ENGINEERING & ECONOMICS RESEARCH, INC.

DISCLAIMER

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

DISCLAIMER

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

GEOCHEMICAL ENGINEERING AND
MATERIALS PROGRAM PLAN

August 1982

Prepared For:

Geothermal and Hydropower Technologies Division

U.S. Department Of Energy

Project Officer:

Leon Lehr

Prepared By:

Engineering and Economics Research, Inc.

1951 Kidwell Drive

Vienna, Virginia 22180

Contract No. DE-AC-01-81RA-50415

EER Project No. ET23H

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
A. Purpose of Program	1
B. Problem Definition	2
C. Rationale	5
D. Objectives	7
E. Strategy	8
II. PROGRAM CONTENT	9
A. Program Structure	9
B. Program Elements	9
1. Materials for Borehole Components	9
2. Materials for Energy Conversion Components	10
3. Materials Testing and Corrosion Control	11
4. Fluid Characterization	12
5. Geochemical Monitoring and Control	13
6. Fluid Handling	15
III. IMPLEMENTATION PLAN	17
A. Management Approach	17
B. Multi-Year Activity Schedule	18
C. Environmental Considerations	18
IV. RESOURCE REQUIREMENTS	20
A. Budget Estimates	20
B. Person Power Estimates	20
V. MANAGEMENT PLAN	23
A. Assigned Responsibilities	23
B. Project Management	23
C. Major Milestones	23

LIST OF EXHIBITS

	<u>Page</u>
1. Some Significant Geochemistry and Materials Related Problems Experienced or Expected in Site-Specific Developments	3
2. Activity Schedule By Program Element	19
3. Estimated Budget Requirements By Program Element	21
4. Estimated Person-Year Requirements By Program Element	22
5. Major Outyear Milestones for GEM Program	24

I. INTRODUCTION

A. Purpose of Program

The Department of Energy (DOE) was designated as lead agency in discharging the overall legislative mandate* for federal R&D to assist the private sector in developing appropriate technology for exploiting geothermal energy resources. The Geochemical Engineering and Materials (GEM) Program was conceived, as part of DOE's overall strategy, to address specific and plant-wide problems and uncertainties in the use of materials and in geochemical engineering. This program assists industry in the conduct of long-term, high-risk R&D needed to overcome the significant technical and economic GEM-related obstacles faced by developers and potential developers of this alternative energy source. The program focusses on:

- Increasing the knowledge about the properties of materials and their performance under geothermal energy system conditions
- Developing and utilizing more reliable and/or cost-effective materials than previously available
- Developing a greater understanding of and control over geochemical processes during fluid production and transport, energy conversion, and waste management.

As a stand-alone program and as support to other DOE geothermal technology development programs, the GEM Program contributes to the feasibility of designing and operating efficient, reliable, and safe fluid handling and energy conversion systems.

* • Geothermal Energy Research, Development, and Demonstration Act of 1974.
• Federal Non-nuclear Energy Research and Development Act of 1974.
• Geothermal Steam Act of 1970.

B. Problem Definition

Technical and economic materials-related problems have figured prominently since the early attempts to design and operate geothermal energy systems, particularly for electricity generation. Numerous and occasionally very expensive materials failures have been experienced in the field, sometimes due to the unavailability of appropriate materials, a lack of awareness of suitable materials already existing, or a lack of knowledge about geochemical characteristics and behavior.

Similarly, inefficient and ineffective components and systems have been designed and occasionally constructed on the basis of erroneous or incomplete geochemical data. Furthermore, the day-to-day operation of even a properly designed geothermal energy facility requires constant monitoring and data analysis to maintain optimum performance and avoid downtime-causing occurrences.

Exhibit 1 identifies selected significant technical problems which have been experienced or are anticipated at a number of U.S. geothermal development sites, both for electric and direct-heat applications. These examples illustrate the range of problems of concern and reveal the special need for publicizing successes and failures within the geothermal community.

In the materials area, the major problem-areas which have been addressed in the past and which still require further R&D are:

- Corrosion (e.g., general, pitting, crevice, fatigue, stress, corrosion cracking)
- Non-corrosive (chemical, physical and thermal) degradation of materials

EXHIBIT 1

SOME SIGNIFICANT GEOCHEMISTRY AND MATERIALS RELATED PROBLEMS

EXPERIENCED OR EXPECTED IN SITE-SPECIFIC DEVELOPMENTS

SITE	TYPE OF UTILIZATION SYSTEM *	LOCATION OF PROBLEM	DESCRIPTION OF PROBLEM	CAUSE OF PROBLEM
Raft River, ID	Electric, binary	Production wells	Failure of a number of downhole pumps	Miscellaneous causes, including adverse effects of fluid on pump materials
		Cooling system	Short expected service life of surface-contact condenser and reduced brine flow rates	Corrosion of inappropriately selected carbon steel condenser and scaling in the condenser (the cooling system uses aerated geothermal water).
East Mesa, CA	Electric, binary	Production well	Failure of a number of downhole pumps	Miscellaneous causes, including adverse effects of fluid on pump materials
		Energy conversion system	Cross-contamination of brine and working fluid streams	Inadequate design and/or operating procedures of heat exchange system
		Energy conversion system	Catastrophic failure of condenser	Corroding through (internal and external) of HX tubes
		Energy conversion system	20-40 lb/day of steel being corroded out of piping systems	
		Production well	Short life (2-3 months) of line-shaft pump bearings	Scaling and possible lubrication problem
East Mesa, CA	Electric, binary downhole generator	Cooling system	Inappropriate carbon steel selected for working fluid condenser using aerated geothermal water for cooling	Similar to Raft River condenser problem, but developer here unaware of Raft River experience
East Mesa, CA	Electric, flash	Production well and energy conversion system	Scaling	Formation and precipitation of CaCO ₃ in brine
East Mesa, CA	Desalination plant	Brine disposal (injection well)	Plugging of well	Excess solids in brine
Geysers, CA	Electric, steam	Energy conversion system	Failure of stainless steel diffusers in steam discharge muffler	Primarily chloride stress corrosion cracking; steam composition at time was unknown
		Cooling system	Serious corrosion of heat exchange surfaces	Use of aerated geothermal steam condensate as cooling water; requires T316 and/or Ti HX surfaces

*May be only in pilot-plant or planning stages.

EXHIBIT 1

SOME SIGNIFICANT GEOCHEMISTRY AND MATERIALS RELATED PROBLEMS

EXPERIENCED OR EXPECTED IN SITE-SPECIFIC DEVELOPMENTS

(CONCLUDED)

SITE	TYPE OF UTILIZATION SYSTEM *	LOCATION OF PROBLEM	DESCRIPTION OF PROBLEM	CAUSE OF PROBLEM
Geysers, CA (Con't)	Electric, steam (Con't)	Brine and waste disposal	Surface disposal of steam condensate not allowed; abatement of H ₂ S produces large quantities of solid waste	Environmentally-unacceptable concentrations of NH ₃ and B in condensate
		Brine disposal (injection well)	Brine injected into old production well migrated into and cooled nearby producing well	Plugging of injection well in lower formations led to injected liquid entering permeable zones nearer surface
Baca, NM	Electric, flash		Final design review revealed many areas lacking appropriate corrosion engineering consideration	Limited operating experience with geothermal power plants and inadequate industry awareness of this experience
Salton Sea, CA	Electric, flash	Brine disposal (injection well)	Troublesome precipitation in well	Mixture of spent brines from two different production wells for injection resulted in BaSO ₄ precipitate from Ba ²⁺ in one brine from SO ₄ ²⁻ in another
Steamboat Springs, NV		Brine disposal (injection well)	Severe scaling in well	
Westmorland, CA		Brine disposal (injection well)	Loss of injectivity	
Clear Lake, CA		Brine disposal (surface disposal)	Environmentally-unacceptable brine	100 ppm boron
Brady Hot Springs, NV		Brine disposal (injection well)	Inflow of cold water and scaling	
Beowawe, NV		Brine disposal (injection well)	Inflow of cold water and scaling	
Klamath Falls, OR	Direct-heat, space heating	Energy conversion system	Leaks in copper tubing for supply lines and fan coils	Corrosion and scaling of inappropriate materials due to incomplete understanding of site geochemistry
			Failure of silicon bronze impeller	Dezincification
Mammoth Lake, CA		Production well	Failure of downhole-pump bearings	
Brady Hot Springs, NV		Production well	Blowout due to external corrosion of casing	H ₂ S corrosion

- Inadequate mechanical properties of materials
- Incompatible materials
- Cost of materials and technical/economic trade-offs of alternatives to more costly materials
- Shortage of reliable and relevant materials performance data for geothermal environments.

In the geochemical engineering area, significant problems which continue to be addressed are:

- Inadequately characterized geothermal fluids
- Unreliable fluid sampling and analysis procedures
- Poor understanding and predictability of geochemical behavior
- Suspended solids/precipitation/scaling
- Lack of accurate and durable in-line chemical process monitoring equipment and established data analysis techniques.

C. Rationale

An accurate and comprehensive working knowledge of geothermal fluid characteristics and behavior and of materials performance and limitations is essential for:

- Supporting equipment and system design and fabrication
- Reducing the life-cycle costs of components and systems
- Maximizing energy conversion efficiency
- Ensuring environmental acceptability and operational safety of the project.

With downtime for a typical commercial-size (50 MWe) geothermal power facility expected to cost \$100,000 per day or more, the need to prevent materials-related failures and other shutdowns due to fluid engineering deficiencies/accidents is obvious. More subtle than this,

but no less important, are the unnecessary costs that can be associated with "conservative" engineering practices adopted in the face of incomplete or unreliable information, e.g., specifying a more expensive construction material than really needed. The life-cycle costs of systems can thus be reduced through reduced capital costs, extended hardware life, and decreased O&M costs, although not all of these parameters will be favorably affected by every development.

In order to ensure that potential geothermal energy developers, equipment designers/manufacturers, and service companies can avoid or overcome such problems, an organized, industry-wide R&D effort is needed. The geothermal industry is not organized in a manner appropriate for planning and carrying out a "generic" R&D program in this area. There has generally been insufficient incentive for the private sector to expend significant private R&D resources and to bear the associated risks.* The factors which tend to discourage major private-sector initiatives include the:

- Industry-wide approach needed to assess problems and implement high-impact R&D strategies
- Significant monetary and person-power costs of performing the needed R&D
- Long time-schedule for completing the R&D
- Relatively small geothermal energy resource base and market for R&D products compared to other energy technologies
- On-going R&D commitments of private companies in non-geothermal energy areas.

*For example, a recent appeal to industry and the American Petroleum Institute for support of needed 350°C downhole testing of geothermal well completion cements met with little success: industry representatives cited the small number of geothermal wells compared to oil wells, the general state of the economy, and a slow-down of drilling activity as some reasons for this situation.

Where private-sector initiatives have occurred, they have been project-specific and/or proprietary and, therefore, unlikely to benefit the entire industry.

Other potential problems which could result from a fragmented industry R&D effort include duplicative R&D and the repetition of design/operational mistakes due to the lack of awareness of the experience of other participants. (As an example of the latter problem, carbon steel was selected for the condenser in Sperry's design for a downhole binary-cycle power unit at East Mesa in spite of the known inadequacy of this material in a similar application at DOE's Raft River facility.)

Therefore, a lead federal role in materials and geochemical engineering problem-solving has been judged appropriate and in the best interests of promoting the widest possible development of this alternative energy resource. The economic risks of the needed R&D are significant, but the potential technical and economic pay-offs are substantial.

D. Objectives

To meet the challenges in this area, DOE/GHTD and industry have been focussing cooperative efforts in four general areas:

- Obtaining and evaluating accurate materials performance data under geothermal conditions
- Developing, where available materials are inadequate, reliable and cost-effective materials for geothermal applications
- Determining relevant chemical characterization and behavior data for geothermal and other fluids in the energy system
- Devising appropriate fluid engineering techniques.

Specific objectives being pursued are:

- Formulation of appropriate materials selection procedures
- Where necessary, development of modified or new materials to fulfill the durability requirements and cost constraints of geothermal service

- Development of "non-materials" approaches to corrosion control
- Development of techniques to characterize geothermal and other relevant fluids and to monitor operational physical/chemical fluid parameters
- Assessment of process-engineering requirements for efficient and safe fluid handling and component/system design
- Acquisition and analysis of data and development of techniques to better understand and predict geochemical behavior downhole and in the plant.

Currently envisaged objectives for beyond FY 1983 call for R&D in the GEM area to primarily support injection technology and heat-cycle technology development activities.

E. Strategy

The strategy employed in developing the GEM Program is to:

- Identify and sponsor long-range, high-risk R&D the private sector will not initiate that will provide the special hardware, techniques, and information needed by the geothermal industry in the area of materials and geochemical engineering
- Focus on projects whose results will be in the public domain rather than on projects of an essentially proprietary or patentable nature
- Involve private industry to the fullest extent possible, especially in terms of cost-sharing major R&D projects
- Balance the involvement of national laboratories, industrial organizations, and universities in conducting R&D
- Rely on national laboratories for significant advice in the overall R&D program, supplemented by direct industrial input.

This strategy ensures that the program:

- Is responsive to high-priority industry needs,
- Has a high probability of success, and
- Is conducted at minimum cost to the federal government.

II. ~~PROGRAM CONTENT~~ SCOPE

A. Program Structure

The GEM Program has been organized into six elements:

- Materials for Borehole Components
- Materials for Energy Conversion Components
- Materials Testing and Corrosion Control
- Fluid Characterization
- Geochemical Monitoring and Control
- Fluid Handling

The program elements are not necessarily mutually exclusive in terms of the relevance of R&D results produced in one element to problems addressed in another. For example, accurate information about geothermal fluid characteristics is essential for identifying appropriate materials for downhole and surface equipment applications.

B. Program Elements

1. Materials for Borehole Components

The objective of this program element is to evaluate conventional materials and, where needed, to develop cost-effective substitute or alternate materials for use in geothermal well drilling, completion, and fluid production equipment. Improvements in drilling and completion related materials have been needed to resist the unusually high temperatures and chemically-aggressive fluids encountered in geothermal wells. The cost of drilling and completing a typical geothermal well is \$750,000 to \$1,000,000 compared to about \$30,000 for a comparable oil well. A significant portion of the relatively large expense of a geothermal well is attributable to the

accelerated degradation of materials. For example, drill bits (which cost \$3,000 - \$18,000 each) will typically last several hundred hours in oil well drilling compared to 10-20 hours in geothermal application.

Major R&D efforts to date have included:

- Development and technology transfer of high-temperature elastomers
- Development of new well completion cements and cementing procedures
- Identification of suitable non-metallic materials for certain geothermal well applications
- Identification of improved (longer-life) drill bit materials
- Development of more rugged downhole cable and cablehead.

Future R&D in this area will concentrate on developing high-temperature non-metallic materials (particularly elastomers) and on basic metallurgical studies related to downhole materials uses.

2. Materials for Energy Conversion Components

The primary emphasis of this effort is to define and evaluate materials problems in geothermal energy plants and to facilitate the dissemination of relevant information to the geothermal community. In addition, selected R&D is conducted on priority problems as needed. A comprehensive working knowledge of materials performance and limitations is necessary for helping to avoid materials-related component failures. The high costs of capital equipment, plant downtime, O&M activities, and equipment replacement can be very effectively reduced through improved materials applications knowledge and procedures. For example, with the Heber binary-cycle power

plant incorporating \$10-20 million of heat exchangers and with downtime at such a facility estimated to cost \$100,000 per day, a major corrosion-induced heat exchanger failure (such as recently occurred at Magma Electric Co.'s East Mesa plant) would be very expensive.

Major projects to date include:

- Preparation and publication of a handbook outlining materials selection guidelines for geothermal plants, which includes a resource chemical classification system and documentation of site-specific experiences
- Development of cost-effective polymer concrete for pipes and vessels
- Distribution of a materials-related newsletter (circulation ~2200)

There is currently no R&D solely directed at addressing materials problems in energy conversion system equipment. There are, however, efforts in elastomers and metal seals which will benefit both down-hole and surface plant problems. Planned R&D in this program element will be concerned with analyzing and developing basic metallurgical theories to further enhance understanding of physical/chemical properties and phenomena of materials in geochemical environments.

3. Materials Testing and Corrosion Control

This program element has two aims:

- Develop non-destructive evaluation (NDE) techniques for drilling components, well completion materials, and, where necessary, energy conversion component materials in order to predict and prevent failure
- Determine the causes and mechanisms of corrosion by geothermal fluids and, where appropriate, devise techniques to minimize and monitor corrosion.

These NDE and corrosion control activities together will aid considerably in avoiding costly downtime, component replacement, and possible

well abandonment. For example, air or aerated-water drilling commonly employed at The Geysers and Baca sites requires corrosion inhibitors (to prevent drill pipe corrosion) costing \$5,000 - \$9,000 per day per well, a figure approaching rig costs; alternative approaches to corrosion control might lower this cost significantly. Another example is an NDE technique developed for detecting conditions which could lead to drill pipe failure, helping to avoid the expense of recovering broken pipe from a well.

In the past, corrosion studies have been performed for downhole heat exchangers for direct-heat applications, for surface piping, and for well casing. In the NDE field, state-of-the-art NDE techniques for casing and cement have been assessed and a technique for detecting incipient failure of drill pipe has been developed. The only future research scheduled for this program element concerns the development of cathodic techniques for corrosion protection, which is already underway in FY 1982; prototype systems will be developed first for casing applications.

4. Fluid Characterization

Accurate and reliable information on geothermal fluid characteristics is essential for: selecting suitable construction materials; designing fluid handling components and systems; identifying chemical process monitoring needs; maximizing energy conversion efficiency; and addressing potential environmental waste problems. This program element addresses these needs through the establishment of standardized fluid sampling and analysis procedures, compiling the results of characterization.

studies of specific resources for reference and planning purposes, and by conducting/reviewing case studies at geothermal energy facilities.

Major projects in this area have been:

- Identification of industry-accepted, standardized geothermal fluid sampling and analysis procedures and publication of these in a technical manual
- Preparation of a computerized database (with a hardcopy document) on chemical characteristics of site-specific geothermal fluids
- Assessment of the information and instrumentation requirements for downhole characterization of geothermal brines.

Current efforts are:

- Sampling and analysis methods development for leak detection and working-fluid loop corrosion monitoring in binary-cycle power plants
- Analysis of chemical and thermal data from the operational 10-MWe binary-cycle power plant of Magma Electric Co. at East Mesa (this information is being collected in conjunction with the field testing of new sensors and instrumentation developed under the next program element).

Planned activity in this area centers on identifying the significant chemical components of geothermal fluids and refining a multi-ion temperature/pressure theory for their behavior.

5. Geochemical Monitoring and Control

The objectives are to:

- Develop, as necessary, prototype in-line chemical sensors and associated instrumentation that can perform reliably and accurately in high-temperature, chemically-aggressive geothermal environments
- Field test these prototype devices in an operational plant to verify the technical performance of monitoring packages, collect valuable geochemical data under plant operating

conditions, help identify plant design and operational problems, and permit the design of integrated plant fluid monitoring systems.

The design and development of reliable and accurate sensors and accompanying instrumentation for geothermal energy applications is an area of very high payoff. Conventional fluid monitoring hardware and techniques have not been adequate for the high-temperature, chemically-complex fluid environments which characterize geothermal energy conversion facilities. The immediate in-line detection/measurement of certain geochemical parameters and changes therein is essential for efficient and safe energy conversion and support processes. The chemical constituents and properties of the fluid are critical factors in equipment design, equipment performance (and failure), energy conversion efficiency, identification of potentially dangerous conditions, materials selection, etc.

An invaluable feature of the development effort is the enthusiastic cooperation of Magma Electric Co., who has allowed DOE/PNL to instrument their 10-MWE binary geothermal power plant. Magma realized early on the importance of accurate and timely monitoring of chemical characteristics and has, at some expense to itself, provided PNL with sensor penetration locations and other support to field test prototype devices and to design a plant-wide monitoring system. Two years of monitoring/testing experience have been completed so far.

Thirteen prototype sensors have at one time or another been planned for development, of which 3 (redox, corrosion, and conductivity probes) are ready to be commercialized by industry.

Current activity involves:

- Technology transfer to industry of the redox, corrosion, and conductivity sensors
- Development of ceramic pH, isobutane corrosion, and binary leak detection probes
- Continued field testing of prototypes at the Magma facility (currently shut-down due to condenser failure)
- Tentative planning for development of an injection-line particle meter
- Instrumentation design support for Heber binary-cycle plant (funded under Heber project).

In addition to carry-over work from the above FY 1983 projects, outyear plans call for development and testing of a semiconductor device to simultaneously measure several chemical species.

6. Fluid Handling

This program element addresses a wide range of technological problems and uncertainties associated with designing and operating efficient and safe fluid handling/processing systems. This includes consideration of fluid production, fluid transport, energy conversion, and waste control support activities. The aim is to acquire and analyze basic fluid engineering data, with special emphasis on the understanding and control of precipitation/scaling and on process chemistry modeling. Since the processing of large volumes of hydrothermal fluids is intrinsic to geothermal power systems, it is imperative that the most efficient and safe fluid engineering techniques be used in order to maximize the thermal performance of the systems and avoid unplanned events.

In the past, a considerable amount of data has been collected through numerous projects on the thermal properties, solubilities, and kinetics of chemical species giving rise to precipitation and scaling in geothermal fluids. Models have been developed and refined, using these data, to predict the nature and magnitude of solids problems. One project has produced models to elucidate the precipitation products, rates, and locations for SO_4^{2-} , Cl^- , and S^- . Certain other efforts have focussed on the processing of geothermal brine for injection. In addition, tests of over 100 potential precipitation/scale control additives have taken place, most for silica at Salton Sea, with few clear successes; one very effective anti-scalant for carbonate was identified.

The only significant project underway in this area during FY 1982 is continued solids deposition modeling, specifically for CO_3^{2-} and silicates. Future activity will carry on basic research into the chemical behavior of geothermal fluids with the primary purpose of devising and testing brine treatment and other measures for controlling scaling and precipitation.

III. IMPLEMENTATION PLAN

A. Management Approach

Achievement of program objectives requires the effective management of a wide range of R&D activities, information/technology transfer mechanisms, and organizational roles. The management approach to the GEM program is to:

- Identify areas where selective federal involvement can be instrumental in enhancing the viability of geothermal energy systems and in attracting increased private-sector commitment.
- Identify appropriate and effective mechanisms for assisting industry in addressing materials and geochemical engineering problems (e.g., basic research, applied R&D, cost-shared field tests, conferences and workshops, handbooks/manuals, and involvement and coordination of professional societies and technical advisory groups).
- Rely on national laboratories for significant technical guidance and for the conduct and subcontracting of some R&D, coordinated with direct DOE contracting to universities, industrial companies, and special government organizations.
- Periodically re-evaluate program direction and R&D needs through project review, workshops or other special events, assessment of GEM accomplishments and setbacks, and identification of significant developments in other GHTD programs and in overall Division objectives.
- Wherever possible, cost-share major R&D projects with industry and persuade industry to bear the expense of utilizing testing facilities made available by DOE.
- Interface with other DOE offices and federal agencies involved in promoting and controlling geothermal energy development in order to: avoid duplication of effort, capitalize on advantageous developments; and identify regulatory and policy issues which may affect the GEM Program.
- Maintain close contact with private sector entities (energy resource developers, utilities, supply/service companies, professional societies, research establishments, and the financial community) to ensure that the program continues to be responsive to their needs.

B. Multi-Year Activity Schedule

The objective and major activities planned for each program element through the end of FY 1987 are identified in Exhibit 2.

C. Environmental Considerations

All GEM Program projects are designed and implemented with the intention of avoiding any undesirable environmental effects. It is anticipated that the successful completion of the R&D will improve the ability to safely produce, transport, and process geothermal fluids and to manage spent brine and other wastes in an environmentally acceptable manner. For example:

- The development of improved drilling and completion materials will improve the integrity and life of production and injection wells.
- More informed materials-selection and materials-engineering decisions will help reduce the risk of inadvertent releases of geothermal fluids and other substances which may give rise to environmental concern.
- The development of brine treatment techniques for producing highly-injectable brines will lessen the possibility of damaging subsurface geologic formations and, consequently, hydrologic features.

EXHIBIT 2
ACTIVITY SCHEDULE BY PROGRAM ELEMENT

PROGRAM ELEMENT	OBJECTIVE	FISCAL YEAR R&D ACTIVITY				
		1983	1984	1985	1986	1987
Materials for Borehole Components	Develop high-temperature non-metallic materials	Test fluorinated elastomers as seals and bushings at 360°F				
Materials for Energy Conversion Components	Determine basic metallurgical concepts for geothermal applications	Analyze and correlate properties of currently used metals	Identify significant elements and alloying procedures	Collect laboratory data for new metallurgical procedures		Begin field tests of new procedures
Materials Testing and Corrosion Control	Identify/develop methods for controlling corrosion	Conduct field test of cathodically-protected well casing				
Fluid Characterization	Identify chemical species and reactions involved in geothermal fluid processing	Complete carbonate and silicate parameters	Develop integrated multi-ion temperature/pressure theory			
Geochemical Monitoring and Control	Develop prototype in-line chemical sensors and instrumentation for geothermal energy systems	Complete pH electrode tests	Design and develop semiconductor device to simultaneously measure several ionic species		Test and evaluate prototype semiconductor device	
Fluid Handling	Develop brine treatment to control precipitation/scaling	Analyze experiences with precipitation and scaling problems	Conduct laboratory tests of brine treatment methods	Conduct field tests of brine treatment methods		

IV. RESOURCE REQUIREMENTS

A. Budget Estimates

The estimated budget requirements for the GEM Program by program element for the fiscal years 1983 to 1987 (inclusive) are given in Exhibit 3.

B. Person Power

The estimated person-years required to manage the GEM Program by program element for the fiscal years 1983 to 1987 (inclusive) are given in Exhibit 4.

EXHIBIT 3

**ESTIMATED BUDGET REQUIREMENTS
BY PROGRAM ELEMENT**

PROGRAM ELEMENT	ESTIMATED FUNDING (\$000)					
	Fiscal Year					
	1983	1984	1985	1986	1987	
MATERIALS FOR BOREHOLE COMPONENTS	450	300	100	100	100	1050
MATERIALS FOR ENERGY CONVERSION COMPONENTS	100	200	200	300	400	1200
MATERIALS TESTING AND CORROSION CONTROL	200	250	200	100	100	850
FLUID CHARACTERIZATION	400	400	200	100	0	1100
GEOCHEMICAL MONITORING AND CONTROL	200	200	200	200	200	1000
FLUID HANDLING	250	300	600	700	800	2650
	1600	1650	1500	1500	1600	7850

EXHIBIT 4

ESTIMATED PERSON-YEAR REQUIREMENTS
BY PROGRAM ELEMENT

PROGRAM ELEMENT	ESTIMATED PERSON-YEARS					
	Fiscal Year					
	1983	1984	1985	1986	1987	
MATERIALS FOR BOREHOLE COMPONENTS	.5	.5	.2	.2	.2	1.6
MATERIALS FOR ENERGY CONVERSION COMPONENTS	.2	.2	.3	.4	.5	1.6
MATERIALS TESTING AND CORROSION CONTROL	.2	.2	.3	.2	.2	1.1
FLUID CHARACTERIZATION	.5	.5	.3	.2	0	1.5
GEOCHEMICAL MONITORING AND CONTROL	.3	.2	.3	.3	.3	1.4
FLUID HANDLING	.3	.4	.6	.7	.8	2.8
	2.0	2.0	2.0	2.0	2.0	10

V. MANAGEMENT CONTROL PLAN

A. Assigned Responsibilities

The roles of GHTD offices and contractors are as follows:

- GHTD/Headquarters - Formulates GEM Program strategy, sets technical objectives, and manages the overall program, ensuring that the effort is supportive and non-duplicative of other Division geothermal technology R&D programs. Also allocates general resources and maintains technical interfaces within and outside of DOE.
- GHTD/Field Offices - San Francisco Operations Office implements, coordinates, and monitors projects.
- National Laboratories* - National laboratories provide GHTD with technical information on R&D needs, conduct some R&D in-house, and subcontract some R&D to other organizations. (Certain projects are contracted directly out of GHTD to organizations other than national laboratories.)

B. Project Management

Individual projects are managed from the San Francisco Operations Office, except for those subcontracted out of the national laboratories. This management function incorporates project implementation, progress monitoring, assessment of technical and schedule deviations, project re-direction when needed, and "public" awareness activities.

C. Major Milestones

Major planned milestones for the GEM Program by program element through FY 1987 are shown in Exhibit 5.

* Brookhaven National Laboratory, Battelle Pacific Northwest Laboratory, Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, Sandia National Laboratory, Idaho National Engineering Laboratory, Oak Ridge National Laboratory, and Argonne National Laboratory,

EXHIBIT 5

MAJOR OUTYEAR MILESTONES FOR
GEM PROGRAM

R&D AREA	FISCAL YEAR MILESTONES				
	1983	1984	1985	1986	1987
• Geothermal Fluid Modeling	Cl ⁻ and SO ₄ ²⁻	CO ₃ ²⁻ and silicates	Multi-ion theory		
• Chemical Monitoring Instrument Development		pH electrode tests	Design and develop semiconductor device		Test/evaluate semiconductor device
• Materials Evaluation and Development		Analyze metallic properties	Identification of significant elements and alloying procedures		Lab test new metallurgical procedures
		Test fluorinated elastomers as seals and bushings @ 360°F			
• Corrosion Control	Lab tests of cathodic protection	Field test of cathodic protection for casing			
• Solids Control		Analysis of experiences with precipitation and scaling problems		Lab tests of brine treatment techniques	Field tests of brine treatment techniques