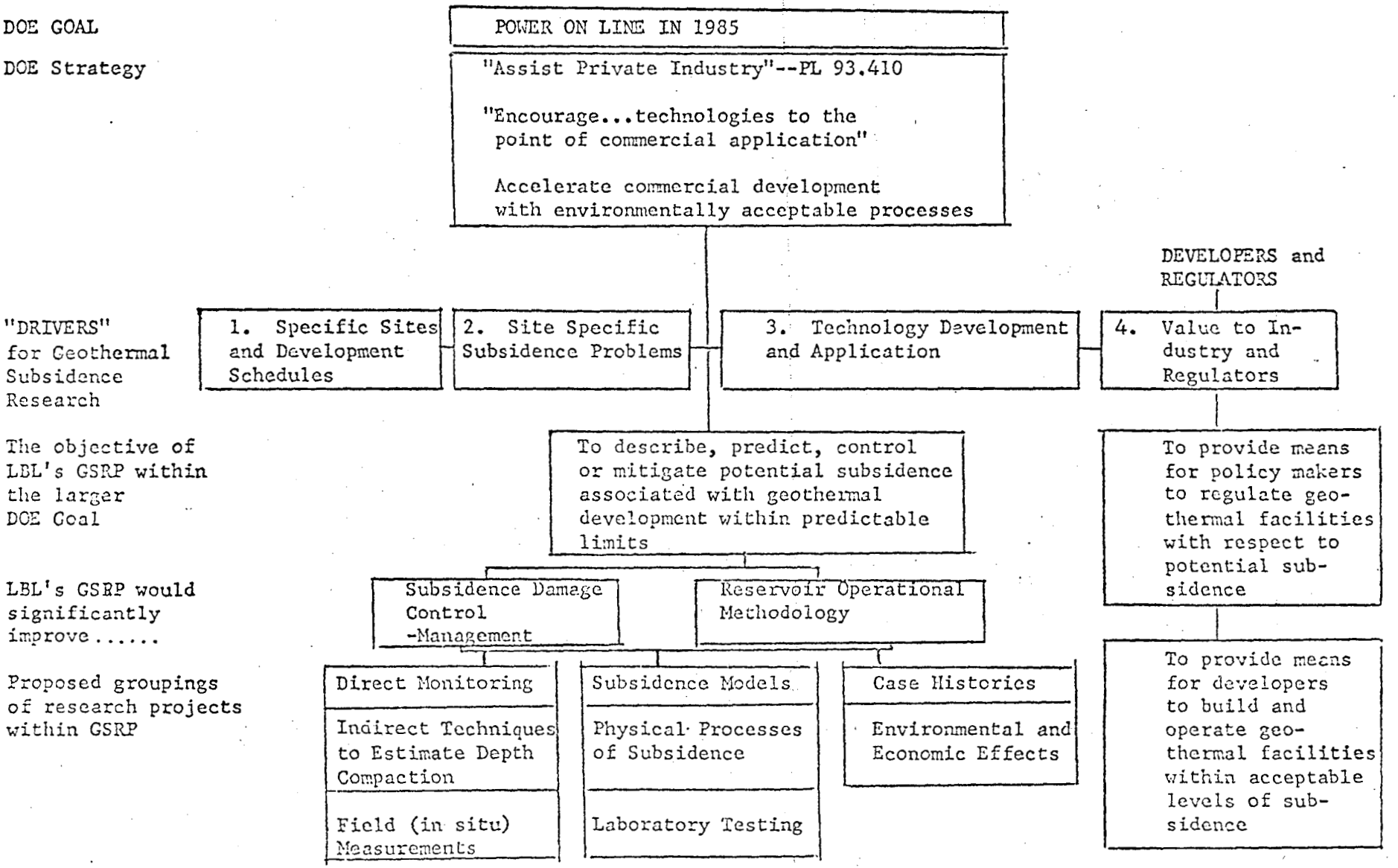
Figure 3

PLANNED SUBSIDENCE PROJECTS FOR FY 1979

GROUP	SUBJECT	RFP DUE	TYPE OF CONTRACT ANTICIPATED
1	Case Histories	--	FFP
1	Risk Analysis	Jan.	FFP
2	A. Hostile Environment	Dec/Jan	FFP
2	B. Radioactive Bullets	Dec/Jan	CPFF
2	Indirect Methods	Dec/Feb	FFP/CPFF
3	Physical Methods	Feb.	FFP
3	Creep Phenomena	April	CPFF

FFP - Firm Fixed Price
CPFF - Cost Plus Fixed Fee

Figure 4


DOE GOAL
POWER ON LINE IN 1985
DOE Strategy
"Assist Private Industry"--PL 93.410
"Encourage...technologies to the point of commercial application"
Accelerate commercial development with environmentally acceptable processes
DEVELOPERS and REGULATORS
"DRIVERS" for Geothermal Subsidence Research
1. Specific Sites and Development Schedules
2. Site Specific Subsidence Problems
3. Technology Development and Application
4. Value to Industry and Regulators
The objective of LBL's GSRP within the larger DOE Goal
To describe, predict, control or mitigate potential subsidence associated with geothermal development within predictable limits
To provide means for policy makers to regulate geothermal facilities with respect to potential subsidence
LBL's GSRP would significantly improve.....
Subsidence Damage Control -Management
Reservoir Operational Methodology
Proposed groupings of research projects within GSRP
Direct Monitoring
Indirect Techniques to Estimate Depth Compaction
Field (in situ) Measurements
Subsidence Models
Physical Processes of Subsidence
Laboratory Testing
Case Histories
Environmental and Economic Effects
To provide means for developers to build and operate geothermal facilities within acceptable levels of subsidence