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DOE Prog Plans

MEMORANDUM

August 6, 1981

TO: Charles Bufe

FROM: Carl A. Ruscetta

SUBJECT: Preliminary Draft: Program Plan Geothermal Exploration and Assessment Technology

Confirming your conversation with Susan Prestwich, DOE/ID, enclosed please find a preliminary draft of the Exploration Technology program plan that was worked up by Dennis Nielson, Susan and I for your examination and comment. Dennis Nielson is expected back in Salt Lake on Tuesday, 11 August and will be available for discussion of this "very rough draft" with you.

Best regards,

Carl A. Ruscetta

Carl A. Ruscetta

CAR:jp

enclosure

cc D. Nielson
S. Prestwich

PRELIMINARY DRAFT

Program Plan

Geothermal Exploration and Assessment Technology

August, 1981

INTRODUCTION

This document represents an update of the Geothermal Exploration and Assessment Technology Program Plan. The purpose of this program is to provide assistance to the Nation's industrial community by helping to remove technical and associated economic barriers which inhibit the discovery and assessment of geothermal resources. As discussed in a later section of this document, this approach will aid efforts to bring geothermal electric power production and direct heat applications on line by developing new technology for industry and increase the success rates for both high and low temperature resource exploration programs. The goal of this program is to identify and implement basic and applied research which will improve exploration success in the mid- and far-term (i.e., 2000 to 2020).

These program goals reflect present overall Geothermal directives "to work with industry to identify technical problems that significantly affect the technical and economic feasibility of hydrothermal applications, to assess the need for Federal involvement in seeking solutions, and, where applicable, to perform the high risk/high payoff research and development needed."

High temperature resources are marginally cost competitive and are being actively developed by industry, however, the resources below 400°F, which occur in greatest abundance, require technologic advancements to be economically feasible. The present geothermal R&D objectives are aimed at the development of new or improved technology in order to economically expand the resource base by a factor of four, and at the same time compliment industry activities.

DOE has set a goal to reduce geothermal field development costs by 25%, which, along with reductions in overall development and utilization expense, could potentially create a 30% cost reduction for the development of moderate temperature resources. The Exploration Technology program is structured to provide significant technology advancements to achieve this goal.

The Program in Geothermal Exploration and Assessment Technology is structured to respond to industry needs. The plan is based on a substantial review, conducted in concert with industry, the USGS, and academia, of the technical and associated economic barriers to commercial hydrothermal development which currently face industry. Continued input from the industrial community will provide meaningful program input, review, and update and will ensure consideration of exploration and assessment problems associated with development of low- to high-temperature convective hydrothermal resources, and other resource types if required. The current program emphasis is on moderate-temperature convective hydrothermal resources.

The Geothermal Exploration and Assessment Technology Program complements the following DOE/DGE research programs dealing with other aspects of geothermal development:

- Reservoir Engineering
- Well Log Interpretation
- Well Log Instrumentation
- Drilling and Completions
- Subsidence
- Induced Seismicity

Strong ties and cooperation have been established with DOE's Industry Coupled Program. In addition, this Program is closely related to the U. S.

Geological Survey's Geothermal Research Program which has objectives dealing with characterizations of various kinds of geothermal systems, regional and national assessments of geothermal resources, and evaluation and development of scientific concepts for identifying and describing these resources. A careful coordination with all of these programs will be maintained to ensure that no undesirable overlap occurs.

TECHNICAL BARRIERS TO DISCOVERY AND ASSESSMENT OF GEOTHERMAL ENERGY

In order to address the basic goal of the Geothermal exploration and Assessment Technology Program and aid in removing the technical and associated economic barriers to the discovery and assessment of geothermal resources, the following barriers have been defined with industry input and are summarized in Table 1.

Table 1: Summary of Technical Barriers to Discovery and Assessment of Geothermal Resources.

1. Conceptual and prediction models of geothermal systems are unreliable.
2. Regional- and district-scale exploration techniques are inadequate.
3. Drill site selection techniques need improvement and development.
4. Assessment methods need refinement and technology development.
5. Technology transfer needs stimulating.

1. Conceptual and predictive models of geothermal systems are unreliable.

The geoscience methods used by the exploration geologist locate the structural controls and products of geothermal systems such as hydrothermal alteration and high heat flow. In general these methods do not define the geothermal system in itself. Thus, it is necessary to have a conceptual model of the geothermal system to apply the proper exploration methods. Improvements in exploration tools could be developed much more rapidly if reliable reservoir models existed because these models, coupled with suitable numerical or analog analyses, could more quickly sort the many questions for potential technique improvement and thus allow the geoscientist to concentrate on the most fruitful means of attack.

2. Regional- and district-scale exploration techniques are inadequate.

The geothermal industry is presently drilling only the most obvious geothermal prospects in the U. S., i.e., systems deemed most promising because of surface manifestations such as hot springs and fumaroles. There are, however, large regions within the U. S. which do not show these manifestations but which may contain hidden geothermal resources and efficient methods must be devised to assess the potential of these areas. The development of exploration techniques will result in the discovery of new geothermal districts. Within known districts it is also probable that many buried resources remain undiscovered. It is in these areas that the industry is presently turning its attention and where wildcat wells have the highest chance of success. As indicated in Table 2, however, the success ratios for wildcat wells is still quite low.

3. Drill site selection techniques improvement and development.

The evidence for poor drill site selection techniques is demonstrated in Table 2. Even in geothermal resource areas, step out drilling in 1978 (Smith et al., 1979) resulted in only one producing well out of seven drilled. It is difficult to determine, comprehensively, the strengths and weaknesses of available exploration techniques for the following reasons: the resource could be situated in a variety of geological structures and rock types; too few usable reservoirs have been found to provide sites for test and evaluation of improved techniques and instrumentation; and the technology currently in use or potentially available is complex. There is a need to be able to correlate the data of various exploration and assessment techniques with the reservoir characteristics determined by deep drilling to improve the interpretation

TABLE 2
Comparison of geothermal and oil and gas wells drilled in U. S. 1975-1978 (Nielson, 1980)

	Total Geothermal Wells			Success Ratio	Geothermal Wildcat Wells			Success Ratio
Year	Drilled	Producers	Success Ratio	Total Oil & Gas	Drilled	Producers	Success Ratio	Oil & Gas Expl.
1975	46	37	.80	.644	6	1	.166	.233
1976	52	39	.75	.657	21	2-3	.95-.143	.265
1977	52	25	.38	.673	15	0	0	.270
1978	58	30	.52	.654	13	2	.154	.253

Data from: Dhillon et al., 1978; Smith and Matlick, 1976; Smith et al., 1977, 1978, 1979; and DOE/EIA, 1978.

of surface and near-surface measurements. The current lack of a reliable exploration technology and the necessity for deep drilling make geothermal exploration a costly, high-risk undertaking.

4. Assessment techniques need refinement and technology development.

At the present time there is no reliable way to determine extent, depth, temperature, nature of fluid, or productivity of a potential geothermal resource -- without a number of deep drill holes which actually sample the reservoir. Yet deep drilling costs, especially in the reservoir rocks themselves, are very high. Accordingly, there would be a large cost benefit to geothermal development if less expensive surface and/or shallow drilling techniques could be used to make reservoir predictions or to extend substantially the data derived from fewer boreholes.

A number of the geoscience methods, such as geochemical and electrical, offer promises but these current methods need refinement in detection method and interpretation.

5. Technology transfer needs stimulating.

New high risk/high payoff technologies must be quickly and efficiently transferred to industry for its use to reduce field development costs and stimulate development. The conventional techniques of technical reports and workshops are appropriate but inadequate. New means of making technology transfer both timely and effective need to be found.

BENEFIT OF IMPROVED EXPLORATION SUCCESS

Under the present tax structure an investment in a geothermal resource will not generate a return (ROI) until the field begins to generate revenue. Therefore, exploration companies have a need to reduce the required risk captial and reduce the time required to develop a given resource. Capital requirements can be reduced by streamlining the exploration stage leading to well siting. It is the aim of the Geothermal exploration and Assessment Technology program to not only make the exploration stage more efficient in terms of cost, but also to increase the reliability of the methods such that the success rate of wells is increased. The result will be an increased success rate of wells at a decreased cost of exploration required to site those wells.

Prior exploration technology development placed emphasis on the high-temperature geothermal systems which are presently being explored for electric applications. Very little data on exploration for direct heat resources presently exists. Of course, drilling costs will be the same for the lower temperature resources. However, the lower value of individual resources will require low-cost, very efficient exploration prior to the siting of a test well. The resources themselves are probably going to be as difficult to find as the high-temperature systems. The Geothermal Exploration and Assessment Technology Program will provide a significant component in the development of exploration case studies and the formulation of exploration architectures for low- to intermediate-temperature geothermal systems. Rising energy costs have stimulated broad interest in the direct heat applications, however, high exploration costs and lack of models of the geothermal systems could easily dampen the enthusiasm which currently exists for their development. The

Geothermal Exploration and Assessment Technology Program will provide the mechanism for high risk/high payoff technology R&D necessary for industry to economically pursue exploration and development of resources with temperatures below 400°F.

GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY DEVELOPMENT PROGRAM

The objective of the Exploration Technology Development Program is to increase the cost-effectiveness of existing tools and techniques and to develop new tools and techniques for exploration and resource assessment.

The geothermal industry continues to be plagued by exploration failures even in the Basin and Range where many systems appear at the surface as hot springs. In addition, unsuccessful wells are common at The Geysers, Baca, and Imperial Valley although these systems are in a development rather than an exploration phase. These failures add substantially to the overall field development costs and have discouraged many companies from exploring for geothermal resources.

At present exploration for high-temperature geothermal systems is carried out using technologies originally devised for petroleum or mining exploration. These methods are not optimum nor sometimes even applicable for geothermal exploration or discovery. Even current thermal techniques have not been specifically developed for geothermal exploration, but rather are applications of conventional heat flow studies or of well logging.

Nearly all the geothermal exploration presently funded by the private sector is directed toward those systems with temperatures greater than 400°F. However, it has long been known that the predominant portion of the resource base is made up of temperatures of less than 400°F. Exploration technologies for these systems are in an even more primative state of development than for the high-temperature systems. In addition, because of the lower temperatures and less certain economics, the private sector is not presently involved in developing exploration proceedures for these systems. Thus, if we are to expand the economically exploitable resource base to systems with temperatures below 400°F, DOE support for development of exploration proceedures is required.

One important portion of Exploration Technology Development has been the extramural component. Funds are made available for DOE solicitations that are issued for specific topics. The selection of topics is carefully structured from data that UURI collects from industry and from other DOE Programs, such as the Industry Coupled Program, the State Coupled Program and the User coupled Confirmation Drilling Program, on an annual basis. At the present time DOE-ID has 4 contracts in effect as a result of FY 1980 procurements.

A second important component of the Exploration Technology Development Program is the in-house subcontract technology development that UURI performs. This in-house work is often directed towards complex problems which require long term, sustained research to solve.

The team of geoscientists that we have assembled has unique qualifications to perform certain aspects of geothermal technology development. We maintain an integrated team of experts whose individual members work closely together. We work with the Department of Geology and Geophysics at the University of Utah because of the specialized equipment and instruments available there as well as their expertise. For convenience in discussion, we have divided the presentation of UURI tasks into those concerned with geological, geochemical, and geophysical technique development. But the proposed program is fully coordinated both in-house and also with the extramural program. We have proposed work on only those topics that are high priority and for which we have specific expertise.

The specific tasks proposed under this program are outlined below.

Technical Assistance:

1. Provide support for program planning. Maintain the Exploration Technology Development Program plan up-to-date as requested by DOE.
2. Provide data and recommendation to DOE regarding solicitations for extramural technology development. Obtain updated information from industry regarding the highest priority items for technology development work.
3. Provide assistance in monitoring contracts that result from DOE solicitations under this program.

Geological Technique Develoment:

The main thrust of our efforts to date has been developing better geologic models for hydrothermal systems. Because so few such systems have been explored worldwide, detailed knowledge that is necessary for industry to plan and execute cost-effective exploration and resource evaluation programs is lacking. The work proposed for FY 1982 will examine thermal histories and geometries of thermal system and attempt to quantify the systematics of permeability along fault and fracture zones.

1. Fission Track Systematics. Fission track dating can be used to document the ages of thermal events including the duration of geothermal systems and the expansion or contraction of those systems. A base line of geochronologic data was established for Roosevelt Hot Springs, Utah in FY 1980. During FY 1981 a fission-

track laboratory was made fully operational in UURI, and fission track data were generated for surface samples. Work in FY 1982 will evaluate variations in the size of the geothermal system at Roosevelt Hot Springs during its evolution with time. We will extend the present study to include samples from the drill holes at Roosevelt to gain a three-dimensional picture.

2. Fault Permeability Studies. In most geothermal systems, faults and fractures associated with faults provide conduits for the geothermal fluids and are the usual target of exploration drill holes. However, fault zones may change permeability along strike and with depth and may grade from highly permeable to impermeable in short distances. Detailed studies of the fault and fracture systems will be conducted to determine spatial variations in fault zone permeability. The goal of the research is to determine the best locations along faults for encountering maximum permeability.

   Field work will serve to document displacement on different fault sets, intrafault zone structure and evidence for paleo-fluid flow as indicated by the presence of hydrothermal alteration along fault zones. Laboratory work will be undertaken to identify alteration assemblages and stable isotope studies will aid in delineating which exposed fault zones were characterized by high fluid flow.

Geochemical Technique Development:

Since 1977 UURI has been actively involved in the development of geochemical techniques designed to 1) reduce drilling costs, 2) increase the cost-effectiveness of exploration, and 3) predict the physical and chemical properties of subsurface reservoir rocks and fluids. Results of research are also very useful in helping to monitor changes in reservoir conditions during production. There has been a great deal of industry interest in this research, and at least one major geothermal group is equipping a laboratory to apply the results of our research to exploration problems. Trace-element, mineralogic, thermochemical and isotopic investigations provide answers to many problems, and geochemical exploration models developed for geothermal systems in the Basin and Range are currently being tested by UURI and the geothermal industry. The refinement of these models and their application in other geologic terrains is a major goal of the FY 82 program at UURI.

1. Quantify the geochemical models currently being developed; test and quantify geochemical zoning models by comparison with measured subsurfce conditions, predicted and known stability fields of the associated mineral assemblages and, where possible, other geochemical thermometers.
2. Refine and test dynamic computer models designed to predict the physico-chemical conditions related to mineral dissolution, and precipitation (deposition) and alteration in geothermal reservoirs. Compare the results with actual mineral assemblages and distribution of recharge and discharge zones in a documented geothermal system.
3. Refine and test isotopic and geochemical models designed to predict reservoir permeability, porosity, water-rock ratios, and fluid residence times.

<u>Geophysical Technique Development:</u>

Most of UURI's work in geophysical technique develpment over the past several years has been in development of user-interactive computer-based modeling techniques for interpretation of electrical and potential field geophysical data. Electrical exploration techniques are used extensively by industry even though current interpretation methods are poorly developed. Interpretation of most surveys by industry relies on computer computation of the expected geophysical response from a layered-earth (one-dimension) or two-dimensional geologic model of the subsurface. However, most geothermal areas are complex geologically and require three-dimensional models for accurate representation. Lack of interpretational capability often contributes to improper siting of expensive drill holes, leading to exploration costs that are high.

Development of computer algorithms for three-dimensional interpretation is difficult. Sophisticated mathematical work is required, and development of new mathematical methods is an important part of the work. Part of our work is aimed at decreasing cost of available modeling techniques. Some computer programs cost several thousand dollars per model to run, a cost that prohibits industry from making sufficient runs for adequate modeling.

1. Continue development of three-dimensional integral-equation and hybrid algorithms for interpretation of electrical geophysical data in geothermal environments.
2. Continue evaluation of the controlled-source electromagnetic (CSEM) technique in a geothermal environment.
3. Add 20 magnetotelluric (MT) stations in southern Utah to obtain the regional conductivity setting for the high temperature geothermal resources located there.
4. Evaluate the controlled-source audio-magnetotelluric (CSAMT)

technique using a new digital receiver.

Based upon the survey of industry needs and the technical barriers to geothermal discovery and assessment as previously discussed, additional geophysical technique development and refinement in electrical and electromagnetic modeling and seismological investigations is clearly indicated. A continuation of the work being done at the Lawrence Berkeley laboratories through FY 82 would consist of two basic tasks as follows;

Task 1: Electrical and Electromagnetic Modeling and technique Development

1. Self Potential Research

   To obtain a better, more quantitative understanding of the physical processes that contribute to the SP anomalies observed over geotherml-hydrothermal systems; to learn how to distinquish "geothermal" SP anomalies from those caused by other sources.

2. Electrical and Electromagnetic Modeling

   To continue work in developing faster 2-D, 3-D modeling codes based on the hybrid approach; to document codes and distribute information to industry.

3. Electromagnetic Technique Development

   to improve/refine existing electromagnetic techniques, making them most cost-effective and capable of resolving subsurface conditions with a higher degree of reliability, particularly in geologically complex environments.

   A. To continue work on a combined EM and MT system that will allow the user to obtain simultaneous earth responses from dipole (man-made) and other plane wave (natural) sources.

B. To begin design and fabrication of a new magnetotelluric (MT) system for DOE/DGE research purposes.

Task 2: Seismological Investigations

1. Three-Dimensional Imaging

To apply three-dimensional wave imaging techniques to seismic reflection data over geothermal reservoirs; to apply fundamental and non-standard imaging techniques to the problems of reservoir delineation.

2. Passive Seismic Monitoring

To apply passive seismic techniques to fundamental problems of detection and recognitions of seismic energy released by geothermal-hydrothermal systems.

A. The Automatic Seismic Processor (ASP) will be used in a combined surface and down-hole mode to monitor fracture tip propagation resulting from hydrofracturing.

B. Digital event recorders and downhole geophones will be used to monitor natural seismic energy emanating from an undeveloped geothermal reservoir in an attempt to resolve the question of whether hydrothermal systems emit seismic energy.

ACCOMPLISHMENTS

Geothermal Exploration and Assessment Technology Program

Since the beginning of this program, the following specific tasks have been accomplished with the cooperation of the various agencies, universities and laboratories involved;

1. Publication of exploration strategy for the Basin and Range Province.

2. Tested and evaluated the seismic reflection method as a geothermal exploration tool.
3. Developed models of trace element zonation in and around geothermal systems and developed exploration proceedures based on these models.
4. Student support - both thesis and part-time employment. The program has aided the education of professionals for the geothermal industry. At ESL/UURI, approximately 20 graduate and undergraduate students have been utilized in connection with geothermal projects.
5. Developed user-interaction computer based modeling techniques for interpretation of electrical potential field geophysical data.

Table 3 describes the present status of the various projects that were recommended by the Technical Review Committees in concert with industry, the USGS and academia at the begining of the Geothermal Exploration and Assessment Technology Program.

TABLE 3
SUMMARY OF RECOMMENDATIONS OF TECHNICAL REVIEW COMMITTEES OF THE GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION	STATUS
STRUCTURE, STRATIGRAPHY, AND	1. Surface Geology -detailed geologic mapping -aerial photography	1	225K/yr	5 yrs	USGS
	2. K-Ar Dating--to refine models of relationship of magma systems & geoth systems.	2	75K/yr	5 yrs	Ongoing-nearly complete.
	3. Subsurface Studies Structural permeability	3	40K/yr		TBD
	Gravity (3 surveys/yr)		105K/yr	5 yrs	No
	4. Rock Properties	4	30K/yr		
	5. Igneous Studies Models of magma system evolution - chemistry.	5	155K/yr	3-5 yrs	USGS-Cascades
EXPLORATION ARCHITECTURE	1. Refinement of MT		250K/yr	on going	
	2. Groundwater effects on thermal measurements		100K/yr	on going	To be completed this year.
	3. Regional fluid geochem		100K/yr	USGS task	
	4. Regional gas geochem		100K/yr	USGS task	
	5. K-Ar dating - regional		100K/yr	USGS task	
	6. Joint collection and inversion of data.		50K/yr		Should be completed thru procurements.

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION	STATUS
ELECTRICAL METHODS	1. EM modeling & inversion	1			
	a) cost-effective 2d & 3D modeling programs		300K/yr	3 yrs	Done in-house.
	b) alterante inversion schemes		100K/yrs	3 yrs	Alt. modeling being done in-house.
	2. Controlled source EM field studies	2	100K/yr	2 yrs	Completed next year. EM-60
	3. Rock properties	3	200K/yr	3 yrs	
	4. Regional MT map	1	50K/yr	2 yrs	Not worth doing
	5. Calibration sites & procedures	2	60K/yr	1 yr	Being done
	6. MT Workshop	3	20K/yr		
	7. Testing of following (no budget recommenda-tion provided):				
	-Induced Polarization				Done
	-Magnetometric Resistivity				
	-Long array MT				
	-Singular coincident loop TPEM.				
	8. Self Potential Workshop		10K/yr		Done
WATER/ROCK INTERACTION	1. Mineralogy, geochem-istry, + petrology in geothermal resrvoirs.		600K/yr	2 yrs	On going in-house & procurements.
	2. Workshop on water/rock in geothermics		25K/yr		Done

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION	STATUS
	3. Rock + fluid properties		200K/yr	2 yrs	
	4. Geothermometers		175K/yr	2 yrs	In progress w/procurement.
	5. Obtain core				
THERMAL METHODS	1. Bottom hole T during drilling				
	2. Relations between thermal conductivity and physical parameters		60K/yr	3 yrs	Attempted thru procurement.
	3. Effects of groundwater flow on thermal measurements		100K/yr	5 yrs	Done in FY 81.
	4. "Free hole" Program		1000K/yr	5+ yrs	
	5. Shallow & intermediate depth drilling.		1500K/yr		Industry.
	6. Deep hole T transmission system.		100K/yr	3 yrs	DOE project.
SEISMIC METHODS	1. Data compilation and dissemination	1	100K/yr		Done
	2. Rock properties	2	75K/yr	2	
	3. Research in processing & interpretation	3	75K/yr	2	Nothing done.
	4. Seismic @ Valles Caldera	4	200K 100K	1st year 2nd year	

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION	STATUS
	5. Clear Lake Survey	5	125K 25K	1st year 2nd year	
	6. Microseismic noise @ Beowawe	6	30K 15K	1st year 2nd year	
	7. Microearthquake	7	50K 50K	1st year 2nd year	
	8. Basic research on micro-earthquake processing & interpretation	8	70K/yr	4 yrs	CA work

CURRENT NEEDS

Specific problems in geothermal exploration that are now being addressed by the Exploration Technology Program are listed below. These problems were identified through discussions with industry and other experts in geothermal systems.

1. Improve understanding of structures that convey geothermal fluids to allow prediction of zones of permeability.
2. Be able to characterize the size and permeability of a system through isotopic analyses of fluids from the system.
3. Quantify geochemical zoning models by comparison with known subsurface conditions and thermodynamically predicted stability fields.
4. Develop 3-D algorithms for interpretation of electrical data in geothermal environments.
5. Complete regional MT studies designed to establish regional exploration models for hidden geothermal systems.
6. Evaluate passive seismic techniques as exploration and reservoir engineering tools.

MANAGEMENT PLAN

GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

Figure 1 portrays the management structure for the Program in Geothermal Exploration and Assessment Technology. Figure 2 portrays the flow of information and the coordinating structure vis-a-vis other related programs. Every effort will be made a) to design minimum but essential overlap with other related programs, and b) to support interface efforts concerned with resource types other than hydrothermal.

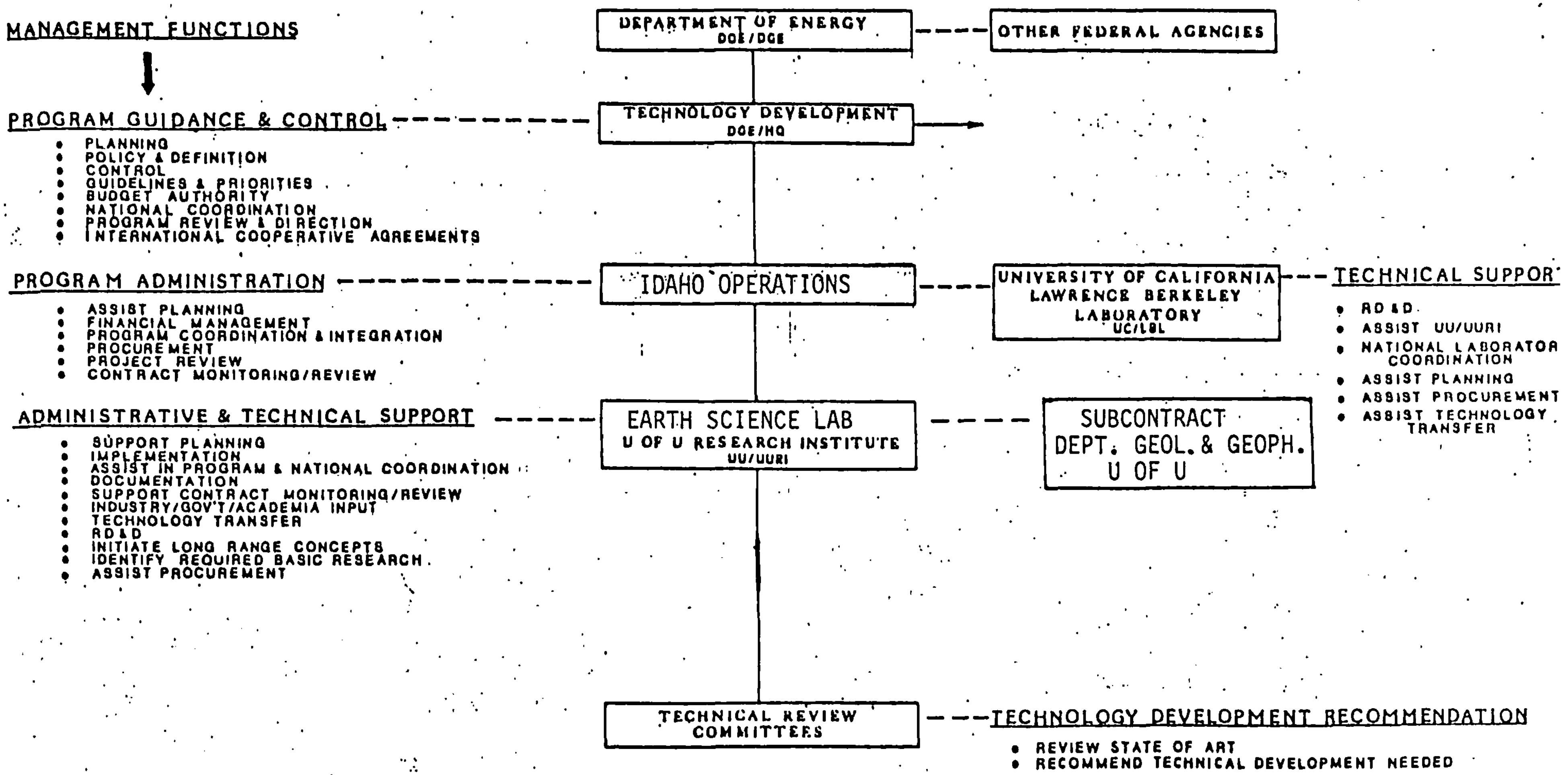
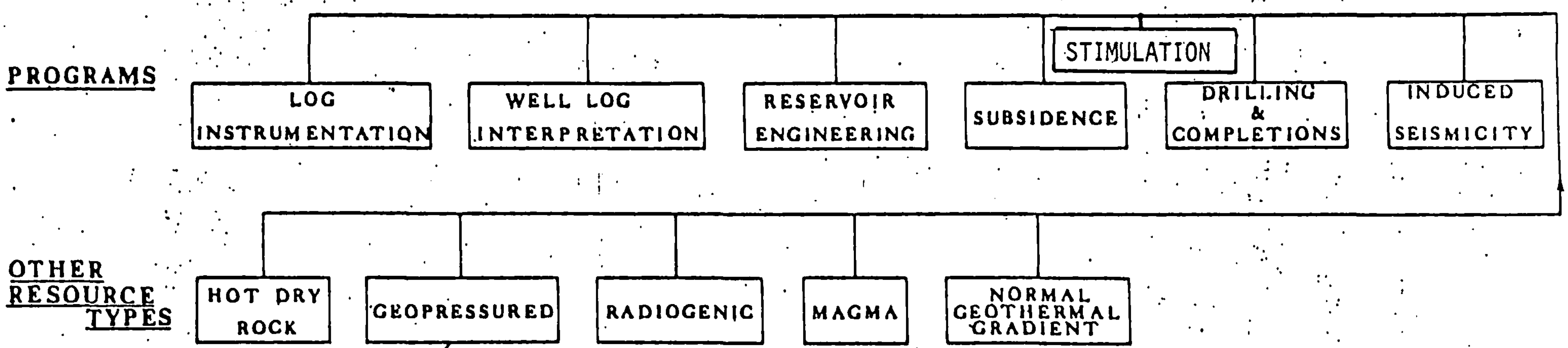

MANAGEMENT FUNCTIONS
PROGRAM GUIDANCE & CONTROL
• PLANNING
• POLICY & DEFINITION
• CONTROL
• GUIDELINES & PRIORITIES
• BUDGET AUTHORITY
• NATIONAL COORDINATION
• PROGRAM REVIEW & DIRECTION
• INTERNATIONAL COOPERATIVE AGREEMENTS
PROGRAM ADMINISTRATION
• ASSIST PLANNING
• FINANCIAL MANAGEMENT
• PROGRAM COORDINATION & INTEGRATION
• PROCUREMENT
• PROJECT REVIEW
• CONTRACT MONITORING/REVIEW
ADMINISTRATIVE & TECHNICAL SUPPORT
• SUPPORT PLANNING
• IMPLEMENTATION
• ASSIST IN PROGRAM & NATIONAL COORDINATION
• DOCUMENTATION
• SUPPORT CONTRACT MONITORING/REVIEW
• INDUSTRY/GOV'T/ACADEMIA INPUT
• TECHNOLOGY TRANSFER
• RD&D
• INITIATE LONG RANGE CONCEPTS
• IDENTIFY REQUIRED BASIC RESEARCH
• ASSIST PROCUREMENT
DEPARTMENT OF ENERGY DOE/DGE
OTHER FEDERAL AGENCIES
TECHNOLOGY DEVELOPMENT DOE/HQ
IDAHO OPERATIONS
UNIVERSITY OF CALIFORNIA LAWRENCE BERKELEY LABORATORY UC/LBL
TECHNICAL SUPPOR
• RD&D
• ASSIST UU/UURI
• NATIONAL LABORATOR COORDINATION
• ASSIST PLANNING
• ASSIST PROCUREMENT
• ASSIST TECHNOLOGY TRANSFER
EARTH SCIENCE LAB U OF U RESEARCH INSTITUTE UU/UURI
SUBCONTRACT DEPT. GEOL. & GEOPH. U OF U
TECHNICAL REVIEW COMMITTEES
TECHNOLOGY DEVELOPMENT RECOMMENDATION
• REVIEW STATE OF ART
• RECOMMEND TECHNICAL DEVELOPMENT NEEDED

FIGURE 1

FIGURE 2



PROGRAMS
STIMULATION
LOG INSTRUMENTATION
WELL LOG INTERPRETATION
RESERVOIR ENGINEERING
SUBSIDENCE
DRILLING & COMPLETIONS
INDUCED SEISMICITY
OTHER RESOURCE TYPES
HOT DRY ROCK
GEOPRESSURED
RADIOGENIC
MAGMA
NORMAL GEOTHERMAL GRADIENT

1. DOE/DGE

The Manager, Exploration technology, acting with the concurrence of the Program Manager, Geothermal Technology Development and with the concurrence of the Director, Division of Geothermal Energy (DOE/DGE) will provide overall programmatic guidance for the definition, planning, direction, and control of the Program in Exploration Technology. DOE/DGE will also provide overall financial guidance to the DOE-supported participants in the program, including subprogram-level guidance to the Geothermal Program at the Idaho Operations Office. The Manager for Exploration Technology will be responsible for coordinating this progrm with national geothermal program elements contained within DOE, as illustrated in Figure 1, with the USGS and other agencies participating in the national geothermal program.

2. DOE Idaho Operations Office

The Office of Geothermal Energy, Idaho Operations Office, will provide program administration including planning assistance, financial management, program coordination and integration, procurement, project review, contract monitoring/review and procurement activities.

3. Earth Science Lab/University of Utah Research Institute (ESL/UURI)

ESL/UURI will provide adminsitrative and technical support for exploration and assessment technology. In detail, ESL/UURI will be responsible for: planning support; program implementation;

assisting in program and national coordination; program documentation; supporting contract monitoring and review; obtaining and collating industry, government and academic inputs; assuring technology transfer; conducting RD&D; initiating the development of long-range conceptual models of geothermal resource types; and identifying items requiring applied and basic research in support of the program.

4. University of California/Lawrence Berkeley Laboratory (UC/LBL)

The UC/LBL activities may include assistance with program planning procurement, technology transfer, coordination of the efforts of related programs at UC/LBL and at other national laboratories, and conducting RD&D.

5. Relationship to Other Programs

It will be the responsibility of DOE/DGE to ensure coordination of this program with USGS geothermal programs. DOE/DGE also will ensure coordination with regional and generic programs in hydrothermal and other resource types as shown in Figure 1.

PRELIMINARY DRAFT

Program Plan

Geothermal Exploration and Assessment Technology

January, 1980

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CONTENTS

INTRODUCTION

This document represents an update of the Geothermal Exploration and Assessment Technology Program Plan. It is based on a document published in 1978 (U. of Utah, Dept. Geology and Geophysics, 1978) and draws heavily from that work. The purpose of this program is to provide assistance to the Nation's industrial community by helping to remove technical and associated economic barriers which inhibit the discovery and assessment of geothermal resources. As discussed in a later section of this document, this will aid efforts to bring geothermal electric power production and direct heat applications on line by increasing the success rates of exploration programs and by encouraging participation in exploration programs. Increased exploration and increased success rates are required if the DOE goals for electric power generation and direct heat utilization are to be met. A secondary goal of this program is to identify and implement basic and applied research which will improve exploration success in the mid- and far-term (i.e., 2000 to 2020).

Near-term problems, and strategies to solve those problems, are generally better defined than are mid- or far-term problems. Near-term work encompassed by this Program Plan deals mainly with development of new technology for exploration and assessment within known areas of surficially-expressed high-temperature convective hydrothermal systems, whereas mid- and far-term work deals mainly with development of technology to discover new resources which usually lack significant surface manifestation and whose discovery is vital to the Nation's mid- and far-term energy needs. Part of this Program

Plan deals with continued elucidation of exploration and assessoant problems over the next few years so that effective methods will be available for all stages in the national geothermal program.

Federal involvement in providing such assistance is detailed in Public Law 93-410, the Geothermal Energy Research, Development, and Demonstration Act of 1974, and in ERDA-86, the Definition report for the Geothermal Energy Research, Development and Demonstration Program, published by ERDA in October, 1975, in response to P.O. 93-410.

The Program in Geothermal Exploration and Assessment Technology is an industry-driven program. The plan is based on a substantial review, conducted in concert with industry, the USGS, and academia, of the technical and associated economic barriers to commercial hydrothermal development which currently face industry (Ward, 1978; Goldstein, Norris and Wilt, 1978; Nielson, 1980). Continued input from the industrial community through several standing Technical Review Committees will ensure meaningful program input, review, and update and will ensure consideration of exploration and assessment problems associated with development of low- to high-temperature convective hydrothermal resources and of geopressured, hot dry rock, magma, radiogenic, and normal geothermal gradient resources, if required. Current emphasis is on high-temperature convective hydrothermal resources.

The Geothermal Exploration and Assessment Technology Program complements the following DOE/DGE research programs dealing with other aspects of geothermal development:

- Reservoir Engineering

-Well Log Interpretation

-Well Log Instrumentation

-Drilling and Completions

-Subsidence

-Induced Seismicity

Strong ties and cooperation have been established with DOE's Industry Coupled Program, State Coupled Program, and User Assistance Program. In addition this Program is closely related to the U. S. Geological Survey's Geothermal Research Program that has objectives dealing with characterizations of various kinds of geothermal systems, regional and national assessments of geothermal resources, and evaluation and development of scientific concepts for identifying and describing these resources. A careful coordination with all of these programs will be maintained to ensure that no undesirable overlap occurs.

Benefit/cost studies have been made for the elements in this Program Plan. These studies indicate that as much as 50% of the total $20 million needed to prove the existence of a 200 MWe convective hydrothermal reservoir could be saved through improvement in exploration and assessment technology (Ward, 1978). Considered in light of the more than 200 high-temperature hydrothermal systems that are expected to be explored by industry in the United States by the year 2000, the accrued benefits will be approximately 40 times the estimated program costs (Dhillon, et al., 1978). This program will also provide significant benefits to exploration for and assessment of moderate- and low-temperature hydrothermal systems as well as to the other resource types.

TECHNICAL BARRIERS TO DISCOVERY AND ASSESSMENT OF GEOTHERMAL ENERGY

Technical, economic and institutional barriers strongly inhibit commercialization of geothermal energy in the United States. This fact was formally recognized by the Congress with the passage of Public Law 93-410. P.O. 93-410 and ERDA-86 both list goals and objectives to be accomplished in order to assist industry to develop geothermal energy. That industry needs this assistance is amply demonstrated in such documents as Ward (1978), Dhillon et al. (1978), and Nielson (1980).

Ward (1978) emphasized that the industry has not found efficient means for exploring for geothermal resources. This is clearly demonstrated by the variety of geoscience methods currently being used in the northern Basin and Range (Ward et al., in press). Dhillon et al. (1978) concluded from discussions with industry representatives that improved interpretation techniques were required if increased exploration success is to be realized. They also emphasized that the success of such a program as the Geothermal Exploration and Assessment Technology Program could be quantified by the increase in success ratios of geothermal wells. Nielson (1980) compared the success ratios of wells drilled by the geothermal industry with those drilled by the petroleum industry, and that comparison is shown in Table I. The poor track record of the geothermal industry is evident. Nielson (1980) pointed out that improved success ratios would increase the amount of geothermal resources found per exploration dollar expended, and would also increase the amount of geothermal exploration by making the return on investment more competitive with other resource types.

In order to address the basic goal of the Geothermal exploration and Assessment Technology Program and aid in removing the technical and associated economic barriers to the discovery and assessment of geothermal resources, the following barriers have been defined and are summarized in Table 2.

1. Conceptual and predictive models of geothermal systems are unreliable.

The geoscience methods used by the exploration geologist locate the structural controls and products of geothermal systems such as hydrothermal alteration and high heat flow. In general these methods do not define the geothermal system itself. Thus, as emphasized by Ward et al. (in press) it is necessary to have a conceptual model of the geothermal system to apply the proper exploration methods. This fact is also emphasized by an evaluation of the effectiveness of different exploration methods in different geothermal environments (Dhillon et al., 1978). When physical and chemical property values are assigned to the components of such models, they can be used to predict the expected surface, surface-to-borehole, and borehole-to-borehole response of the geological, geophysical, geochemical, and hydrological techniques which research geoscientists are trying to refine. Improvements in exploration tools could be developed much more rapidly if reliable reservoir models existed because these models, coupled with suitable numerical or analog analyses, could more quickly sort the many questions for potential technique improvement and thus allow the geoscientist to concentrate on the most fruitful means of attack.

Table 2: Summary of technical barriers to discovery and assessment of geothermal resources.

1. Conceptual and prediction models of geothermal systems are unreliable.

2. Regional- and district-scale exploration techniques are inadequate.

3. Drill site selection techniques need improvement and development.

4. Assessment methods need refinement and technology development.

5. Technology transfer needs stimulating.

2. Regional- and district-scale exploration techniques are inadequate.

The geothermal industry is presently drilling the best geothermal prospects in the U.S., i.e., systems easily found because of surface manifestations such as hot springs and fumaroles. However, there are large regions within the U.S. which do not show these manifestations but which may contain hidden geothermal resources. Efficient methods must be devised to assess the potential of these areas. The elimination of this barrier will result in the discovery of new geothermal districts. Within known districts it is probable that many buried resources remain undiscovered also. It is in these areas that the industry is presently turning its attention and where wildcat wells have the highest chance of success. As indicated in Table I, however, the success ratios for wildcat wells are quite low.

3. Drill site selection techniques need improvement and development.

The evidence for poor drill site selection techniques is demonstrated in Table I. Even in geothermal resource areas, step out drilling in 1978 (Smith et al., 1979) resulted in only one producing well out of seven drilled. It is difficult to determine, comprehensively, the strengths and weaknesses of available exploration techniques for the following reasons: the resource could be situated in a variety of geological structures and rock types; too few usable reservoirs have been found to provide sites for test and evaluation of improved techniques and instrumentation; and the technology currently in use or potentially available is complex. There is a need to be able to correlate the data of various exploration and assessment techniques with the reservoir characteristics determined by deep drilling to improve the

TABLE 1
Comparison of geothermal and oil and gas wells drilled
in U. S. 1975-1978 (Nielson, 1980)

	Total Geothermal Wells			Success Ratio	Geothermal Wildcat Wells			Success Ratio
Year	Drilled	Producers	Success Ratio	Total Oil & Gas	Drilled	Producers	Success Ratio	Oil & Gas Expl.
1975	46	37	.80	.644	6	1	.166	.233
1976	52	39	.75	.657	21	2-3	.95-.143	.265
1977	52	25	.38	.673	15	0	0	.270
1978	58	30	.52	.654	13	2	.154	.253

Data from: Dhillon et al., 1978; Smith and Matlick, 1976; Smith et al., 1977, 1978, 1979; and DOE/EIA, 1978.

TABLE 3
SUMMARY OF RECOMMENDATIONS OF TECHNICAL REVIEW COMMITTEES OF THE GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION
STRUCTURE, STRATIGRAPHY, AND IGNEOUS PROCESSES	1. Surface Geology -detailed geologic mapping -aerial photography	1	225K/yr	5 yrs
	2. K-Ar Dating --to refine models of relationship of magma systems & geoth. systems.	2	75K/yr	5 yrs
	3. Subsurface Studies Structural	3	40K/yr	
	Gravity (3 surveys/yr)		105K/yr	5 yrs
	4. Rock Properties	4	30K/yr	
	5. Igneous Studies Models of magma system evolution - chemistry.	5	155K/yr	3-5 yrs
EXPLORATION ARCHITECTURE	1. Refinement of MT		250K/yr	
	2. Groundwater effects on thermal measurements		100K/yr	
	3. Regional fluid geochem		100K/yr	
	4. Regional gas geochem		100K/yr	
	5. K-Ar dating - regional		100K/yr	
	6. Joint collection and inversion of data.		50K/yr	

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION
ELECTRICAL METHODS	1. EM modeling & inversion	1		
	a) cost-effective 2D & 3D modeling programs		300K/yr	3 yrs
	b) alternate inversion schemes		100K/yr	3 yrs
	2. Controlled source EM field studies	2	100K/yr	2 yrs
	3. Rock Properties	3	200K/yr	3 yrs
	4. Regional MT map	1	50K/yr	2 yrs
	5. Calibration sites & procedures	2	60K/yr	1 yr
	6. MT Workshop	3	20K/yr	
	7. Testing of following (no budget recommendation provided): -Induced Polarization -Magnetometric Resistivity -Long array MT -Singular coincident loop TPEM.			
WATER/ROCK INTERACTION	1. Mineralogy, geochemistry, + petrology in geothermal reservoirs.		600K/yr	2 yrs
	2. Workshop on water/rock in geothermics		25K/yr	
	3. Rock + fluid properties		200K/yr	2 yrs
	4. Geothermometers		175K/yr	2 yrs
	5. Obtain core			

COMMITTEE	RECOMMENDATIONS	PRIORITY	FUNDING	DURATION
THERMAL METHODS	1. Bottom hole T during drilling			
	2. Relations between thermal conductivity and physical parameters		60K/yr	3 yrs
	3. Effects of groundwater flow on thermal measurements		100K/yr	5 yrs
	4. "Free hole" Program		1000K/yr	5+ yrs
	5. Shallow & intermediate depth drilling		1500K/yr	
	6. Deep hole T transmission system.		100K/yr	3 yrs
SEISMIC METHODS	1. Data compilation and dissemination	1	100K/yr	
	2. Rock properties	2	75K/yr	2
	3. Research in processing & interpretation	3	75K/yr	2
	4. Seismic @ Valles Caldera	4	200K 100K	1st year 2nd year
	5. Clear Lake Survey	5	125K 25K	1st year 2nd year
	6. Microseismic noise @ Beowawe	6	30K 15K	1st year 2nd year
	7. Microearthquake	7	50K 50K	1st year 2nd year
	8. Basic research on microearthquake processing & interpretation	8	70K/yr	4 yrs

interpretation of surface and near-surface measurements. The current lack of a reliable exploration technology and the necessity for deep drilling make geothermal exploration a costly, high-risk undertaking.

4. Assessment techniques need refinement and technology development.

At the present time there is no reliable way to determine extent, depth, temperature, nature of fluid, or productivity of a potential geothermal resource -- without a number of deep drill holes which actually sample the reservoir. Yet deep drilling costs, especially in the reservoir rocks themselves, are very high. Accordingly, there would be a large cost benefit to geothermal development if less expensive surface and/or shallow drilling techniques could be used to make reservoir predictions or to extend substantially the data derived from fewer boreholes.

A number of the geoscience methods offer promise. Geochemical and isotopic thermometry show promise of reliable remote prediction of reservoir temperatures, but these techniques are still being developed. Electrical geophysical methods are potentially capable of detecting hot saline fluids in porous rocks and thus showing the current extent and depth of a reservoir, but unambiguous data interpretation has not been achieved. Other methods offer hope to solve parts of the the total problem.

5. Technology transfer needs stimulating.

Because the purpose of the federal involvement in geothermal development is the fostering of a viable geothermal industry, it is particularly important that new technologies are quickly and effectively transferred to industry for its use. The conventional techniques of technical reports and workshops are appropriate but inadequate. New means of making technology transfer both timely and effective need to be found.

BENEFIT OF IMPROVED EXPLORATION SUCCESS

Under the present tax structure an investment in a geothermal resource will not generate a return (ROI) until the field begins to generate revenue. Therefore, exploration companies have a need to reduce the required risk capital and reduce the time required to develop a given resource. Capital requirements can be reduced by streamlining the exploration stage leading to well siting. It is the aim of the Geothermal Exploration and Assessment Technology Program to not only make the exploration stage more efficient in terms of cost, but also to increase the reliability of the methods such that the success rate of wells is increased. The result will be an increased sucess rate of wells at a decreased cost of exploration required to site those wells.

Ward (1978) shows a cost estimate of industry's expenditures for discovery and assessment of a 200 MWe hydrothermal field. He estimated that the development cost of such a field is about $200 million and about $20 million is the cost required to prove the field. Thus 10 per cent of the total cost represents the risk capital required to interest major investors in supporting the project.

Ward et al. (in press) have presented an exploration architecture for hydrothermal systems in the Basin and Range which estimates that the exploration costs up to the deep testing of a geothermal target amount to approximately $350,000. Expenditures such as this are only warranted for high-temperature systems which are capable of generating electricity with presently available technology. It was esimated in the 1978 Program Plan that these front-end costs, exclusive of drilling, could be reduced by approximately 50% and the drilling success ratio could be increased. Dhillon et al. (1978) have estimated that a 29% increase in the success ratio can result in a savings of $287 million to $526 million (equivalent 1978 dollars) in the 1978-2000 time frame.

The most expensive stage in a geothermal exploration project is the drilling of production test holes. Geothermal well drilling costs have been discussed by Chappell et al. (1979). They have shown that costs have been escalating over the past decade at a rate which is higher than the average national inflation rate. They have also shown that average drilling costs increase exponentially as a function of depth. Figure 1 is duplicated from their paper and gives an idea of well costs as a function of depth. The FY 1979 budget for the Exploration and Assessment Technology Program was approximately $2,300,000. Examination of Figure 1 shows that $2.3 million is the approximate cost of one 9000 foot geothermal well. Total budget for FY 1980 is $__________ which is equivalent to one _______ foot geothermal well. Thus current expenditures are minimal, and by resulting in only one additional successful deep well, the entire yearly budget can be justified.

The above discussion emphasizes the high-temperature geothermal systems which are presently being explored for electric applications. Very little data on exploration for direct heat resources presently exists. Of course, drilling costs will be the same for the lower temperature resources. However, the lower value of individual resources will require low-cost, very efficient

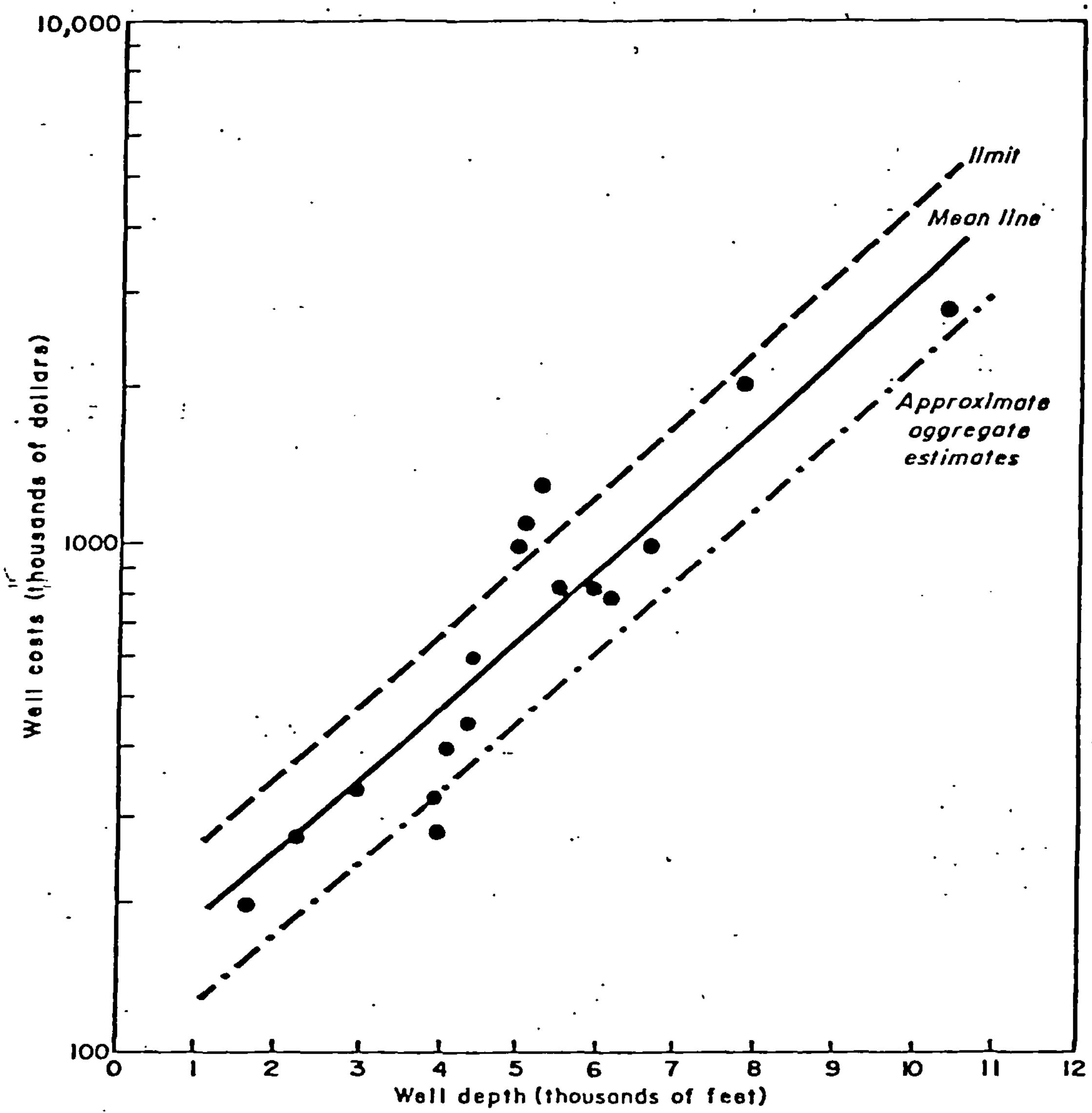


Figure 1: Wells costs vs. depth. (Chappell et al., 1979).

exploration prior to the siting of a test well. The resources themselves are probably going to be as difficult to find as the high-temperature systems. During FY 1980, the Geothermal Exploration and Assessment Technology Program will provide a significant component in the development of exploration case studies and the formulation of exploration architectures for low- to intermediate-temperature geothermal systems. Rising energy costs have stimulated broad interest in the direct heat applications and it is the charter of the Division of Geothermal Energy to encourage the development of these resources. We do not at the present time have sufficient data to give a quantitative benefit analysis of the Geothermal Exploration and Assessment Technology Program in lower temperature environments; however, high exploration costs and lack of models of the geothermal systems could easily dampen the enthusiasm which currently exists for their development.

TECHNICAL PLAN

GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

Technical Review Committee Approach to Task Definition

In order to initiate this DOE program and define specific needs of the geothermal exploration industry, seven consortia of geothermal experts were convened during late 1977 and early 1978 to define technical problems facing the industry. The reports of these consortia were reviewed by managers from industry, and the resultant recommendations were used to formulate FY 1979 DOE procurements and to define technology development programs at the Earth Science Laboratory/University of Utah Research Institute, the Department of Geology and Geophysics/University of Utah, and the Lawrence Berkeley Laboratory. The reports of the seven consortia along with the review by industry managers are documented by Ward (1978). A DOE program plan for the Geothermal Exploration and Assessment Technolgy Program is based on this document (Univ. of Utah, Dept. Geol. and Geophys., 1978).

The technical review committees of the Geothermal Exploration and Assessment Technology Program are made up of experts from industry as well as academic and research institutions. There are currently six committees which cover these areas: Water/Rock Interaction; Structure, Stratigraphy, and Igneous Processes; Exploration Architecture; Electrical Methods; Seismic Methods; and Thermal Methods. These committees meet to define the state-of-the-art in geothermal exploration and to recommend exploration technology development. Figure 2 illustrates the role of these committees in defining the specific tasks of the Geothermal Exploration and Assessment

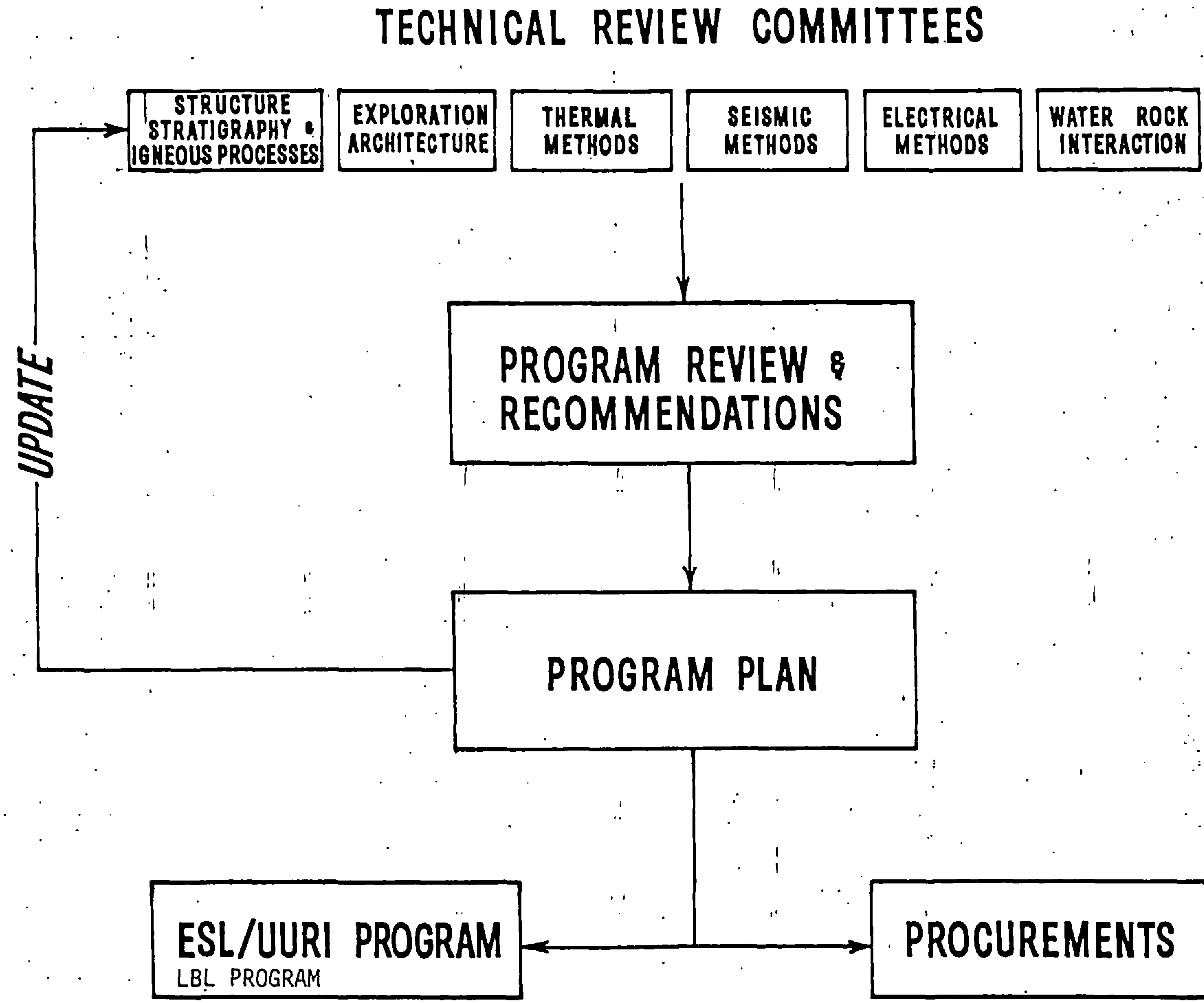

TECHNICAL REVIEW COMMITTEES
STRUCTURE STRATIGRAPHY & IGNEOUS PROCESSES
EXPLORATION ARCHITECTURE
THERMAL METHODS
SEISMIC METHODS
ELECTRICAL METHODS
WATER ROCK INTERACTION
UPDATE
PROGRAM REVIEW & RECOMMENDATIONS
PROGRAM PLAN
ESL/UURI PROGRAM
LBL PROGRAM
PROCUREMENTS

FIGURE 2

technology Program. The reports of the individual committees are contained in Nielson (1980), and their recommendations are summarized in Table 3.

4.2 Task Descriptions--Earth Science Lab/UURI and UU/GG

The Earth Science Laboratory/University of Utah Research Institute and the Dept. of Geology and Geophysics/ University of Utah are involved in a number of continuing studies aimed at reducing the importance of the barriers which were defined in Table 2. These studies are derived from recommendations of the technical review committees and might be generalized as follows.

Integrated geological, geochemical, and geophysical studies are underway to develop conceptual models of geothermal systems. Up to this time, these studies have concentrated on the high-temperature systems, specifically Roosevelt Hot Springs, Utah. However, new efforts are underway to develop similar models for low- to moderate-temperature geothermal resources. From the knowledge generated by the above work, exploration strategies for the low- to moderate-temperature resources will be developed.

Studies of trace elements and stable isotopes are contributing to the above system models and are being specifically directed toward prediction of approach to fluid entries in geothermal test wells. Empirical relationships have been established and work is presently underway to quantify the methods.

Studies of the application of electrical geophysical techniques to the exploration for geothermal resources is an additional ongoing program. This work involves the testing of resistivity, induced polarization, magneto-telluric, audio-magnetotelluric, and electromagnetic systems in geothermal areas. In additon, two- and three-dimensional modeling routines are being developed and tested.

4.3 Lawrence Berkeley Laboratory Task Descriptions

4.4 Procurements for FY 1980

Procurements for FY 1980 are in the preliminary evaluation stages. Following the recommendations of the Technical Review Committees and in light of the limited amount of funding available, the following topics will be addressed:

1. Identify, describe, and interpret the characteristic signatures of water/rock interactions and their systematic variations in recording fluid flow and thermal history in active hydrothermal systems.

2. Improve and develop geothermometers.

3. Establish the basis of empirical relationships between thermal conductivity and physical parameters derived from standard geophysical well logs.

4. Establish standards for calibration and testing of electrical methods.

5. Evaluate microearthquake surveys as an exploration method for geothermal systems.

4.5 Relationship of Tasks to Barriers

The relationships of the above defined tasks to the barriers summarized in Table 2 are shown in Table 4. As shown, each barrier is addressed by a number of different tasks.

Table 4: Relationships of tasks to barriers which inhibit the exploration and assessment of geothermal resources.

MANAGEMENT PLAN

GEOTHERMAL EXPLORATION AND ASSESSMENT TECHNOLOGY PROGRAM

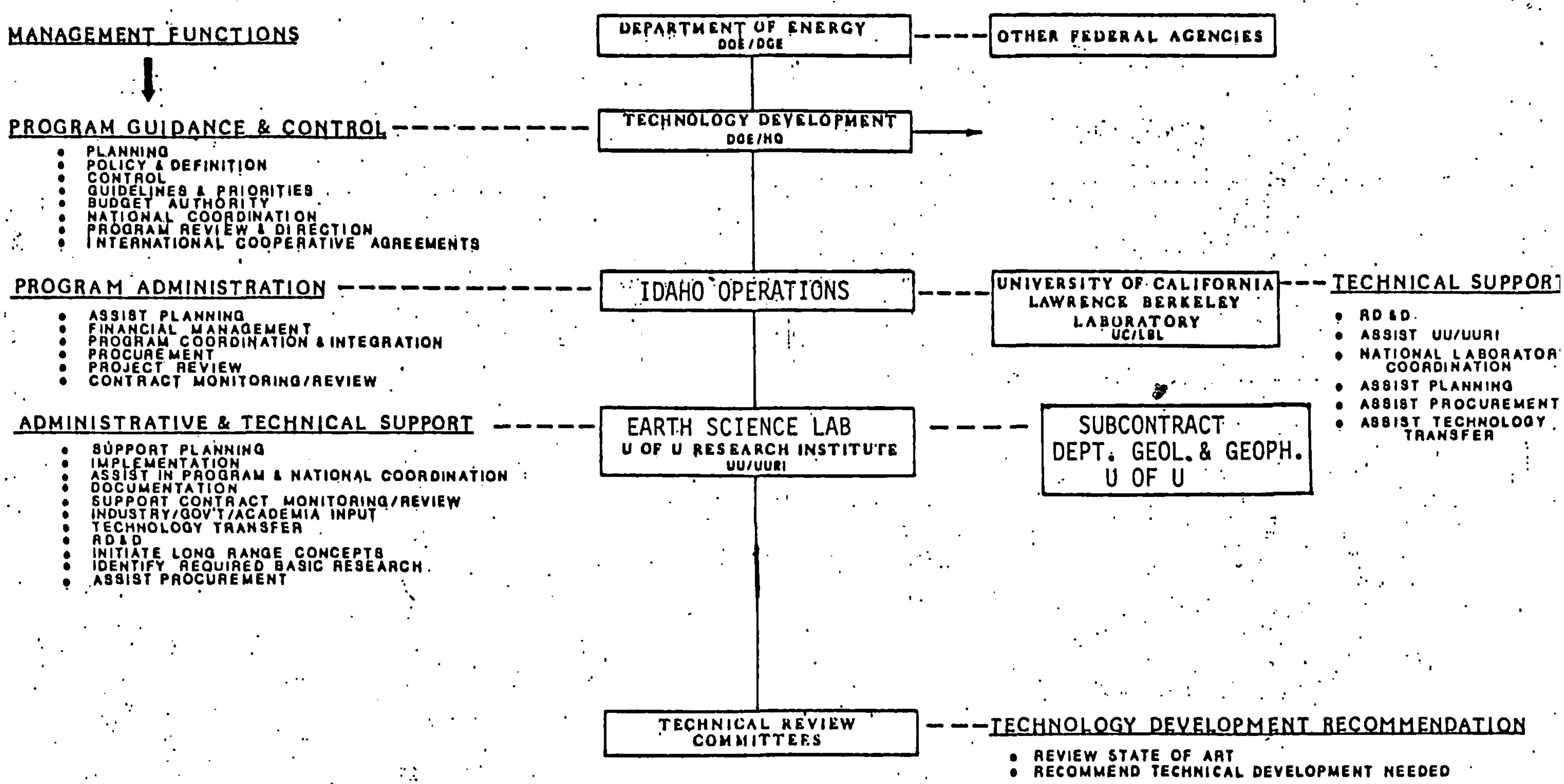
Figure 3 portrays the management structure for the Program in Geothermal Exploration and Assessment Technology. Figure 4 portrays the flow of information and the coordinating structure vis-a-vis other related programs. Every effort will be made a) to design minimum but essential overlap with other related programs, and b) to support interface efforts concerned with resource types other than hydrothermal.

5.1 DOE/DGE

The Manager, Exploration Technology, acting with the concurrence of the Program Manager, Geothermal Technology Development and with the concurrence of the Director, Division of Geothermal Energy (DOE/DGE) will provide overall programmatic guidance for the definition, planning, direction, and control of the Program in Exploration Technology. DOE/DGE will also provide overall financial guidance to the DOE-supported participants in the program, including subprogram-level guidance to the Geothermal Program at the Idaho Operations Office. The Manager for Exploration Technology will be responsible for coordinating this program with national geothermal program elements contained within DOE, as illustrated in Figure 4, and with the USGS and other agencies participating in the national geothermal program.

5.2 DOE Idaho Operations Office

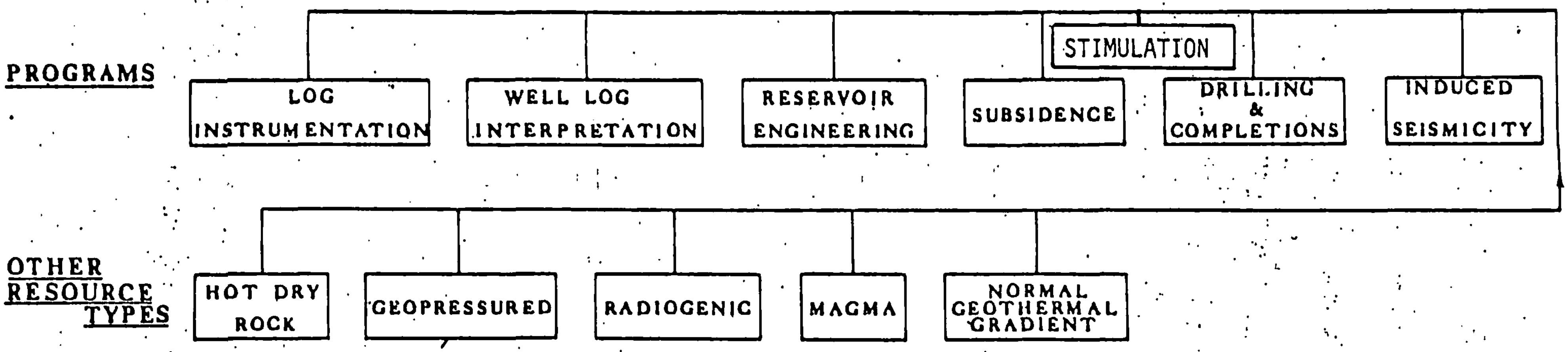
The Office of Geothermal Energy, Idaho Operations Office, will provide program administration including planning assistance, financial management,



MANAGEMENT FUNCTIONS
PROGRAM GUIDANCE & CONTROL
• PLANNING
• POLICY & DEFINITION
• CONTROL
• GUIDELINES & PRIORITIES
• BUDGET AUTHORITY
• NATIONAL COORDINATION
• PROGRAM REVIEW & DIRECTION
• INTERNATIONAL COOPERATIVE AGREEMENTS
PROGRAM ADMINISTRATION
• ASSIST PLANNING
• FINANCIAL MANAGEMENT
• PROGRAM COORDINATION & INTEGRATION
• PROCUREMENT
• PROJECT REVIEW
• CONTRACT MONITORING/REVIEW
ADMINISTRATIVE & TECHNICAL SUPPORT
• SUPPORT PLANNING
• IMPLEMENTATION
• ASSIST IN PROGRAM & NATIONAL COORDINATION
• DOCUMENTATION
• SUPPORT CONTRACT MONITORING/REVIEW
• INDUSTRY/GOV'T/ACADEMIA INPUT
• TECHNOLOGY TRANSFER
• RD&D
• INITIATE LONG RANGE CONCEPTS
• IDENTIFY REQUIRED BASIC RESEARCH
• ASSIST PROCUREMENT
DEPARTMENT OF ENERGY
DOE/DGE
OTHER FEDERAL AGENCIES
TECHNOLOGY DEVELOPMENT
DOE/HQ
IDAHO OPERATIONS
UNIVERSITY OF CALIFORNIA
LAWRENCE BERKELEY
LABORATORY
UC/LBL
TECHNICAL SUPPOR
• RD&D
• ASSIST UU/UURI
• NATIONAL LABORATOR
COORDINATION
• ASSIST PLANNING
• ASSIST PROCUREMENT
• ASSIST TECHNOLOGY
TRANSFER
EARTH SCIENCE LAB
U OF U RESEARCH INSTITUTE
UU/UURI
SUBCONTRACT
DEPT. GEOL. & GEOPH.
U OF U
TECHNICAL REVIEW
COMMITTEES
TECHNOLOGY DEVELOPMENT RECOMMENDATION
• REVIEW STATE OF ART
• RECOMMEND TECHNICAL DEVELOPMENT NEEDED

FIGURE 3

FIGURE 4


PROGRAMS
LOG INSTRUMENTATION
WELL LOG INTERPRETATION
RESERVOIR ENGINEERING
STIMULATION
SUBSIDENCE
DRILLING & COMPLETIONS
INDUCED SEISMICITY
OTHER RESOURCE TYPES
HOT DRY ROCK
GEOPRESSURED
RADIOGENIC
MAGMA
NORMAL GEOTHERMAL GRADIENT

program coordination and integration, procurement, project review, contract monitoring/review and procurement activities.

5.3 Earth Science Lab/University of Utah Research Institute (ESL/UURI)

ESL/UURI will provide administrative and technical support for exploration and assessment technology. In detail, ESL/UURI will be reponsible for: planning support; program implementation; assisting in program and national coordination; program documentation; supporting contract monitoring and review; obtaining and collating industry, government and academic inputs; assuring technology transfer; conducting RD & D; initiating the development of long-range conceptual models of geothermal resource types; and identifying items requiring applied and basic research in support of the program.

5.4 University of California/Lawrence Berkeley Laboratory (UC/LBL)

The UC/LBL activities may include assistance with program planning, procurement, technology transfer, coordination of the efforts of related programs at UC/LBL and at other national laboratories, and conducting RD & D.

5.5 Relationship to Other Programs

It will be the responsibility of DOE/DGE to ensure coordination of this program with USGS geothermal programs. DOE/DGE also will ensure coordination with regional and generic programs in hydrothermal and other resource types as shown in Figure 4.

MEMORANDUM

January 22, 1980

TO: Christensen, Moore, Cole, Capuano, Glenn, Wright, Ward, Sill, Ross, Schaff

FROM: Nielson

RE: Procurement writing assignments: Exploration and Assessment Technology Program

As part of our Exploration and Assessment Technology Program, we provide assistance to DOE in writing RFP's and PRDA's. As I indicated in a previous memo, about $500K is available for outside work. The recommendations of the previous memo have been approved by DOE and they would like drafts by February 15.

Would you please write a procurement along the lines indicated by the enclosed suggestion from the Marina del Rey Conference. These documents should have the following:

1. INTRODUCTION: which states the problem and its importance in geothermal exploration. Any references pertinent to the problem should be included in this portion of the write-up.

2. STATEMENT OF WORK (SOW): This portion of the procurement should define the work to be done. Be specific about content of reports and field or laboratory tests required.

Also comment upon the budget requirements of the procurement you are developing. Because of funding limitations, it would be good to keep these in the $100K range, but do not sacrifice a good product to do this. You also have the option of arguing that the project is not worth doing. It is also possible to have more than one study under each topic. For instance, it may be desireable to have one procurement which deals with high-temperature application of geothermometry and another which concentrates on development of low-temperature geothermometry

I anticipate that these assignemts should only take the working group a couple of hours. If you have any questions, please contact me. Please charge to 69991 (geology), 69992 (geophysics), or 69993 (geochemistry).

Den.

WORKING GROUPS

I. Water/Rock Interaction

Christensen
Moore

II. Geothermometer (USGS Coop)

Cole
Capuano

III. Thermal Conductivity vs. Geophysical Well Logs.

Glenn
Wright

Bob Gray recommends you talk with John Costain to make sure this is not a diplication of effort.

IV. Calibration of Electrical Methods

Ward
Sill

V. Microearthquake Survey and Analysis

Ross
Schaff

of geothermometers in high-T environments. Drafting of procurement to be coordinated with USGS.

III. ESTABLISH EMPIRICAL RELATIONS BETWEEN THERMAL CONDUCTIVITY AND PHYSICAL PARAMETERS DERIVED FROM STANDARD GEOPHYSICAL WELL LOGS.

Level of Funding. $75,000

Introduction

The purpose of this study is to derive empirical relationships between thermal conductivity and other physical parameters such as velocity, porosity, density, etc., that can be obtained from standard geophysical well logs. This type of correlation between thermal conductivity and physical parameters derived from geophysical well logs has been established for sandstones primarily from the geothermal areas of the Imperial Valley. The intent of this study is to determine these correlations for other rock types with emphasis on igneous, metamorphic, and sedimentary rocks from geothermal environments. With the establishment of these empirical correlations between thermal conductivity and physical parameters from standard geophysical well logs, many new heat flow values and thermal properties as a function of depth can be obtained from previously existing boreholes, e.g., oil and gas wells, uranium holes, deep water wells, and geothermal wells which were geophysically logged as well as from newly drilled ones, such as the DOE/DGE industry coupled geothermal wells.

Scope of Work

Develop empirical relations between thermal conductivity and physical parameters derived from standard geophysical well logs. Measure the thermal conductivity of drill cutting and/or cores obtained from intermediate (300m) to deep (5 km) boreholes that have a suite of geophysical logs run in them. Determine a suite of physical parameters, i.e., porosity, density, sonic velocity, etc., from the geophysical logs. Perform regression analysis on these interrelated physical parameters to establish empirical relations for thermal conductivity as a function of rock type. Perform this type of analysis on several of the DOE/DGE industry coupled geothermal holes in order to confirm the validity of the empirical relations.

Types of Holes

It is not intended that this study be restricted to geothermal wells, rather, oil and gas tests on any other suitably logged wells should be utilized. However, the study does overlap with and would benefit from any proposed study involving coring, logging, and normal conductivity analysis at geothermal wells.

IV. RECOMMENDATIONS ON STANDARDS FOR CALIBRATION AND TESTING OF SYSTEMS FOR ELECTRICAL METHODS.

Level of Funding. $60,000

Standard calibration schemes are needed for the deterministic testing of electrical data acquisition and reduction systems. Such schemes would provide the means for reliable assessment of entire system performance, including the instrumentation and any subsequent data reduction employed. Standard specifications would enhance uniformity of knowledge and application in the industry.

OTHER EXPLORATION TECHNOLOGY PROJECTS (RFP, PRDA)

1. Self Potential Research (RFP)

   (a) Accumulate a data base of SP anomalies over known geothermal areas.

   (b) Develop new analytical solutions:
   - vertical fault solution (solved)
   - dipping fault solution
   - complext fault zones; more than one vertical contact

   (c) Study the phenomena and explain the physics better.

   (d) Measure coupling coefficients in situ at geothermal reservoirs.

2. Active Seismic Research (PRDA or RFP)

   (a) Study feasibility, design an experiment, and/or perform simulation regarding use of high resolution (active) seismic and 3D migration.
   (1) to discern structure at selected geothermal reservoirs.
   (b) monitor changes in liquid/vapor conditions.

   (b) Conduct field experiment to detail a geothermal reservoir by means of a 2D seismic survey and 3D migration techniques-

3. Magnetotelluric Research (RFP or PRDA)

   (a) Assemble, evaluate, discuss MT survey results and interpretations for various specific and/or general geothermal areas:
   e.g., Salton trough, other rift valleys
   Central Nevada - Basin and Range
   High Cascade volcanic province
   Volcanic Calderas, volcanic covered areas
   (RFP (1981, 1982)

   (b) Develop new concepts for 3D MT interpretation (PRDA, RFP, or both).

MEMORANDUM

TO:	S. H. Ward	S. H. Evans	D. Foley
	P. M. Wright	H. P. Ross	R. L. Bruhn
	W. E. Glenn	W. R. Sill	J. R. Bowman
	J. N. Moore	S. C. Schaff	G. W. Hohmann

FROM: D. L. Nielson

SUBJECT: Procurements: Exploration and Assessment Technology Program.

External review of the recommendations of the Marina del Rey Technical Review Committees produced only six responses from industry (Union-2, Microgeophysics-1, Phillips-1, Southland Royalty-1, and Earth Power Production-1). Two of the respondants were committee members at Marina del Rey.

Approximately 500K is available for procurements to address priorities set at the conference and by the subsequent external review. The following topics have received top priority and we will develop procurements to address some of the topics. In order to be useful as a procurement, the project must be well defined and be able to produce significant advances within the normal contract period of one year. In addition, due to limited funding, awards should be less than $100K. It is possible to make more than one award under each topic.

I am considering the following for funding. Your comments will be appreciated.

I. IDENTIFICATION, DESCRIPTION AND INTERPRETATION OF THE CHARACTERISTIC SIGNATURES OF WATER/ROCK INTERACTIONS AND THEIR SYSTEMATIC VARIATIONS IN RECORDING FLUID FLOW AND THERMAL HISTORY IN ACTIVE HYDROTHERMAL SYSTEMS.

Level of Funding. $100,000

Justification. In order to explore intelligently, we need better definition of exploration targets. Such studies will also provide the scientific underpinnings for reservoir assessment, reservoir engineering and field management.

Specific Approaches. A PRDA should be requesting basic studies of subsurface mineralogy, petrology and geochemistry in specific geothermal reservoirs for which adequate surface geophysics exist and which have been drilled adequately so that the nature of the resource is known and reasonable subsurface sampling exists.

The approach should be broadly integrative and use a variety of techniques. It could include studies of hydrothermal mineral zoning, isotropic and chemical analyses, geothermometry and studies of physical properties of rocks. The aim would be to study these parameters in three dimensions and to investigate how these reservoirs evolved in space and time. This can only be achieved in fields where drilling is adequate. These results can then be compared with the surface signature to test various surface geothermometers, vectoring techniques and other exploration methods. Attention must also be given to developing the appropriate techniques of sampling gases, fluids, and solids both in the wells and at the surface.

The studies may involve studies of some fields which have not yet been well characterized from the point of view of water/rock reactions, but for which drill samples exist, or may involve the improvement and development of on-going projects on fields which have been better investigated. The fields chosen should include a range of high to low temperatures, and of different rock types, fluid chemistry and fracture control.

NOTE: ESL plans studies at Roosevelt, Beowawe, and Baltazor.

II. IMPROVEMENT AND DEVELOPMENT OF GEOTHERMOMETERS.

Level of Funding. $100,000

Justification. Geothermometers are useful, cost-effective and poorly understood exploration tools, which are commonly misapplied. There is a need to develop new and refine old methods, and to put them on a sound basis of theory.

Specific Approaches. A PRDA should be issued on the general topic of geothermometry requesting the development, refinement, improvement and testing of various geothermometers. Solute, isotopic, organic and radiogenic methods could be included. They should apply to high and low temperatures. Specific input on the chemical, thermodynamic, and kinetic controls of the geothermometers should be sought. Such an approach will develop new families of geothermometers and put limits on the applicability of existing ones.

NOTE: It may be advantageous to break this up into two procurements. One dealing with the development of geothermometers for low-temperature environments and the other dealing with refinement and improvement of geothermometers in high-T environments. Drafting of procurement to be coordinated with USGS.

III. ESTABLISH EMPIRICAL RELATIONS BETWEEN THERMAL CONDUCTIVITY AND PHYSICAL PARAMETERS DERIVED FROM STANDARD GEOPHYSICAL WELL LOGS.

Level of Funding. $75,000

Introduction

The purpose of this study is to derive empirical relationships between thermal conductivity and other physical parameters such as velocity, porosity, density, etc., that can be obtained from standard geophysical well logs. This type of correlation between thermal conductivity and physical parameters derived from geophysical well logs has been established for sandstones primarily from the geothermal areas of the Imperial Valley. The intent of this study is to determine these correlations for other rock types with emphasis on igneous, metamorphic, and sedimentary rocks from geothermal environments. With the establishment of these empirical correlations between thermal conductivity and physical parameters from standard geophysical well logs, many new heat flow values and thermal properties as a function of depth can be obtained from previously existing boreholes, e.g., oil and gas wells, uranium holes, deep water wells, and geothermal wells which were geophysically logged as well as from newly drilled ones, such as the DOE/DGE industry coupled geothermal wells.

Scope of Work

Develop empirical relations between thermal conductivity and physical parameters derived from standard geophysical well logs. Measure the thermal conductivity of drill cutting and/or cores obtained from intermediate (300m) to deep (5 km) boreholes that have a suite of geophysical logs run in them. Determine a suite of physical parameters, i.e., porosity, density, sonic velocity, etc., from the geophysical logs. Perform regression analysis on these interrelated physical parameters to establish empirical relations for thermal conductivity as a function of rock type. Perform this type of analysis on several of the DOE/DGE industry coupled geothermal holes in order to confirm the validity of the empirical relations.

Types of Holes

It is not intended that this study be restricted to geothermal wells, rather, oil and gas tests on any other suitably logged wells should be utilized. However, the study does overlap with and would benefit from any proposed study involving coring, logging, and normal conductivity analysis at geothermal wells.

IV. RECOMMENDATIONS ON STANDARDS FOR CALIBRATION AND TESTING OF SYSTEMS FOR ELECTRICAL METHODS.

Level of Funding. $60,000

Standard calibration schemes are needed for the deterministic testing of electrical data acquisition and reduction systems. Such schemes would provide the means for reliable assessment of entire system performance, including the instrumentation and any subsequent data reduction employed. Standard specifications would enhance uniformity of knowledge and application in the industry.

The committee recommends establishment of standards for calibration by two means: A) synthetic data tests, and B) standard field test sites. Use of both schemes is recommended as the synthetic data test provides an accurate test of the system without uncertainties introduced by the noise and conditions of field environment, and the standard test site allows evaluation of performance with actual sensor installation and under field conditions.

A) Synthetic Data Test

Synthetic data test schemes are required for two basic types of methods:

a) The natural source system calibrator consists of a signal generator driving a network which produces electric (E) and/or magnetic (H) field signals of known characteristics as required by the method. A sample MT system calibrator consists of resistive attenuators to produce the E-field signals and a long current helix (or alternately a Helmholtz coil arrangement) to produce the H-field signals. E and H component groups, say (Ex, Hy) and (Ey, Hx, Hz), can each be driven by independent random noise generators. The effective MT impedance is determined by the source network parameters.

b) The controlled source system calibrator consists of a passive network which accepts the controlled source output and produces signals with known transfer characteristics to drive the receiving instrument(s).

For some systems a portion of the system might need to be deleted from the synthetic data test, for example, a large loop antenna for a magnetic source. For such a case, the missing portion of the system would need to be represented in the calibration network or accounted for in the expected response. Field calibration on an actual site of known characteristics should finally be performed to test integrity of actual sensor installation and overall field techniques.

Geotronics Corporation has already devised and implemented an MT synthetic data calibration scheme, and it was therefore recommended by the Electrical Methods committee that Darrell Word publish in Geophysics a short note documenting the scheme in order to make the information available in the literature.

B) Standard field test sites

Standard calibration and test sites for electrical methods equipment would:

1) Allow existing field equipment to be calibrated over known resistivities to ensure that accurate data is being obtained under field conditions.
2) Provide well-documented test sites for newly developed equipment and modifications of existing equipment.

There was general agreement that the following conditions should be satisfied in establishing the standard sites:

1. For convenience of access there should be several sites in different geographic areas.
2. There should be both "difficult" sites with complex subsurface geometry and "easy" sites which should approximate simple half-space or horizontally layered conditions.

3. The sites should be as well documented as possible; areas with good control over subsurface geometry and resistivity from deep well logs should be sought. This will be especially valuable in evaluating the performance of newly designed equipment. It may also be desirable to conduct electrical surveys of lands immediately adjacent to the calibration sites to determine what interference with calibration might be expected due to nearby bodies with contrasting conductivities.

4. Standard electrode positions should be clearly and permanently marked for equipment calibration use in order to achieve reproducible results. Such permanently marked electrode positions might, for example, be provided for X-spread MT and dipole-dipole soundings while leaving the experimenter with new equipment free to choose his own configuration.

To implement and make available a useable set of calibration standards for the electrical methods, the consortium recommends funding of a small program to produce a concise set of specifications of standards for both synthetic data testing and field testing and to produce a single document of the specifications. The program should include a definition of the synthetic data schemes and the selection and description of field test sites and test procedures. The synthetic data calibration systems should be as basic and straightforward as is feasible for ease of reproduction. The field test sites should be selected in each of several locations on the basis of access convenience as well as various technical considerations.

Some work to this end has already been done by various groups and individuals; e.g., some test sites have been established and used, and some effective schemes for synthetic data calibrations are in use. The existing work need to be extended and systematized toward production of the standard specifications.

It is recommended that an ad hoc committee be appointed to define an RFP on the overall project, to be let by DOE. The RFP should allow for subcontracting of portions of the work, such as evaluation of proposed test sites, outside consulting on the calibration systems, and appropriate physical marking of the test sites.

V. MICROEARTHQUAKE SURVEY AND ANALYSIS

Level of Funding. $100,000

The geothermal industry is spending a large fraction of their budget on microearthquake surveys. Instrumentation is currently being developed to provide digital data in a cost-effective manner. Additional high quality data is needed within the public domain to evaluate the utility of the method. The individual seismograms are needed for the basic research on extracting the most information from this data. This research will have an immediate impact on exploration technology for geothermal resources. Research should focus on more accurate hypocenter location using 3-D velocity models, fault plane solutions, estimating stress drop, energy release, and b-slopes for geothermal regions using the spectra of microearthquakes. The hypocenters of microearthquakes mark active fault zones and indicate the level of seismicity that exists. In future prospect studies, microearthquake surveys should be performed with 12-bit, 3 component, multi-station (12-16) arrays. These data would provide a basis for research on the relationship between geothermal reservoirs and microearthquake occurrence. Because of the continued data acquisition and interest by industry users in microearthquakes as an exploration tool, an increase in the cost-effectiveness of this method through improved interpretation techniques and acquisition equipment will have an immediate impact on the geothermal exploration program. Recent equipment development will provide the opportunity to define the existence of the elusive "geothermal earthquake". By defining a uniqueness associated with earthquakes in geothermal regions, especially in Basin and Range prospects, a cost-effective exploration method would be developed. Areas of research should include detailed locations using 3-D velocity models and energy release (in space and time), spectral analyses for source characterization, and V_p/V_s, Q_p/Q_s modeling. These data should then be compared with regional data to detect any anomalous behavior.

Propagation characteristics of P- and S-waves have shown that this technique is useful for detecting velocity and attenuation anomalies associated with hydrothermal alteration, fluid content, structural inhomogeneities, faults, and elevated temperatures. Depending on station spacing and frequency band, P-wave delays are useful for outlining deep, broad anomalies associated with heat sources as well as for near-surface phenomenon such as densification due to hydrothermal alteration and change in fluid content or state. S-wave propagation characteristics are useful for determining Poisson's ratio and fluid content. Surface wave studies should be directed toward inversion for Q as well as S-wave velocity and crustal thickness.

A detailed microearthquake survey should be recorded across a geothermal prospect. Teleseismic and regional earthquakes can be recorded simultaneously and will provide a model of the velocity and attenuation variations deep within the crust. The data acquired in this survey will be interpreted by hypocenter locations to map active faults, velocity and attenuation anomalies, and fault plane solutions related to the stress regime. In addition, it will provide data for long-term basic research on utilization contained in microearthquake surveys.

VI. WORKSHOP

Funding: 15K

Abundant data on geothermal areas has been acquired in recent years under the sponsorship of DOE and USGS. Often various geoscience data sets exist for specific areas, but no synthesis and interpretation has been attempted. It is highly effective to bring together various workers to foster data integration and the formulation of exploration models.

Please advise me if these topics overlap with any research that you know about. I have tried to avoid duplication of work being carried out at GG and ESL. Also comment on usefulness, budget, and specific statements of work for the projects. The above suggested funding totals $450K which gives us some amount of flexibility in adding projects and redefining projects listed here.

Other projects that may be funded are:

1. Acquisition of core as add on to Industry Coupled monies.
2. Basic research into the significance of the "deep conductor" detected by MT soundings.

3. Compilation of regional seismic data.

4. Refinement and comparison of volatile geochem methods.

EXPLORATION TECHNOLOGY MEETING
SALT LAKE CITY, UTAH

JANUARY 15, 1980

PROPOSED AGENDA

I. Review of Current Projects

   A. UURI/UU
   B. LBL
   C. IDO - Current Procurements

II. Development of Rationale and Approach for Future Projects

   A. Objectives
   B. Mix Between In-house and Extra - Mural Activities.
   C. Direction of In-house projects
   D. Future Procurements
   E. Milestones for Program
   F. Criteria for Evaluating Success of Program
   G. Update of Program Plan

III. Spending Plan for FY 1981

IV. Structure and Input of Technical Review Committees