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FINAL REPORT
GEOCHEMICAL ENGINEERING AND MATERIALS:
PROGRAM STATUS
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1.0 PROGRAM OVERVIEW

1.1 Introduction

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. R&D sponsored under this program has been directed at assisting industry in:

- Increasing the knowledge about the properties and performance of materials 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 control.

In this way, the GEM Program contributes to the feasibility of designing and operating efficient, economic, and safe fluid handling and energy conversion systems.

This document describes the GEM Program as it was implemented through FY 1982. The document summarizes and updates the information contained in two earlier reports prepared for GHTD** and adds a des-

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

- ** • Geothermal Materials Program Strategy, C. H. Crane and D. C. Kenkeremath, NTIS #DOE/RA/12183-01, Oct. 1980.
 • Geochemical Engineering Problem Identification and Program Description, C.H. Crane and D.C. Kenkeremath, NTIS #DOE/ID/12183-T2, May 1981.

cription of FY 1982 program activities. Included as appendices are brief descriptions of all past and current R&D projects sponsored under the program. The GEM Program was initiated under the Energy Research and Development Administration (ERDA) and continued by DOE's Division of Geothermal Energy (DGE), now renamed the Geothermal and Hydropower Technologies Division (GHTD).

1.2 Rationale

Many attempts by industry to develop hydrogeothermal resources for energy production over the last few decades in the U.S. have encountered technical and economic problems associated with materials and fluid engineering. These problems include:

- High-temperatures (up to and occasionally exceeding 500°F), which can exceed the thermal resistance of many construction materials.
- Corrosive and erosive fluids, which can be particularly devastating in turbines, heat exchangers, and pipes (e.g., at Magma Electric Company's East Mesa binary-cycle plant, 20-40 lb/day of steel were being corroded out of piping systems; in addition, Magma's condenser recently failed catastrophically due to corrosion).
- Fouling and scaling, which can severely restrict and eventually block fluid flows in pipes, heat exchangers, and production and injection wells (e.g., wells drilled at Steamboat Springs have experienced loss of production within days due to down-hole CaCO₃ scale buildup; brine at East Mesa can deposit as much as 1.5 inches of carbonate scale at the flash point in less than 100 hours).
- Chemically-complex fluids, which make chemical process monitoring, predictability, and control very problematic (e.g., continuous monitoring of pH, CO₂, O₂, S⁻, conductivity, particulates, and other items may be vital baseline information for adequate process control).

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
- Controlling capital costs
- Minimizing plant O&M costs and downtime
- 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.

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 infrastructure does not lend itself at this time to the planning and conduct of a "generic" R&D program in this area. There has generally been insufficient incentive for the private sector to expend significant R&D resources and to bear the associated risks involved. (For example, a recent appeal to industry and the American Petroleum Institute for support of needed 350°C down-hole 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 slowdown of drilling activity as some reasons for this situation.) Where private-sector initiatives have occurred, they have been

project-specific and 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, 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.

1.3 Objectives

To meet such challenges, DOE/GHTD and industry have been focusing cooperative efforts in four generic areas:

- Obtaining and evaluating accurate materials performance data under geothermal conditions
- Developing, as needed, reliable and cost-effective materials for geothermal applications
- Acquiring relevant geochemical data
- Devising appropriate fluid engineering and monitoring techniques.

Specific objectives which have been 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 methods to evaluate materials performance and conditions
- Development of "non-materials" approaches to corrosion control
- Development of techniques to characterize geothermal fluids and to monitor on-line 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.

1.4 Strategy

Achievement of program objectives requires the effective management of a wide range of R&D problems and information/technology transfer mechanisms. DOE's strategy in developing the GEM Program has been, with private sector input, to:

- Determine the underlying reasons for unsuccessful or inefficient experiences in the areas of materials and geochemical engineering
- Identify and prioritize technical and economic problems which must be resolved in order to establish the feasibility and competitiveness of geothermal energy projects in these areas
- Assess the adequacy of existing technology for geothermal energy applications
- Determine the short-term and long-term ability and willingness of the private sector to initiate R&D in critical areas
- Identify areas where selective federal support and coordination activities 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 (e.g., basic research, applied R&D, cost-shared field tests, conferences and workshops, handbooks/manuals, and involvement of professional societies and technical advisory groups).

DOE's strategy for implementing and monitoring the GEM Program has been to:

- Rely on national laboratories for significant technical guidance and for the conduct and subcontracting of R&D, coordinated with direct DOE contracting to universities, industrial companies, and special government organizations.
- Emphasize information/technology transfer aspects of problem-solving activities
- Periodically re-evaluate program direction and R&D needs through project review, workshops or other special events, assessment of GEM Program accomplishments and setbacks, evaluation of significant developments in other GHTD programs and in overall Division objectives, etc.
- Determine how best to address the wide range of problems with minimal use of federal resources and how to maximize inter-project support while minimizing the overall impact of any unsuccessful projects
- 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.

Important government bodies participating in this process include the National Academy of Sciences/National Materials Advisory Board, Committee on Materials and Technology/Energy Materials Coordinating Committee, DOE/Office of Basic Energy Sciences, and Environmental Protection Agency. Industrial professional societies actively involved in the GEM Program are the American Society for Testing and Materials, American Petroleum Institute, National Association of Corrosion Engineers, American Concrete Institute, National Water Well Association,

American Society of Heating, Refrigerating, and Air Conditioning
Engineers, Society of Petroleum Engineers, and the Federation of
Materials Societies.

2.0 PROGRAM FEATURES

2.1 Problems Addressed

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 peak performance and avoid downtime-causing occurrences.

Exhibit 2.1 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, significant problem-areas addressed are:

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

EXHIBIT 2.1

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 2.1

**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 concentra- tions 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 appro- priate corrosion engineering consideration	Limited operating experience with geo- thermal 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 under- standing of site geo- chemistry
			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

- 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 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.

2.2 Structure

The GEM Program has been organized into seven elements:

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

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.

Exhibit 2.2 outlines the subelements which are incorporated in each program element. As with the elements themselves, all of the

EXHIBIT 2.2

GEM PROGRAM ELEMENTS AND SUBELEMENTS

MATERIALS FOR BOREHOLE COMPONENTS

- Well cements (organic, inorganic)
- Tubulars (metals, plastics, alternates)
 - joining
- Packers (elastomers, polymers, metals, others)
- Drilling components
 - bits (metals, diamonds, ceramics, other composites)
 - seals (metals, elastomers)
 - bearings (metals, non-metals)
 - drill pipe (metals)
- Pumps
 - bearings (metals, non-metals)
 - seals (metals, elastomers)
 - shafts (metals)
 - piping (metals)
- Logging
 - instrument casing (metals, non-metals)
 - seals (elastomers)
 - insulation (elastomers)
- Wellhead
 - safety valves
 - wellhead valves
 - elbows
 - seals
 - stuffing boxes
- Cable (metals, elastomers, ceramics)

MATERIALS FOR ENERGY CONVERSION COMPONENTS

- Turbines
 - coatings
 - corrosion and erosion
 - fatigue resistance
- Pressure vessels (metals, non-metals)
 - joining and field repair
 - lining
 - coatings
- Steam Separators (metals, non-metals)
 - joining and field repair
 - lining
 - coatings
- Pumps
 - bearings (metals, non-metals)
 - seals (metals, elastomers)
 - coatings
- Piping (metals, non-metals)
 - welding
 - lining
 - coatings

EXHIBIT 2.2

GEM PROGRAM ELEMENTS AND SUBELEMENTS

(CONTINUED)

- Valves
 - seals
 - coatings
 - heat treatment
- Heat Exchangers
 - materials selection
 - corrosion and erosion
 - seals
- Cooling Towers (cements, alternates)
 - wet
 - dry
- Waste Processing

MATERIALS TESTING AND CORROSION CONTROL

- Nondestructive Testing of Drill Pipe
 - laboratory development and screening
 - small-scale field testing
 - large-scale field testing
- Nondestructive Testing of In-Situ Well Materials
 - cement
 - casing
 - corrosion/chemical stability/thermal stability
- Nondestructive Testing of Energy Conversion Component Materials
- Corrosion Inhibitors
- Corrosion Monitors
 - development
 - testing
- Cathodic and Anodic Protection
- Corrosion Field Testing

FLUID CHARACTERIZATION

- Sampling and Analysis Methods Development
- Plant Fluid Characterization
- Fluid Inventory

GEOCHEMICAL MONITORING AND CONTROL

- Sensor Development
- Plant Instrumentation
- Down-well Instrumentation

EXHIBIT 2.2

GEM PROGRAM ELEMENTS AND SUBELEMENTS

(CONCLUDED)

FLUID HANDLING

- Solids and Scale Control
- Plant Unit Operations and Operating Procedures
- Fluid Disposal
- Integrated Waste Treatment and Byproduct Recovery
- Integrated Cooling Water Systems
- Modeling of Fluid Process Chemistry

INFORMATION AND TECHNOLOGY TRANSFER

- Handbooks/Manuals
- Conferences and Workshops
- Newsletters
- Professional Societies Interaction
- Product Technology Transfer
- New Standards

subelements within a particular program element are not necessarily mutually exclusive. For example, high-temperature elastomers developed under the program may find sealing applications in downhole pumps, surface pumps, drill bits, and heat exchangers. Although a significantly leaner program is in effect for FY 1982, there is currently R&D activity in all seven program elements. However, the existing effort within each element is far more focussed than previously in order to address priority problems with reduced funding.

2.3 Funding

Exhibit 2.3 shows the overall federal funding for the GEM Program through the end of FY 1982. The substantial decrease in FY 1982 funding compared to FY 1981 can be easily seen.

2.4 Relationship to Other GHTD Programs

Although the GEM Program is addressing many specific problems, much of the data and technology developed under the program has direct and indirect benefits for other DOE geothermal energy programs. Other programs with significant information and technology needs in materials and/or geochemistry are the Hydrothermal Energy Conversion Technology (HECT) Program, Drilling and Completion Technology (DCT) Program, and Environmental Control Technology (ECT) Program. The Geoscience Technology (GT) Program and Reservoir Stimulation (RS) Program may also benefit indirectly, especially in the area of geothermal fluid characterization and geochemical modeling.

In this way, the GEM Program can also be characterized as a generic support R&D program for the Division's geothermal technology dev-

EXHIBIT 2.3

GEM PROGRAM FUNDING FY 1978 - 1982

elopment efforts. Some examples of areas where the GEM Program has had or could have implications for areas of concern to other programs are shown in Exhibit 2.4.

EXHIBIT 2.4

AREAS WITHIN OTHER GHTD GEOTHERMAL PROGRAMS WHICH MAY BENEFIT FROM GEM PROGRAM R&D

GEM ACTIVITY AREAS	HYDROTHERMAL					HOT DRY ROCK	GEOPRESSURED
	DCT	HECT	ECT	GT	RS		
Cements	• Completion					• Completion	• Completion
Polymer concrete		• Piping • Pressure vessels					
Alternate casing materials	• Casing						
Metallic corrosion studies	• Drilling hardware • Casing	X					
Elastomers	• Downhole packer • Drill-bit seals	• Downhole and surface pump seals • Line-shaft pump bearings • HX seals					
Drill bit materials	• Drill bits					• Drill bits	• Drill bits
Cable		• Downhole electric pumps		• Logging			
Materials selection guidelines	X	X					
Drill-pipe NDE	• Drill-pipe inspection						
Corrosion meter							

X Indicates program-wide relevance for identified program.

EXHIBIT 2.4 (CONCLUDED)

GEM ACTIVITY AREAS	HYDROTHERMAL					HOT DRY ROCK	GEOPRESSURED
	DCT	HECT	ECT	GT	RS		
Cathodic corrosion protection	<ul style="list-style-type: none"> • Casing • Drill pipe? 	<ul style="list-style-type: none"> • Piping 					
Sampling and analysis methods	<ul style="list-style-type: none"> • Downhole fluid environment characterization • Materials selection 	<ul style="list-style-type: none"> • Geofluid characterization • Process fluid monitoring • Materials selection • System safety 	<ul style="list-style-type: none"> • Waste characterization 				
Sensors and instrumentation		<ul style="list-style-type: none"> • Process fluid monitoring and control • System safety 					
Solids and scale control	<ul style="list-style-type: none"> • Production well plugging 	<ul style="list-style-type: none"> • Scaling of pipes, HX's, etc. 	<ul style="list-style-type: none"> • Injection well plugging 				
Geochemical modeling	<ul style="list-style-type: none"> • Production well phenomena 	<ul style="list-style-type: none"> • Component and system design • System safety 	<ul style="list-style-type: none"> • Injection phenomena 				
Cooling water treatment		<ul style="list-style-type: none"> • Brine make-up cooling systems 					
Geochemical engineering reference manual	X	X	X				
Injection-related studies			<ul style="list-style-type: none"> • Injection disposal 				<ul style="list-style-type: none"> • Injection

X Indicates program-wide relevance for identified program.

3.0 PROGRAM R&D

This section describes the objectives and scope of each of the program elements. It also lists the projects sponsored under each element, grouped by pre-FY 1982 and FY 1982 (current) projects. Project descriptions are contained in Appendix A (materials-related projects) and Appendix B (geochemical engineering projects); the projects have been assigned arbitrary code numbers so that relevant projects can be conveniently identified in the body of this report. Over 80 projects have been undertaken since the program began, about half in the materials area and half in the geochemical engineering area. Exhibits 3.1 and 3.2 identify FY 1982 projects in these two areas, respectively.

3.1 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 components. Applications include drill bits, drill pipe, cement, casing, cable (for logging and electric pumps), and seals and packers. Such improvements in drilling and completion related materials are needed to resist the unusually high temperatures and chemically-aggressive fluids encountered in geothermal wells.

Exhibit 3.3 identifies past and current projects concerned with downhole materials. (Some of the projects listed are not limited in the scope of problems addressed to the downhole environment; the results of these projects can be expected to also have direct effects

EXHIBIT 3.1

FY 1982 MATERIALS-RELATED PROJECTS

R&D AREA		PROJECT AND CONTRACTOR
SEALS	ELASTOMERS	<ul style="list-style-type: none"> • Develop and test elastomer compounds for use in brine, oils, and isobutane (L'Garde, Inc.)
		<ul style="list-style-type: none"> • Transfer technology for high-temperature elastomers (L'Garde, Inc.)
		<ul style="list-style-type: none"> • Develop and test fluorinated elastomers (Exfluor Research Corp./BNL)
	METALLIC	<ul style="list-style-type: none"> • Develop and test Nitinol shape memory alloy seals (Rockwell International)
DOWNHOLE PUMP BEARINGS		<ul style="list-style-type: none"> • Test application of elastomers in downhole pump bearings (Solar Turbines)
DOWNHOLE CEMENTS		<ul style="list-style-type: none"> • Test cement samples downhole and evaluate results (BNL/Mexico) • Determine feasibility of cavitation mixing/emulsification of geothermal cements (Daedalean Associates, Inc.)
CORROSION CONTROL		<ul style="list-style-type: none"> • Determine feasibility of cathodic protection for corrosion control (BNL/San Diego State University)
POLYMER CONCRETE		<ul style="list-style-type: none"> • Continue development and evaluation of polymer concrete for construction/lining of piping and vessels (BNL)
MATERIALS EVALUATION AND FAILURE ANALYSIS		<ul style="list-style-type: none"> • Up-date Geothermal Materials Selection Guidelines Handbook (Radian Corporation)
		<ul style="list-style-type: none"> • Evaluate specific materials requirements and proposed applications, as needed (Radian Corporation)
		<ul style="list-style-type: none"> • Analyze partially or completely failed components, as needed (Radian Corporation)

EXHIBIT 3.2

FY 1982 GEOCHEMICAL ENGINEERING PROJECTS

R&D AREA		PROJECT AND CONTRACTOR
SENSORS AND INSTRUMENTATION	PROTOTYPE DEVELOPMENT	● Ceramic pH probe (General Electric)
		● Isobutane corrosion probe (PNL)
		● Binary-system leak detector (PNL)
		● Particle meter - tentative planning (PNL)
	FIELD TESTING	● Reinstallation of Magma monitoring system (PNL/Magma Electric Co.*)
		● Addition of isobutane corrosion monitoring (PNL/Magma Electric Co.*)
		● Addition of leak detector (PNL/Magma Electric Co.*)
		● Heber project support - not funded under GEM Program (PNL)
	TECHNOLOGY TRANSFER	● Project Opportunity Notice for commercialization of corrosion, conductivity, and redox probes (PNL)
		● Tentative planning for field testing of resulting commercial products (PNL)
SAMPLING AND ANALYSIS METHODS		● Develop S&A methods to support binary-system cross-stream leak detection (PNL)
INFORMATION/ TECHNOLOGY TRANSFER		● Prepare Geochemical Engineering Reference Manual (Terra Tek)
FLUID MODELING		● Continue modeling efforts to incorporate carbonates and silicates (University of California, San Diego)
COOLING WATER TREATMENT		● Identify corrosion and scale control water treatments appropriate for Raft River plant make-up (Idaho National Engineering Laboratory)

* Magma Electric Co. is not a DOE contractor, but is collaborating with PNL in this part of the program.

EXHIBIT 3.3

R&D PROJECTS FOR MATERIALS FOR BOREHOLE COMPONENTS

Pre-FY 1982		Project No. *
1	o Development of High-Temperature Geothermal Elastomers (L'Garde, Inc.)	A-1
1	o Geothermal Seals Screening (National Bureau of Standards)	A-6
	o New High-Temperature Cementing Materials for Geothermal Wells (Pennsylvania State University)	A-8
	o High-Temperature Cementing Materials for Completion of Geothermal Wells (Battelle Columbus Laboratories)	A-9
	o Hydrothermal Cements for Use in the Completion of Geothermal Wells (Southwest Research Institute)	A-10
	o Development of Cement for Geothermal Wells (Colorado School of Mines)	A-11
	o Cementing of Geothermal Wells: Phosphate-Bonded Cements (University of Rhode Island)	A-12
	o Development of Geothermal Well Completion Systems (Dowell Division, Dow Chemical Co.)	A-13
	o Geothermal Cement Screening (National Bureau of Standards)	A-14
1	o Benefit/Cost Analysis of Geothermal Technology R&D: Geochemical and Materials Engineering (The MITRE Corp)	A-25
	o Economic Impact of Using Nonmetallic Materials in Low-Intermediate Temperature Geothermal Well Construction (National Water Well Association)	A-26
1	o Economic Assessment of Using Nonmetallic Materials in the Direct Utilization of Geothermal Energy (Burns and Roe Industrial Services Corp.)	A-27
	o Improved Drill Bit Materials (Terra Tek, Inc.)	A-34
	o High-Temperature Logging Cable and Cablehead Development (Sandia National Laboratories)	A-35
	o Static Testing of Geothermal Cables (Aerospace Research Corp.)	A-36
	o Metal Sheath Cable Development (Halpen Engineering, Inc.)	A-37

* Refers to project description sheets in Appendix A.

1 Project with significant implications for Materials for Energy Conversion Components program element.

2 Project with significant relevance to Information and Technology Transfer program element.

EXHIBIT 3.3

R&D PROJECTS FOR MATERIALS FOR BOREHOLE COMPONENTS (Concluded)

Pre-FY 1982 (Continued)		Project No. *
1,2	o Assessment of Materials Needs for the Utilization of Geothermal Energy (National Materials Advisory Board, National Academy of Sciences)	A-38
FY 1982		
1,2	o Elastomers Technology Transfer (L'Garde, Inc.)	A-2
1	o Environmental Compatibility Testing (L'Garde, Inc.)	A-3
1	o Fluorinated Elastomers for Geothermal Environments (Exfluor Research Corp./Brookhaven National Laboratory)	A-4
1	o Shape Memory Alloy Seals (Rockwell International)	A-5
	o Cementing of Geothermal Wells (In-house, subcontracted, and cooperative R&D program)	A-7
	o Downhole Cement Field Testing and Evaluation (Brookhaven National Laboratory in cooperation with Comision Federal Electricidad (CFE) and Instituto de Investigaciones Electricas (IIE)).	A-15
	o Feasibility of Cavitation Mixing of Geothermal Cements (Daedalean Associates, Inc.)	A-16
	o Downhole Pump Bearings (Solar Turbines International)	A-21
1	o Materials Evaluation and Failure Analysis (Radian Corporation)	A-23

on materials-related concerns in the above-ground energy conversion, system.) Particularly long (multi-year) R&D efforts have been devoted to downhole cements and high-temperature seals. Numerous well completion cements have been identified or formulated and have been exposed downhole to 210°C geothermal brine (at Cerro Prieto) for 12 months; however, similar higher-temperature (350°C) testing is needed to properly evaluate cement performance. Improved/new elastomer compounds have been developed which can withstand harsh brine conditions at 260°C for short periods of time (24 hours); data on completed 6-month laboratory tests in isobutane and oils at 190°C are being evaluated. Although long-term field confirmation has not yet been conducted, some of these elastomers are now commercially available.

Other successfully completed efforts include: the development of improved and novel electrical cables for downhole pumps and logging tools; problem definition and magnitude assessment of metallic corrosion of casing, drill-pipe, etc.; identification of drill-bit steels for 400°C operation; and verification of the economic advantages of using alternate materials (e.g., thermoplastic and fiberglass-reinforced-plastic for well casing) for well construction.

3.2 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.

Exhibit 3.4 identifies past and current projects concerned with energy conversion system materials. (Some of the projects listed are not limited in the scope of problems addressed to the surface plant; the results of these projects can be expected to also have direct effects on materials-related concerns in downhole environments.) A major thrust has been to prepare a handbook on materials selection guidelines for geothermal plants in order to ensure that the diversity of parties involved in geothermal energy development have the most relevant and accurate information on materials applications. A related activity has been the preparation and distribution of a materials-related newsletter (recently terminated). There is currently no R&D directed solely at addressing materials problems in energy conversion system equipment.

3.3 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.

Exhibit 3.5 identifies past and current projects concerned with NDE techniques and corrosion control. Corrosion studies have been performed for downhole heat exchangers for direct-heat applications, surface piping, and well casing. The only current project in this

EXHIBIT 3.4

R&D PROJECTS FOR MATERIALS FOR ENERGY CONVERSION

Pre-FY 1982		Project No. *
1	o Development of High-Temperature Geothermal Elastomers (L'Garde, Inc.)	A-1
1	o Geothermal Seals Screening (National Bureau of Standards)	A-6
	o Polymer Concrete (Brookhaven National Laboratory)	A-17
	o Design and Fabrication of Polymer Concrete Pipe for Testing in Geothermal Energy Processes (Lindsey Industries, Inc.)	A-18
	o Polymer Concrete Vessels for Use in Geothermal Power Plants (Brookhaven National Laboratory)	A-20
2	o Materials Selection Guidelines for Geothermal Energy Utilization Systems (Radian Corp.)	A-24
1	o Benefit/Cost Analysis of Geothermal Technology R&D: Geochemical and Materials Engineering (The MITRE Corp.)	A-25
1	o Economic Assessment of Using Nonmetallic Materials in the Direct Utilization of Geothermal Energy (Burns and Roe Industrial Services Corp.)	A-27
1,2	o Assessment of Material Needs for the Utilization of Geothermal Energy (National Materials Advisory Board, National Academy of Sciences)	A-38
FY 1982		
1,2	o Elastomers Technology Transfer (L'Garde, Inc.)	A-2
1	o Environmental Compatibility Testing (L'Garde, Inc.)	A-3
1	o Fluorinated Elastomers for Geothermal Environments (Exfluor Research Corp./Brookhaven National Laboratory)	A-4
1	o Shape Memory Alloy Seals (Rockwell International)	A-5
	o Polymer Concrete Lined Pipe for Electric Generating Purposes (Brookhaven National Laboratory/Polymer Concrete Research, Inc.)	A-19
1	o Materials Evaluation and Failure Analysis (Radian Corp.)	A-23

* Refers to project description sheets in Appendix A.

1 Project with significant implications for Materials for Borehole Components program element.

2 Project with significant relevance to Information and Technology Transfer program element.

EXHIBIT 3.5

R&D PROJECTS FOR MATERIALS TESTING AND CORROSION CONTROL

Pre-FY 1982		Project No. *
o Downhole Heat Exchangers in Geothermal Direct Utilization Applications (Research Triangle Institute)		A-28
o Piping Materials Field Testing (Lawrence Livermore Laboratory)		A-31
o Localized Corrosion of Casing (Case Western Reserve)		A-32
o Test and Evaluation of API Casing Materials (Lawrence Livermore Laboratory)		A-33
o An Assessment of Non-Destructive Testing of Well Casing, Cement and Cement Bond in High-Temperature Wells (Lawrence Livermore Laboratory/GeoEnergy Corp.)		A-29
o The Application of a Non-Destructive Evaluation Technique Utilizing Internal for Detecting Incipient Failure of Drill Pipes (Daedalean Associates,		A-30

element is concerned with the development of a cathodic technique for corrosion prevention.

3.4 Fluid Characterization

Accurate and reliable information on geothermal fluid characteristics is essential for selecting suitable construction materials, designing fluid handling components and systems, maximizing energy conversion efficiency, and identifying 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.

Exhibit 3.6 identifies past and current projects in the area of fluid characterization. The PNL - conducted sampling and analysis methods project is listed as both a completed and current project because a Geothermal Sampling and Analysis Methods Handbook has already been published, but some S&A work for binary plant leak detection is underway. An important aspect of this program element is the 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 by PNL.

3.5 Geochemical Monitoring and Control

The objective is to develop, as necessary, prototype in-line chemical sensors and associated instrumentation that can perform

EXHIBIT 3.6

R&D PROJECJTS FOR FLUID CHARACTERIZATION

Project No. *	
Pre-FY 1982	
o Sampling and Analysis Methods (Battelle Pacific Northwest Laboratories)	B-5
o Compilation of Data on Fluids from Geothermal Resources in the U.S. (Lawrence Berkeley Laboratory)	B-31
2 o Assessment of the Characterization (in situ-Downhole) of Geothermal Brines (National Materials Advisory Board, National Academy of Sciences)	B-32
FY 1982	
o Sampling and Analysis Methods (Battelle Pacific Northwest Laboratories)	B-15
1 o Sensors and Instrumentation Field Testing (Battelle Pacific Northwest Laboratory)	B-13

* Refers to project description sheets in Appendix B.

1 This project is primarily under the Geochemical Monitoring and Control program element.

2 Project with significant relevance to Information and Technology Transfer program element.

reliably and accurately in high-temperature, chemically-aggressive geothermal environments. These prototype devices are then field tested 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.

Exhibit 3.7 identifies past and current projects in the areas of geochemical monitoring and control. Thirteen 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 and 3 (ceramic pH, isobutane corrosion, and binary leak detection probes) are currently under prototype development. In addition, the development of an injection-line particle meter is being tentatively planned.

The field testing phase has been accomplished through an on-going cooperative program with Magma Electric Co. at their on-line East Mesa binary-cycle plant. Two years of monitoring/testing experience have so far been achieved, with valuable benefits for DOE's planned Heber binary-cycle project.

3.6 Fluid Handling

This program element addresses a wide range of technology 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. Special emphasis is placed on

EXHIBIT 3.7

R&D PROJECTS FOR GEOCHEMICAL MONITORING AND CONTROL

Project No.*	
Pre-FY 1982	
o Standard Electrode Development (Stanford Research Institute)	B-2
o Development of Reference Electrode (Battelle Pacific Northwest Laboratories)	B-3
o Development of High-Temperature Glass pH Sensor (Leeds and Northrup Company)	B-4
o Development of High-Temperature Glass pH Sensor (Owens Illinois, Inc.)	B-5
o Development of High-Temperature Chemically Sensitive Semiconductor (University of Pennsylvania) <u>Terminated</u>	B-7
o Development of High-Temperature CO2 Sensor (Leeds and Northrup)	B-8
o Development of High-Temperature Sulfide Sensor (Beckman Instruments)	B-9
o Development of Conductivity Probe (Battelle Pacific Northwest Laboratories)	B-10
o Development of Redox Probe (Battelle Pacific Northwest Laboratories)	B-11
o Development of Corrosion Rate Meter (Battelle Pacific Northwest Laboratories)	B-12
o Chemical Measurement Techniques Development (Lawrence Livermore Laboratory)	B-33
FY 1982	
o Sensors and Instrumentation Development (Battelle Pacific Northwest Laboratories)	B-1
o Development of High-Temperature Ceramic pH Sensor (General Electric)	B-6
o Sensors and Instrumentation Field Testing (Battelle Pacific Northwest Laboratories)	B-13
¹ o Sensors and Instrumentation Technology Transfer (Battelle Pacific Northwest Laboratories)	B-14

* Refers to project description sheets in Appendix B.

¹ Project with significant relevancy to Information and Technology Transfer program element.

the understanding and control of precipitation/scaling and on process chemistry modeling. The scope of the program element spans basic research (especially into fluid kinetics) to evaluation of conventional technology for geothermal applications.

Exhibit 3.8 identifies past and current projects in the area of fluid handling. 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. Supporting efforts in fluid modeling attempt to apply these data to prediction and control of solids problems. A project which has already modeled sulfate, chloride, and sulfide precipitation is currently working on carbonate and silicates.

Tests of over 100 potential precipitation/scale control additives have taken place, most for silica at Salton Sea. Studies of solids problems in injection lines and wells have also been performed.

3.7 Information and Technology Transfer

The objective is to facilitate the rapid and accurate dissemination of information and technology to concerned parties within the geothermal community and service/supply industries. It is imperative that project plans, accomplishments, and products are made available to others involved in geothermal development so that

- Adequate technology and methods already available can be effectively utilized
- Duplication of effort can be avoided
- R&D can build on previous experiences, and

EXHIBIT 3.8
R&D PROJECTS FOR FLUID HANDLING

Pre-FY 1982	Project No. *
o Solubility of SrSO_4 in Aqueous Solutions (Vetter Research)	B-17
o Hydrodynamic/Kinetic Reactions in Liquid-Dominated Geothermal Systems (Aerojet Energy Conversion Co.)	B-18
o Calorimetric Determination of the Entropies and Gibbs Free Energies of Formation of Selected Scale-Forming Minerals (U.S. Geological Survey)	B-19
o Solubility and Kinetics of Precipitation of Minerals of Importance in Geothermal Applications (State University of New York, Buffalo)	B-20
o Calorimetry of Geothermal Fluids and Related Materials (Arizona State University)	B-21
o Geochemistry of Geothermal Systems (Pennsylvania State University)	B-22
o Measurement of Injectability of Brines (Lawrence Livermore Laboratory)	B-24
o Injection Well Stimulation Chemistry (Vetter Research)	B-25
o Geochemistry Modeling and Fluid Chemistry (Los Alamos Scientific Laboratory)	B-27
o Geothermal Brine Modeling (University of California, La Jolla)	B-28
o Hydrodynamic/Kinetic Reactions and Morphology Changes of Scale-Forming Materials (University of Delaware)	B-29
o Precipitation and Scale Control for Salton Sea Brines (Lawrence Livermore Laboratory)	B-34
o Precipitation and Scaling in Dynamic Geothermal Systems (Oak Ridge National Laboratory)	B-35
o Silica Scaling Study (EIC Corp.)	B-36
o Scale and Formation and Suppression (Dow Chemical Co.)	B-37
o Silica Scale Kinetics (Lawrence Berkeley Laboratory)	B-38
o Scale Inhibition in Geothermal Operations (Vetter Research)	B-39
o Research and Development of Cavitation Descaling Techniques for Heat Exchanger Tubes Used in Geothermal Energy Plants (Daedalean Associates, Inc.)	B-40
o Study of Using Surface Waters to Supplement Injection (Lawrence Livermore Laboratory)	B-41
o Processing of Brines for Injection (Lawrence Livermore Laboratory)	B-42

* Refers to project description sheets in Appendix B.

EXHIBIT 3.8

R&D PROJECTS FOR FLUID HANDLING

Project No. *	
FY 1982	
o Fluid Modeling for Deposition Prediction (University of California at San Diego)	B-26
o Cooling Water Treatment (Idaho National Engineering Laboratory)	B-30

An important aspect of this element is the cooperative programs arranged to transmit, in an interactive manner, technology, information, and new ideas from companies and universities conducting R&D to geothermal developers, equipment manufacturers, and supply/service companies. Professional societies are also involved in this area, particularly for the development of new standards.

Technology transfer is an activity built into the major projects in the GEM Program. However, there are needs for special activities intended to disseminate information relating to problem identification, technology and procedure assessments, and other evaluative processes. Exhibit 3.9 identifies past and current projects in the area of information and technology transfer.

Examples of the types of activities undertaken are:

- Assessments by the National Academy of Sciences of the materials and fluid characterization/monitoring needs of geothermal energy development
- A variety of conferences and workshops on geothermal fluid handling, geochemistry, scale control, etc.
- Publication of a Geothermal Materials Selection Guidelines Handbook
- Current preparation of a Geochemical Engineering Reference Manual
- Information exchange among the U.S., Italy, Mexico, and Iceland on many materials and fluid management subjects.

A significant DOE-sponsored conference entitled "Applying Current Geothermal Corrosion/Materials Technology to Today's Projects" is scheduled for October 1982. This conference (for which there is no registration fee) will cover the latest developments and information in areas including plant instrumentation, precipitation/scaling modeling, materials selection, and advanced materials availability.

EXHIBIT 3.9

INFORMATION AND TECHNOLOGY TRANSFER PROJECTS

Pre-FY 1982		Project No. *
1	o Materials Selection Guidelines for Geothermal Energy Utilization Systems (Radian Corp.)	A-24
1	o Assessment of Materials Needs for the Utilization of Geothermal Energy (National Materials Advisory Board, National Academy of Sciences)	A-38
1	o Assessment of the Characterization (in situ-Downhole) of Geothermal Brines (National Materials Advisory Board, National Academy of Sciences)	B-32
	o Workshops, Conferences, International Information Exchange	A-39 & B-23
1	o Sampling and Analysis Methods (Battelle Pacific Northwest Laboratory)	B-15
FY 1982		
1	o Elastomers Technology Transfer (L'Garde, Inc.)	A-2
1	o Sensors and Instrumentation Technology Transfer (Battelle Pacific Northwest Laboratories)	B-14
	o Geochemical Engineering Reference Manual (Terra Tek, Inc.)	B-16
1	o Materials Selection Guidelines for Geothermal Energy Utilization Systems (Radian Corp.)	A-24
1	o Sampling and Analysis Methods (Battelle Pacific Northwest Laboratory)	B-15
	o Workshops, Conferences, International Information Exchange	A-39 & B-23

* Refers to project description sheets in Appendix A and Appendix B.

1 Projects/activities listed under other program elements.

4.0 PROGRAM PROGRESS

Many of the accomplishments which have resulted from GEM Program R&D have been briefly identified in the program element descriptions of Section 3. This section will cover program accomplishments in a more comprehensive manner.

4.1 Technical Accomplishments

Major program accomplishments are summarized below.

- Well Completion Cements. Suitable cements for geothermal well completion have been identified through requirements analysis, laboratory properties measurement, and long-term (12-month) downhole testing in a 210°C geothermal well (at Cerro Prieto). Field-tested cement samples are currently being evaluated and preliminary results indicate that most have met design criteria. Higher-temperature testing (at 350°C) is still needed to verify cement performance.
- Elastomeric Seals. Elastomer compounds have been identified and developed for high-temperature (260°C) geothermal service. Three out of 34 industrial applicants were selected for transfer of this elastomer technology. Commercial products are now available from BJ-Hughes, Oncor, and Parker. Eight major and 4 smaller DOE projects have been supported in this area and "spontaneous" support has been rendered to at least 76 companies.
- Metallic Seals. Shape memory Nitinol (Ni-Ti) seals have been developed and temperature-actuation to produce a leak-tight seal at 260°C has been demonstrated. These seals are very corrosion resistant.
- Downhole Cable. Electrical cable for logging tools and downhole submersible pumps has been successfully developed. This includes a novel armored cable design. Associated high-temperature cablehead equipment has also been developed.
- Casing. Highly corrosion-resistant casing materials have been identified, including low-alloy steel compositions and alternate materials.
- Drill bits. Two steels have been identified to provide improved bit life up to 400°C in geothermal well drilling.
- Polymer Concrete. Polymer concrete suitable for pipes, pipe lining, and vessels has been developed. The technical advantages, cost-effectiveness, and manufacturing feasibility (for pipe only) of such polymer concrete applications have been established. Life-cycle cost analysis indicates that

the cost of PC-lined steel pipe would be 82% of that of carbon steel pipe over 20 years for a power plant. A 3-foot section of PC pipe exposed to 50-55°C brine for 2.5 years at a direct-heat project site showed no signs of scale deposition, cracking, or corrosion.

- Materials Selection. A comprehensive handbook has been published which: identifies environment- and materials-oriented criteria important in selecting materials for geothermal applications; summarizes world-wide experience with materials in geothermal facilities; and provides guidance in selecting the most technically and economically appropriate materials. A working tool for equipment designers and site operators, this handbook contains a useful classification of geothermal fluid conditions.
- Materials Evaluation. Under this effort, analyses of failed components from geothermal power plants and direct-heat facilities in the U.S. and abroad have been performed. In addition, selected, proposed, and existing materials uses were reviewed (e.g., Baca plant design specifications) to identify materials-related problems and successful applications.
- Precipitation and Scaling. A variety of activities has resulted in an improved understanding of precipitation and scaling phenomena in geothermal fluids and of approaches for controlling solids problems. Activities have included chemical and kinetic studies to collect baseline data, modeling for deposition prediction (see later), and identification and testing of potential antiscalants. One very effective carbonate scale control agent has been identified, but effective silica antiscalants have not yet been identified, despite the testing of as many as 100 chemicals. Other scale control techniques, e.g., cavitation descaling, have also been examined.
- Chemical Process Monitoring. Sensors for measuring four critical parameters (corrosion, conductivity, redox, and pH) have been developed and 3 more devices (ceramic pH probe, isobutane corrosion probe, and binary leak detector) are currently being developed. An on-going cooperative field testing program was begun 2 years ago with Magma Electric Co. at their 10 MWe binary-cycle power plant at East Mesa to test new monitoring equipment in an operational facility. DOE has initiated a technology transfer process for the redox, corrosion, and conductivity probes to enable industry to manufacture monitoring equipment; 16 companies have responded to a PON for the commercialization of these probes. A major corrosion-caused condenser failure at the Magma plant has suspended operation, but the chemical monitoring program will recommence on plant start-up, to include first-time penetration of the isobutane loop for corrosion monitoring and cross-leak detection.

- Sampling and Analysis Methods. An identification and evaluation of existing S&A methods since the mid-1970's, as applied to geothermal fluid characterization and operational plant support, revealed an unacceptably wide divergence of results among different performing laboratories. To improve the reliability and accuracy of S&A activities, methods were reviewed and standardized (with the involvement of ASTM) and published in a Geothermal Fluid Sampling and Analysis Methods Manual. This has resulted in the ability of site personnel to utilize the most appropriate sampling and sample-storage procedures and in a greater confidence that chemical analysis of samples will yield meaningful and accurate information.
- Fluid Modeling. In conjunction with the collection of data on fluid characteristics, modeling efforts have focussed on understanding and predicting the behavior of dynamic, multi-ion geochemical systems. This has been particularly fruitful in the area of precipitation and scaling and in identifying possible approaches to controlling deposition. For example, models for predicting the precipitation products, rates, and locations for sulfate, chloride, and sulfide have been completed and nearly completed for carbonate. This is invaluable information for component designers and plant operators.
- Injection. In addition to the benefits to injection operations of precipitation/scaling studies and model development described earlier, investigations have been carried out into other injection-related problems. These investigations have concentrated on the Salton Sea resource area. Among the projects have been: measurement of the injectability of brine in terms of particle sizes requiring removal before injection; development of a particle removal process to permit injection without significant damage to injection wells; and determination that water from local sources could not be used as injection make-up without processing due to increased solids problems.

4.2 Benefits to Industry

The generic benefits that the GEM Program has so far been effecting can be summarized as in Exhibit 4.1. The program plays a very important technology/information support role in reducing the technological uncertainties and economic risks of geothermal energy exploration and utilization and, ultimately, in achieving a lower cost of power. This helps to reduce the risks perceived by industry

EXHIBIT 4.1

BENEFITS OF GEM PROGRAM

- CORROSION CONTROL
- SOLIDS/SCALE CONTROL
- ADEQUATE PROCESS MONITORING
- MATERIALS SELECTION AND EVALUATION CAPABILITIES
- IMPROVE AVAILABILITY OF COST-EFFECTIVE MATERIALS
- IMPROVE MATERIALS APPLICATION TECHNOLOGY
- IMPROVE GEOCHEMICAL UNDERSTANDING AND PREDICTABILITY

- REDUCE DRILLING COSTS
- IMPROVE PRODUCTIVITY AND LIFE OF WELLS
- MINIMIZE DOWNTIME AND REPAIR COSTS DUE TO MATERIALS FAILURES
- AVOID OVER-DESIGN AND UNDER-DESIGN OF COMPONENTS AND SYSTEMS
- OPTIMIZE ENERGY CONVERSION EFFICIENCY
- ENSURE ENVIRONMENTAL ACCEPTABILITY AND OPERATIONAL SAFETY

- REDUCE COST OF POWER
- REDUCE TECHNOLOGICAL UNCERTAINTIES
- REDUCE ECONOMIC RISKS

← DIRECT →

← INDIRECT →

in attempting to develop geothermal resources and helps improve the cost-competitiveness of this energy source.

A major benefit of DOE-funded R&D, beyond its technical merits, is that its results are available throughout the industry rather than restricted to the sponsoring organization. The large industrial response to the DOE elastomer technology transfer effort (see project description No. A-2) illustrates both the value of this industry-wide approach and the usefulness of the R&D.

The benefits of the program are difficult to quantify, not least because the program is largely oriented towards generic support and toward "subcomponents". However, with downtime at a 50 MWe geothermal power plant estimated to cost around \$100,000/day, a million-dollar R&D program can effectively pay for itself by preventing only 10 days of unscheduled plant shutdown. This amount of downtime could even constitute as little as one day of downtime at ten different facilities. This does not even consider the R&D pay-back in terms of the enhanced technical and economic feasibility of geothermal energy systems.

Substantial progress has been made in all of the "direct benefit" areas identified in Exhibit 4.1. However, FY 1982 R&D is continuing with the aim of producing results in all of these areas. Continued benefits can be expected to accrue to industry from the program.

4.3 FY 1982 Program Modifications

Modifications were made to the GEM Program to produce a leaner program in fiscal year 1982. These changes were made necessary by significant federal R&D funding cuts and by accompanying Division and

program management adjustments. The various problem definition studies undertaken since the inception of the program and the R&D results already produced enabled priority needs to be identified. These needs are being addressed through the continuation of projects already in progress, i.e., no new projects were initiated in FY 1982. The scope of the overall R&D effort has been largely maintained in the current program. The adjustments to the FY 1982 program have been a reduction in scale of expenditure and in the number of projects supported. Historic program emphasis on information/technology transfer continues with a major conference to be held in October 1982, to cover all areas being addressed by FY 1982 GEM Program R&D.

APPENDIX A

GEM PROGRAM MATERIALS PROJECTS

Project No. A-1

PROJECT: Development of High-Temperature Geothermal Elastomers

CONTRACTOR: L'Garde, Inc.

CONTRACT No.: DOE No. DE-AC03-77ET28309 (formerly ERDA Contract No. EG-77-C-03-1308)

PERIOD OF PERFORMANCE: 10/1/76 - 6/30/79

OBJECTIVES:

- Define geothermal elastomeric seal needs and identify target improvements.
- Develop and evaluate elastomers to meet identified requirements.
- Evaluate currently-available elastomers for geothermal service.

RESULTS:

- Successful development of packer elastomers to withstand 500°F (260°C) geothermal brine with 300 ppm H₂S, 1,000 ppm CO₂, 25,000 ppm NaCl in aqueous solution for 24 hrs.
- Four different elastomer systems developed: Ethylene Propylene Diene Terpolymer (EPDM, Nordel*), Fluoroelastomer (FKM, Viton*), EPDM/FKM Blend (Nordel*/Viton*), Propylene-TFE (AFLAS*).
- Demonstration of applicability of these compounds to static O-ring and other elastomer applications.
- Indications that basic compounds adaptable to high-temperature dynamic seals.
- DOE patent application (No. 022,896) for "Cure-In-Place" process.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Geothermal Packers and Packer Elastomers," A.R. Hirasuna and C.A. Stephens, L'Garde, Inc., Geothermal Resources Council Transactions, Vol. 5, pp. 243-246, October 1981.
- "Geothermal Elastomeric Materials (GEM) Program", A.R. Hirasuna, et. al., L'Garde, Inc., NTIS No. SAN-1308-2, July 1979.
- "Geothermal Elastomeric Materials - Twelve-Months Progress Report for Period 1 October 1976 - 30 September 1977", A. R. Hirasuna, et. al., L'Garde, Inc., NTIS No. SAN/1308-1, Dec. 1977.
- "Results of Geothermal Casing Packer Sea Elastomer Compound Development", A.R. Hirasuna, et. al., L'Garde, Inc., Geothermal Resources Council Transactions, Vol. 3, pp. 309-12, Sept. 24, 1979.
- "High-Temperature Geothermal Elastomer Compounds Developed", Geothermal Materials Review newsletter, DOE/ET/27026-05, Vol. 2, No. 4, Fall 1980.
- "Research and Development of Elastomeric Materials for Geothermal Use", Geothermal Materials Review newsletter, Vol. 1, No. 1, Spring 1979.

PROJECT: Elastomers Technology Transfer

CONTRACTOR: L'Garde, Inc.

CONTRACT No.: Brookhaven National Laboratory Subcontract No. 490316-S

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Transfer of manufacturing and application technology/information for EPDM elastomers developed earlier under GEM Program.

RESULTS:

- Thirty-four companies applied for technology transfer, of which 3 were selected.
- High-temperature EPDM elastomers now commercially available from several companies (BJ-Hughes, Parker, Oncor Drilling) for geothermal applications.
- Elastomer-related support to Raft River, Heber, Sperry, and other major DOE projects.
- "Spontaneous" support to 176 companies.

WORK IN PROGRESS:

- Tentative planning for 1982 conference.
- Occasional testing of commercially-produced elastomer products.

PUBLICATIONS:

PROJECT: Environmental Compatibility Testing

CONTRACTOR: L'Garde, Inc.

CONTRACT No.: Brookhaven National Laboratory Subcontract No. 511198-S

PERIOD OF PERFORMANCE: 4/7/80 - Active

OBJECTIVES:

- Test compatibility of existing elastomers (including special elastomers developed earlier under GEM Program) with brine, oils, and isobutane at temperatures up to 510°F (266°C)

RESULTS:

- Identified 34 promising compounds (included specially-developed L'Garde elastomers)
- Performed short-term (120-hr) immersion tests, reducing number to 8.
- Performed short-term (46-hr) O-ring tests in simulated operational environment (up to 266°C).
- Downhole and laboratory experiences indicate Y267 EPDM is superior elastomer for high-temperature aqueous environments. Data are building which indicate superiority for high-temperature static seals in hydrocarbon oil, isobutane, and hydrazine environments.

WORK IN PROGRESS:

- Long-term (6-month) immersion tests.
- Long-term (6-month) O-ring tests scheduled for completion in late-August 1982 (2 failures in 41 days).

PUBLICATIONS:

- Final report expected by end of October 1982.
- "Elastomer Compatibility with Brine, Isobutane and Oil", G.J. Friese, Geothermal Resources Council Transactions, Vol. 5, 1981.

- "High-Temperature Y267 EPDM Elastomer: Field and Laboratory Experiences, August 1981", A.R. Hirasuna, et.al., L'Garde, Inc., Geothermal Resources Council Bulletin, Vol. 11, No. 3, March 1982.
- "High Temperature Y267 EPDM Elastomer Field and Laboratory, Experiences August 1981", A.R. Hirasuna, et.al., L'Garde, Inc., IEEE High Temperature Electronics and Instrumentation Conference, Houston, Texas, Dec. 1981.
- "Environmental Compatibility Test Program - Eighth Quarterly Report", G. J. Friese, L'Garde, Inc., LTR-82-GF-106, 4 May 1982.
- "Performance of Elastomers in Hot Brine, Isobutane and Oils (Environmental Compatibility Testing Program Interim Report)", G. J. Friese, L'Garde, Inc., LTR-81-GF-102, 15 Sept. 1981.

PROJECT: Fluorinated Elastomers for Geothermal Environments

CONTRACTOR: Exfluor Research Corp./Brookhaven National Laboratory

CONTRACT No.: Brookhaven National Laboratory Subcontract No. 486106-S

PERIOD OF PERFORMANCE: 9/1/79 - Active

OBJECTIVES:

- Develop and test new crosslinked perfluorocarbon elastomers produced by direct fluorination.
- Develop optimum filled compositions and fabricate objects such as O-rings of the new elastomers.

RESULTS:

- Screened appropriate elastomers and produced 24 crosslinked fluorinated compounds with desirable properties.
- Best products survived at least 100 days in 300°C simulated geothermal brine.
- Developed various methods to monitor elastomer conditions during testing.
- Exfluor patent application.

WORK IN PROGRESS:

- Casting O-rings of promising elastomers for testing.

PUBLICATIONS:

- "New Fluorocarbon Elastomers for Seals for Geothermal and Other Aggressive Environments", Final Report for Period Sept. 1, 1979 to Nov. 19, 1980, E. T. Dumitru, et. al., Exfluor Research Corp.

PROJECT: Shape Memory Alloy Seals

CONTRACTOR: Rockwell International

CONTRACT No.: Brookhaven National Laboratory Subcontract No. 546251-S

PERIOD OF PERFORMANCE: 3/80 - 7/82

OBJECTIVES:

- Develop novel temperature-actuated seal for geothermal applications utilizing unique properties of Nitinol (Ni-Ti) shape memory alloy.

RESULTS:

- Thirteen Nitinol seals (including face and shaft type) designed, fabricated, and tested (including in downhole pump test facility).
- Demonstration of temperature-actuation to produce leak-tight seal @ 260°C/1,500 psi.
- Supporting materials tests showed high corrosion resistance of Nitinol alloys (generally superior to stainless steels); corrosion performance meets Reda standards for pump applications.
- Kobe successfully tested a Rockwell-supplied Nitinol seal, which remained leak tight after thermal cycling in the temperature range 120° - 232°C. Data will be included in Rockwell final report.

WORK IN PROGRESS:

- Final report expected for distribution by late-July 1982.
- Kobe plans to test a Nitinol shaft seal in a centrifugal-type submersible pump at no cost to DOE.

PUBLICATIONS:

- "Shape Memory Alloy Seals for Geothermal Applications - Twelve-month Progress Report, June 1981 - May 1982", Draft, W.H. Friske and H. Schwartzbart, Rockwell International.

- "Shape Memory Alloy Seals for Geothermal Applications - Twelve-month Progress Report, April 1980 - March 1981, W.H. Friske and H. Schwartzbart, Rockwell International, ESG-81-16, 30 May 1981.

PROJECT: Geothermal Seals Screening

CONTRACTOR: National Bureau of Standards

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Evaluate existing standards for applicability to geothermal uses.
- Develop short-term tests indicative of longer-term service life.
- Screen polymer families for hydrolytic and temperature stability in reductive environments.

RESULTS:

- Laboratory testing has been completed (Phase I).

WORK IN PROGRESS

- Field screening is currently being conducted at Cerro Prieto. Downhole samples have been removed and are undergoing testing.

PUBLICATIONS:

- Final report should be available in Fall of 1982.

PROJECT: Cementing of Geothermal Wells
(In-house, subcontracted, and cooperative R&D program)

CONTRACTOR: Brookhaven National Laboratory, with subcontracts to Battelle's Columbus Laboratories, Colorado School of Mines, Pennsylvania State University, Southwest Research Institute, University of Rhode Island, coordinated with Dowell Division of Dow Chemical Co., National Bureau of Standards.

CONTRACT NO.: DOE Contract No. EY-76-C-02-0016

PERIOD OF PERFORMANCE: 4/76 - 1980

OBJECTIVES:

- Develop and evaluate improved high-temperature cementing materials for completion of geothermal wells through 5 phases: (1) problem definition, (2) cement R&D, (3) property verification, (4) downhole testing, (5) cementing of demonstration wells.

RESULTS: (BNL portion)

- Organized an American Petroleum Institute Task Group on geothermal well cements to assist in technology transfer and establishment of standards.
- 27 cements identified in R&D phase or supplied by industry were evaluated in laboratory, with 16 selected for downhole tests at Cerro Prieto.

(See subcontract descriptions for specific technical accomplishments)

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Cementing of Geothermal Wells", Progress Reports 1-12, L.E. Kukacka, et.al., 1976 - 1980.
- "Geothermal Well Cements, Current Status of R and D and Downhole Testing", L.E. Kukacka, paper presented at International Conference on Geothermal Energy, Florence, Italy, May 11-14, 1982.

- "Development of Cement for Geothermal Wells - Final Report", G.L. Kalousek, Brookhaven National Laboratory, available from NTIS, 1 March 1979.
- "Cements for Geothermal Wells: New Cementing Materials Promise to Withstand the Stresses of Geothermal Wells", U.S. DOE, NTIS Tech Note, Nov. 1981.

PROJECT: New High-Temperature Cementing Materials for Geothermal Wells

CONTRACTOR: Pennsylvania State University

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 422272-S

PERIOD OF PERFORMANCE: 9/77 - 4/80

OBJECTIVES:

- Determine hydrothermal stability of new cementing compositions.
- Determine mechanical and physical properties of these materials in geothermal environments.
- Optimize preparation methods.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "New High-Temperature Cementing Materials for Geothermal Wells; Stability and Properties", Final Report, D.M. Roy, et. al., Pennsylvania State University, July 1980, available from NTIS.

PROJECT: High-Temperature Cementing Materials for Completion of Geothermal Wells

CONTRACTOR: Battelle Columbus Laboratories

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 420825-S

PERIOD OF PERFORMANCE: 7/77 - 3/80

OBJECTIVES:

- Evaluate state-of-the-art of cementing materials and identify/develop materials to meet property requirements of geothermal applications in terms of durability, thickening time, minimum strength loss, and minimum permeability.

RESULTS:

- Developed new cementing compositions with 30-50% cement which meet or surpass requirements, outside of relatively low thickening time values.

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Hydrothermal Cements for Use in the Completion of Geothermal Wells

CONTRACTOR: Southwest Research Institute

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 427964-S

PERIOD OF PERFORMANCE: 10/77 - 9/79

OBJECTIVES:

- Select and optimize existing cement formulations for geothermal requirements and provide laboratory test and evaluation program necessary to initiate a field test program.

RESULTS

- Identified previously-developed SwRI hydrothermal cements which offer unique properties for geothermal well cementing.

WORK IN PROGRESS N/A

PUBLICATIONS

- "Hydrothermal Cements for Use in the Completion of Geothermal Wells", Final Report, D.K. Curtice and W.A. Mallow, Southwest Research Institute, BNL 51183, September 1979, available from NTIS.

PROJECT: Development of Cement for Geothermal Wells

CONTRACTOR: Colorado School of Mines

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Improve/develop cements for long-term service in terms of slurry consistency, early and final strength, compatibility with extraneous constituents, bond formation to steel and wallrock, volume stability, non-corrosion of steel casing, and resistance to saline water attack.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Cementing of Geothermal Wells: Phosphate-Bonded Cements

CONTRACTOR: University of Rhode Island

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 418691-S

PERIOD OF PERFORMANCE: 7/77 - 8/79

OBJECTIVES:

- Develop and test new phosphate cement(s) for completion of geothermal well.

RESULTS:

- Several promising cements identified, but did not meet API placement criteria due to their rapid curing rates.

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Development of Geothermal Well Completion Systems

CONTRACTOR: Dowell Division, Dow Chemical Co.

CONTRACT NO.: DOE Contract No. DEAC02-77ET28324

PERIOD OF PERFORMANCE: 7/77 - 7/80

OBJECTIVES:

- Develop and evaluate a suitable geothermal well cementing material through stability, placement, and chemical measurements, with work centering around Portland and modified Portland systems, silica and/or aluminate systems, and polymer systems.

RESULTS:

- Portland cements of normal weight, similar to those already in use at most geothermal sites, found to be best currently available cementing technology.
- Some promising lightweight systems based upon special modifications of Portland cement were identified.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Development of Geothermal Well Completion Systems", Final Report, E. B. Nelson, Dowell Division, Dow Chemical Co., NTIS No. DOE/ET/28324-9 (no date).

PROJECT: Geothermal Cement Screening

CONTRACTOR: National Bureau of Standards

CONTRACT NO.: DOE Contract No. EA-77-A-01-6010

PERIOD OF PERFORMANCE: 10/77 - 9/80

OBJECTIVES

- Assess strength and durability of cementing materials after exposure to high-pressure, high-temperature geothermal fluids.
- Develop techniques and test procedures for evaluating high-pressure, high-temperature permeability.
- Develop techniques and test procedures for measuring high-pressure, high-temperature fracture toughness and shear strength of cement-metal and cement-rock interfaces.

RESULTS:

- 10 cements identified for further testing exceeded API-approved design criteria in NBS testing program.
- Characterization of 25 cements showed that Portland cements of normal weight, similar to those already in use at most geothermal sites, are very good cements.
- NBS evaluated half of the geothermal cement samples exposed downhole at Cerro Prieto to flowing 210°C brine for 12 months - most held up well.

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Downhole Cement Field Testing and Evaluation

CONTRACTOR: Brookhaven National Laboratory in cooperation with
Comision Federal Electricidad (CFE) and Instituto de
Investigaciones Electricas (IIE)

CONTRACT NO.: DOE Contract No. DE-AC02-76CH00016

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Identify suitable existing and newly-formulated well completion cements through long-term downhole testing and subsequent evaluation.

RESULTS:

- Arranged cost-shared field testing program with Mexicans at Cerro Prieto.
- Cement samples exposed downhole at Cerro Prieto to flowing 210°C brine for 12 months - most held up well.

WORK IN PROGRESS:

- Completing field samples evaluation.
- Wellhead cement samples scheduled for removal from Cerro Prieto in July 1982.
- Review of joint IIE/CFE/BNL/API program on geothermal cements held at API Annual Meeting, June 14-17, 1982. Several industrial participants offered to assist in X-ray diffraction tests on exposed cements.
- Appeal for API or industrial support for needed 350°C downhole tests not received positively. Industry includes small number of geothermal wells compared to oil wells, the general state of the economy, and a slow-down in drilling activity as reasons for no support.

PUBLICATIONS:

- "Geothermal Well Cements, Current Status of R&D Downhole Testing", L.E. Kukacka, paper presented at International Conference on Geothermal Energy, Florence, Italy, May 11-14, 1982.

PROJECT: Feasibility of Cavitation Mixing of Geothermal Cements

CONTRACTOR: Daedalean Associates, Inc.

CONTRACT NO.: Brookhaven National Laboratory Subcontract No.
540651-S

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Determine feasibility of cavitation mixing/emulsification of geothermal well completion cements to improve pumpability and stability.

RESULTS:

- Cavitation mixing tests run with slurries of lightweight and heavyweight (normal) cements.
- Only marginal overall improvement for lightweight cement.
- No effects on standard cement.

WORK IN PROGRESS:

- Further work not recommended by BNL.

PUBLICATIONS:

- "Feasibility Study to Evaluate the Effects of Cavitation Mixing Upon the Pumpability and Strength Characteristics of Cements for Geothermal Applications", Final Report, T. J. Stansfield, Daedalean Associates, Inc., DAI Technical Report No. TJS-8103-001-TR, May 1982.

PROJECT: Polymer Concrete

CONTRACTOR: Brookhaven National Laboratory

CONTRACT NO.: DOE Contract No. DE-AC02-76CH00016

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

RESULTS:

- Patent application (No. 027,689) for high-temperature, chemically-resistant polymer concrete developed under project.

WORK IN PROGRESS:

- Experiments begun to measure fracture toughness, Charpy impact energy, and biaxial tensile strength at NBS of BNL-fabricated polymer concrete specimens exposed to brine at up to 150°C (work to start June-July 1982).
- 200 feet of 2"-diameter PC pipe will be installed (in cooperation with Radian Corp.) in THS direct-application project at Marlin, Texas; this will be the largest amount of PC pipe installed to date in a geothermal facility. As part of this project, BNL has supplied Radian with PC coupons for installation in a test chamber.

PUBLICATIONS:

- "Alternate Method of Preparing Polymer Concrete from Mixtures of Liquid and Solid Monomers", N. R. Carciello, et. al., Brookhaven National Laboratory, J. Appl. Polym. Sci., Vol. 24, No. 10, pp. 2191-93, Nov. 15, 1979.
- "Polymer Systems in Geothermal Applications", A. Zeldin et. al., Brookhaven National Laboratory, J. Appl. Polym. Sci., Vol. 23, No. 11, pp. 3179-91, June 1, 1979.
- "Development of Polymer Concrete Materials for Geothermal Energy Applications", Geothermal Materials Review newsletter, Vol. 1, No. 1, Spring 1979.
- "The Effects of B-C₂S/Class H Cement Mixed Fillers on the Kinetics and Mechanical Properties of Polymer Concrete", T. Sugama, et. al., Cement and Concrete Research, Vol. 10, No. 3, p. 413, 1980.
- "Hydraulic Cement-Type Fillers for Hydrothermally Stable Polymer Concretes", T. Sugama, et. al., J. Materials Science, 15, p. 1498, 1980.

- "Effect of Monomer Composition on the Properties of High Temperature Polymer Concrete", A. Zeldin, et. al., presented at Am. Chem. Soc., Houston, Texas, March 21-26, 1980.
- Patent Application (No. 009,624) for High-temperature Concrete Composites Containing Organosiloxane Cross-linked Copolymers, A. Zeldin, et. al.

PROJECT: Design and Fabrication of Polymer Concrete Pipe for Testing in Geothermal Energy Processes

CONTRACTOR: Lindsey Industries, Inc.

CONTRACT NO.: Brookhaven National Laboratory Subcontract No.
486337-S

PERIOD OF PERFORMANCE: 7/79 - 7/80

OBJECTIVES:

- Design and fabricate sections of PC pipe and appropriate joining methods for testing in geothermal energy applications.
- Expedite transfer of existing technology from BNL to private sector.

RESULTS:

- Successfully tested PC in brine, flashing brine, and steam at up to 500°F (260°C) for as long as 960 days.
- Glass filament wound PC pipe developed with excellent strength, low weight, and competitive cost.
- Connecting technology determined to be slip joints for low-pressure applications and flanged joints for high-pressure applications.
- Established feasibility of commercial-scale manufacturing of PC piping.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Design and Fabrication of Polymer Concrete Pipe for Testing in Geothermal Energy Applications", Final Report, J. E. Schroeder, et. al., Lindsey Industries, July 1981.

PROJECT: Polymer Concrete Lined Pipe for Electric Generating Purposes

CONTRACTOR: Brookhaven National Laboratory/Polymer Concrete Research, Inc.

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 529117-S

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Assess technical and economic benefits of lining pipe with polymer concrete for geothermal energy facilities.

RESULTS:

- Specific PC formulation (developed by BNL) was applied as steel pipe liner.
- Acceptable technical performance expected (determined through measurements of mechanical properties).
- \$8.6 million capital cost and 15.4% ROI estimated for lined-pipe production plant turning out 950m of lined pipe per day.
- Cost of piping a geothermal plant with PC and PC-lined pipe calculated to be \$1.21 million (compared to \$1.33 million for alloy steel piping).
- Life-cycle cost analysis indicates cost of PC-lined steel pipe would be 82% of carbon steel pipe over 20 years.

WORK IN PROGRESS:

- BNL looking for test site for 40 feet of lined pipe, tees, and elbows.

PUBLICATIONS:

- "Design and Fabrication of Polymer Concrete-Lined Pipe for Testing in Geothermal Energy Processes", A.O. Kaeding, Polymer Concrete Research, Inc., Dec. 1981.

PROJECT: Polymer Concrete Vessels for Use in Geothermal Power Plants

CONTRACTOR: Brookhaven National Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Design and evaluate prestressed PC technology for construction of vessels to meet technical requirements of 1st stage flash tank in proposed Heber 50 MWe geothermal power plant.

RESULTS:

- Results indicated that structural integrity of prestressed PC vessel can be ensured under conditions of 170°C and 75 psia.
- Economic feasibility confirmed - cost of production substantially less than an all-steel pressure vessel.

WORK IN PROGRESS:

PUBLICATIONS:

- "Design of Prestressed Polymer Concrete Vessels for Use in Geothermal Power Plants", Draft, B. Koplik, et. al., Brookhaven National Laboratory, Informal Report BNL 31127, Feb. 1982.
- "Large Scale Polymer Concrete Vessels for the Direct Utilization of Geothermal Processes", A. J. Philippopoulos, et. al., Brookhaven National Laboratory, Informal Report BNL-29027, Aug. 1980.

PROJECT: Downhole Pump Bearings

CONTRACTOR: Solar Turbines International

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 490656-S

PERIOD OF PERFORMANCE: 11/79 - 11/80

OBJECTIVES:

- Develop and test improved, high-temperature, long-life (1-5 years) bearing materials for application in geothermal down-hole line-shaft pumps.

RESULTS:

- Construction of test equipment and review of state-of-the-art.
- Tested elastomeric bearings made from materials supplied by L'Garde @200°F for 100 hours and 360°F for 50 hours.
- No wear evident in 200°F test, poor performance at 360°F.
- Softer elastomers appear better.

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Cathodic Protection

CONTRACTOR: Brookhaven National Laboratory/San Diego State University

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Determine concept feasibility and, if favorable, demonstrate corrosion control by cathodic protection.

RESULTS:

- Improvements made in BNL test equipment.
- Looks feasible for piping systems.

WORK IN PROGRESS:

- Literature survey and analysis of applied protection systems.
- Laboratory experiments on polarization.
- Evaluation of steel protection in synthesized brine.
- Tentative planning for prototype testing, with well casing first.
- Two sites have been selected for checking electrochemical effects of impressed currents: one will use an isolated test well as anode and the other will use a trough near the well for locating a laboratory-constructed anode.

PUBLICATIONS:

- "Cathodic Protection in Highly Aggressive Geothermal Environments", R. Bandy and D. Van Rooyen, Brookhaven National Laboratory, paper presented at International Conference on Geothermal Energy, Florence, Italy, May 11-14, 1982. (Organized by BHRA Fluid Engineering and Ente Nazionale per L'Energia Elettrica).

PROJECT: Materials Evaluation and Failure Analysis

CONTRACTOR: Radian Corporation

CONTRACT NO.: DOE Contract No. 80-212003-11

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Investigate, as needed, selected geothermal materials problems experienced in the field.
- Perform failure analyses of materials-related component failures in the field.

RESULTS:

- Failure analysis of numerous components from power and direct-heat facilities in U.S. and abroad.
- Final design review of Baca plant revealed many areas lacking adequate corrosion engineering.
- Participation in activities of relevant societies and associations.

WORK IN PROGRESS:

- Availability for failure analysis investigations.
- Materials and engineering design analysis for cooling systems using brine.

PUBLICATIONS:

- "Geothermal Steam Muffler Diffusers: The Geysers, California. Failure Analysis Report", R. McAlpin and P. F. Ellis, Radian Corp., NTIS No. DOE/ET/27026, April 1980.
- "Geothermal Materials Survey: Arkansas Power and Light Development and Demonstration Project. 100 kW Power System Using Direct Contact Heat Exchangers, El Dorado, Arkansas", P. F. Ellis, Radian Corp., NTIS No. DOE/ET/27026-T4, July 22, 1980.
- "Geothermal Materials Survey: Baca Geothermal Demonstration Power Plant, Baca, New Mexico", P. F. Ellis, Radian Corp., NTIS No. DOE/ET/27026-T5.

- "Turbine Failure at East Mesa", Geothermal Materials Review newsletter, DOE/SF/11503-01, Vol. 3, No. 1, Winter 1981.
- "Geothermal Failure Analysis Studies", Geothermal Materials Review newsletter, DOE/SF/11503-03, Vol. 3, No. 3, Fall 1981.
- "DOE-DGE Analyzes Failed Muffler From The Geysers", Geothermal Materials Review newsletter, DOE/ET/27026-04, Vol. 2, No. 3, Summer 1980.
- "Geothermal Components Solicited for DOE-DGE Analysis Program" (case histories of some component analyses), Geothermal Materials Review newsletter, Vol. 2, No. 1, Winter 1980.

PROJECT: Materials Selection Guidelines for Geothermal Energy Utilization Systems

CONTRACTOR: Radian Corp.

CONTRACT NO.: DOE Contract No. AC02-79-ET27026

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Collect, analyze, and document field performance data for materials used in geothermal energy systems.
- Publish a geothermal materials oriented newsletter.

RESULTS:

- Publication of Materials Selection Guidelines Handbook for surface equipment (see below) - includes corrosivity classification of geothermal fluids.
- Publication of Geothermal Materials Review newsletter (circulation 2200) - final issue, Vol. 3, No. 4, Winter 1982.

WORK IN PROGRESS:

- Up-date of Materials Selection Guidelines Handbook.
- Draft of "Materials Reference for Downhole Geothermal Energy Applications" has been reviewed by Brookhaven National Laboratory.

PUBLICATIONS:

- "A Geothermal Corrosivity Classification System", P.F. Ellis, Geothermal Resources Council Transactions, Vol. 5, October 1981.
- "Materials Selection Guidelines for Geothermal Energy Utilization Systems", P. F. Ellis and M. F. Conover, Radian Corporation, NTIS No. DOE/RA/27026-1, Jan. 1981.
- "Geothermal Materials Review", newsletter, Final Issue: Vol. 3, No. 4, Winter 1982.

PROJECT: Benefit/Cost Analysis of Geothermal Technology R&D:
Geochemical and Materials Engineering

CONTRACTOR: The MITRE Corp.

CONTRACT NO.: DOE Contract No. EG-77-C-01-4014

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Perform benefit/cost analysis for GEM Program R&D projects as of FY 1978.

RESULTS:

- Benefit/cost analysis of 45 R&D projects.
- Total cost saving found to be 3.9 - 8.5% for then-projected installation of geothermal power up to year 2000, with overall benefit/cost ratio of projects from 18.3 to 39.8.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Benefit/Cost Analysis of Geothermal Technology R&D, Volume IV: Geochemical and Materials Engineering", V. T. Nguyen and D. J. Entingh, The MITRE Corp., MITRE Technical Report MTR-7980, Volume IV, May 1979.

PROJECT: Economic Impact of Using Nonmetallic Materials in Low-Intermediate Temperature Geothermal Well Construction

CONTRACTOR: National Water Well Association

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 485874-S

PERIOD OF PERFORMANCE: 6/79 - 4/80

OBJECTIVES:

- Evaluate potential economic impact of using nonmetallic materials in \$150°C geothermal well construction

RESULTS:

- Exhaustive literature search and evaluation on properties and economics of commercially-available nonmetallic well casing and screens showed substantial reductions in drilling and O&M costs could result from their use in geothermal wells (including elastomers for seals, thermoplastic well casing, fiberglass reinforced plastic casing)

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Economic Impact of Using Nonmetallic Materials in Low-Intermediate Temperature Geothermal Well Construction", Volumes I and II, T. E. Gass, et. al., National Water Well Association, Dec. 1979.
- "Economics of Nonmetallic Materials for Geothermal Wells", Geothermal Materials Review newsletter, DOE/ET/27026-04, Vol. 2, No. 3, Summer 1980.

PROJECT: Economic Assessment of Using Non-metallic Materials in the Direct Utilization of Geothermal Energy

CONTRACTOR: Burns and Roe Industrial Services Corp.

CONTRACT NO.: Brookhaven National Laboratory Subcontract No.
442252-S

PERIOD OF PERFORMANCE: ? - 2/79

OBJECTIVES:

- Determine economic advantages of utilizing non-metallic materials (such as polymer concrete, epoxy coatings, asbestos cement, fiberglass reinforced plastic) in geothermal applications up to 300°F (150°C).

RESULTS:

- Establishment of cost-effectiveness of using polymer concrete pipe and polymer concrete vessels.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Economic Assessment of Using Non-metallic Materials in the Direct Utilization of Geothermal Energy", Final Report, S.V. Cabibbo, et. al., Burns and Roe Industrial Services Corp., Feb. 28, 1979.

PROJECT: Downhole Heat Exchangers in Geothermal Direct Utilization Applications

CONTRACTOR: Research Triangle Institute

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 483982-S

PERIOD OF PERFORMANCE: 6/79 - 4/80

OBJECTIVES:

- Define waterline corrosion problem and its economic impact for downhole heat exchangers for direct-heat applications and identify potential solutions.

RESULTS:

- Waterline corrosion problems can be addressed with Ti coating.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Definition Study of Waterline Corrosion Problems in Downhole Heat Exchangers in Geothermal (Non-electric) Applications, and Its Solution by Ti Coating", Research Triangle Institute, Report No. RTI/183501I.

PROJECT: An Assessment of Non-Destructive Testing of Well Casing, Cement and Cement Bond in High-Temperature Wells

CONTRACTOR: Lawrence Livermore Laboratory/Geoenergy Corp.

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Evaluate capabilities of existing casing and cement-bond logging techniques and assess potential geothermal (high-temperature) applications. If current technology does not provide adequate resolution and reliability for estimating casing and cement-bond useful life, define new logging rationales based on either modification of existing techniques or new technology.

RESULTS:

- Types of well failures documented include leaks, dog legs, channeling in the cement, wellbore communication (in multiple completion wells), casing collapse, cement failure, wellhead movement, disengagement of couplings, fractures, cracks, and buckled and sheared casing. One of prime causes of the most expensive failures (casing collapse) is expansion of water pockets between sections with good cement.
- Field tests of number of commercial logs in geothermal wells showed that downhole problems occur around 300°F and most are unreliable around 400°F.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "An Assessment of Non-Destructive Testing of Well Casing, Cement and Cement Bond in High-Temperature Wells", Lawrence Livermore National Laboratory, Report No. UCRL-15032, 1980.

PROJECT: The Application of a Non-Destructive Evaluation Technique Utilizing Internal Friction for Detecting Incipient Failure of Drill Pipes

CONTRACTOR: Daedalean Associates, Inc.

CONTRACT NO.: DOE Contract No. EG-77-C-01-4045

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop internal friction NDE drill-string technology for field testing drill pipe.
- Develop data analysis procedures to enable operator to distinguish various modes of drill-pipe failure.

RESULTS:

- IFD-NDE equipment designed, constructed, and extensively field-tested.
- Developed mathematical models for various modes of failure, based on a significant statistical sample.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "The Application of a Non-Destructive Evaluation Technique Utilizing Internal Friction for Detecting the Incipient Failure of Drill Pipes", Final Report, Daedalean Associates, Inc.
- "Internal Friction Damping Investigated as Means of Predicting Drill Pipe Failure", Geothermal Materials Review newsletter, DOE/ET/27026-01, Vol. 1, No. 2, Summer/Fall 1979.
- "A Nondestructive Evaluation Technique for Detecting the Incipient Failure of Drill Pipes Used in Geothermal Well Drilling", A.A. Hochrein, Jr. and L.L. Yeager, Daedalean Associates, Inc., Geothermal Systems Materials: A Workshop/Symposium, Proceedings, NTIS No. COO-3904-1, Arranged by Radian Corp., May 23-25, 1978.

PROJECT: Piping Materials Field Testing

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- (1) Determine improvements possible in production well casing using controlled-process API, AISI, and ASTM alloy steels and using potentially cost-effective high-alloy steels.
- (2) Determine time dependence of localized corrosion rate under anaerobic Niland brine conditions as a function of metallurgical conditions of low-cost API, AISI, and ASTM carbon and low-alloy steels.

RESULTS:

- (1) Experiment in Magmamax No. 1 well showed that, in hyper-saline brine, API casing and tubing steels perforate in less than 6 months. Improved performance can be obtained using ASTM grades of carbon steel and, particularly, using grades containing at least .75 wt% Cr and 1 wt % Mo. Performance improvement may be attributable to both the addition of more corrosion resistant alloying elements and to the control of impurities (such as sulfide inclusions) that act as sites to initiate localized corrosion.
- (2) Coupons of 8 different carbon and chrome-moly alloy steels were exposed to high-temperature, high-salinity wellhead brine flow at Salton Sea for periods of up to 6 months. Corrosion rate and corrosion attack morphology of each coupon were determined. Exposure time was a test variable and ranged from 1 to 6 months. Test results indicate carbon steels generally suffer high corrosion rates and are susceptible to severe localized attack which shows a mesa-canyon pattern. Chrome-moly alloy steels corrode at much lower rates and show an attack pattern of small shallow pits. With time, these pits grow mostly in the lateral direction. Results suggest that chrome-moly alloy steels offer significant improvement over carbon steels and that the disk-shaped pits are not likely to lead to rapid per-

foration. No significant time-dependent corrosion rate behavior was observed.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- (1) In press.
- (2) "Localized Corrosion of Steels in Geothermal Steam/Brine Mixtures", R.D. McCright, et. al., Lawrence Livermore National Laboratory, Preprint No. UCRL-84489, 1980.

PROJECT: Localized Corrosion of Casing

CONTRACTOR: Case Western Reserve

CONTRACT NO.:

PERIOD OF PERFORMANCE: Terminated in FY 1982 due to lack of funding

OBJECTIVES:

- Reduce localized corrosion of casing by composition and heat treatment, thereby eliminating incipient corrosion centers without large increases in materials and fabrication costs.

RESULTS:

- Tests showed that a relative new alloy, Ni-Cu-Cb, consistently demonstrated good resistance to both general and localized attack.
- Cr-Mo steels surprisingly did not perform well at ambient temperature, but did exhibit substantial improvement @150°C.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Localized Corrosion in Materials for Geothermal Power", A. Roy, et. al., Case Western Reserve, Dec. 1980, available from NTIS.

PROJECT: Test and Evaluation of API Casing Materials

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Determine the API grade of carbon steel best suited for well casing and the composition-dependent variations within API specifications that influence corrosion lifetime.

RESULTS:

- Tubing string of J-55, N-80, and C-75 steels exposed to brine downhole in Woolsey No. 1 well for 69 days. Corrosion penetration rates as high as 500 mils/yr. were found for J-55 and deemed not suitable for geothermal well casing. API grades N-80 and C-75 have potential for providing as much as 20-fold decrease in penetration rates due to beneficial influence of greater amounts of Mo and Si.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Well Casing Materials", R.D. McCright, et. al., in "LLL Industrial Support Program Results on Scale Control, Corrosion, H₂S Abatement, and Injection at the Salton Sea Geothermal Field in FY 1979", R. Quong and L.B. Owen (eds.), Lawrence Livermore National Laboratory, Report No. UCID-18596, 1980.

PROJECT: Improved Drill Bit Materials

CONTRACTOR: Terra Tek, Inc.

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 492267-S

PERIOD OF PERFORMANCE: 9/79 - 9/81

OBJECTIVES:

- Optimize alloys and the heat treatment of candidate alloys to ensure longer life and better penetration rates of drill bits and reamers.

RESULTS:

- Determined high-temperature fracture toughness and fatigue crack resistance of number of steels with improved hot hardness and conventional steels.
- Two steels identified for drilling equipment up to 400°C.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Elevated Temperature Fracture Toughness and Fatigue Testing of Steels for Geothermal Applications", Final Report, R. A. Cutler, et. al., Terra Tek, TR-81-97, Oct. 1981.

PROJECT: High-Temperature Logging Cable and Cablehead Development

CONTRACTOR: Sandia National Laboratories

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Develop new materials and fabrication techniques, as well as innovative design with existing materials, for geothermal downhole cable applications.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Static Testing of Geothermal Cables

CONTRACTOR: Aerospace Research Corp.

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Metal Sheath Cable Development

CONTRACTOR: Halpen Engineering, Inc.

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop promising new cable concept of armored cable with a thin-walled metal tube core or impermeable coating, within which high-temperature insulators and conductors are protected.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Development of a Metal Sheath Cable", A.S. Halpenny (Halpen Engineering, Inc.) and S.J. Gray, IEEE High Temperature Electronics and Instrumentation Conference, Houston, Texas, Dec. 1981.

PROJECT: Assessment of Materials Needs for the Utilization of Geothermal Energy

CONTRACTOR: National Materials Advisory Board, National Academy of Sciences.

CONTRACT NO.: Brookhaven National Laboratory Subcontract No. 494818-S

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Define and assess the materials-related problems present in hydrothermal-geothermal energy utilization and identify technology/approaches for addressing these problems.

RESULTS:

- Comprehensive report published to guide government and private sector efforts in this area.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Materials Needs For the Utilization of Geothermal Energy", Committee on Materials Needs For the Utilization of Geothermal Energy, National Materials Advisory Board, National Academy of Sciences, Report No. NMAB-375, March 1981.

PROJECT: Workshops, Conferences, International Information Exchange
(see also project no. B-23).

CONTRACTOR: Various

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Facilitate rapid and accurate dissemination of information to the geothermal community and service/supply industries so that adequate technology and methods already available can be effectively utilized, duplication of effort can be avoided, R&D can build on previous experiences, and problems requiring particular attention can be identified.

RESULTS:

- Workshop/symposium on Materials in Geothermal Energy Systems, Radian Corp., Austin, Texas, May 23-25, 1978.
- ASTM/DOE Seals Conferences, June 1978, June 1979, May 1980.
- International Information Exchange: U.S./Italy/Mexico/Iceland

WORK IN PROGRESS:

- "Applying Current Geothermal Corrosion/Materials Technology to Today's Projects", DOE-sponsored conference to be held in San Diego, CA, Oct. 6-8, 1982.
- National Society Workshops
- International Information Exchange: U.S./Italy/Mexico/Iceland

PUBLICATIONS:

- Geothermal Systems Materials: A Workshop/Symposium, Proceedings, NTIS no. C00-3904-1, Radian Corp., Austin, Texas, May 23-25, 1978.
- ASTM/DOE Seals Conference, Conference Report CONF-786141, April 1979.

- "Geothermal Energy and Consensus Standards", R.R. Reeber, U.S. Department of Energy, ASTM Standardization News, Vol. 7, No. 10, 1979.
- "Cements for Geothermal Wells: New Cementing Materials Promise to Withstand the Stresses of Geothermal Wells", U.S. DOE, NTIS Tech Note, Nov. 1981.

APPENDIX B

GEM PROGRAM GEOCHEMICAL ENGINEERING PROJECTS

PROJECT: Sensors and Instrumentation Development

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Develop and lab test prototype high-temperature sensors and instrumentation for critical in-line geochemical monitoring duties in geothermal power plants.
- To be accomplished through coordinated program of in-house and subcontracted R&D.

RESULTS:

- Prototype conductivity, redox, and corrosion probes developed and lab tested.

WORK IN PROGRESS:

- Development of ceramic pH probe (General Electric).
- Development of isobutane corrosion probe.
- Development of binary-system leak detector.
- Tentative planning for development of particle meter for injection line.

PUBLICATIONS:

- "Chemical Control and Monitoring Instrumentation for Geothermal Systems", G.A. Jensen, Battelle Pacific Northwest Laboratory, PNL-SA-8051, October 1979 (presented at National Association of Corrosion Engineers, Western Region Conference, February 1980).
- "Development of High Temperature Instruments for Measuring the Water Chemistry of Geothermal Systems", G.A. Jensen, Battelle Pacific Northwest Laboratory, PNL-SA-8155, December 1979 (presented at High Temperature Electronics and Instrumentation Seminar, Houston, Texas, December 3-4 1979).
- "Chemical Sensors for Geothermal Systems", G.A. Jensen, The Northern Engineer, to be published spring 1980.

- "Development of Electrical and Electrochemical Probes for Down Hole and In-Line Chemical Analysis of High Pressure, High Temperature Geothermal Fluids", M.J. Danielson, et.al., Battelle Pacific Northwest Laboratory, PNL-2459, Nov. 1977.
- "Monitoring Field Experiments at Oregon Institute of Technology", M.J. Danielson and R.P. Smith, Battelle Pacific Northwest Laboratory, PNL-3385, Sept. 1980.

PROJECT: Standard Electrode Development

CONTRACTOR: Stanford Research Institute

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop a reference electrode against which other instrumentation can be compared and calibrated to ensure reliability of measurements.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Development of Reference Electrode

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop a reference electrode against which other instrumentation can be compared and calibrated to ensure reliability of measurements.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Development of High-Temperature Glass pH Sensor

CONTRACTOR: Leeds and Northrup Company

CONTRACT NO.:

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Develop and lab test a glass electrode for measuring pH in brines at minimum conditions of 250°C and 5,000 psi in both downhole and above-ground applications.

RESULTS:

WORK IN PROGRESS:

PUBLICATIONS:

- "Detailed Conceptual Design of a High-Temperature Glass pH Electrode for Geothermal Applications", R.M. Taylor, et. al., Leeds and Northrup Co., PNL-3051, May 1979.

PROJECT: Development of High-Temperature Glass pH Sensor

CONTRACTOR: Owens Illinois, Inc.

CONTRACT NO.: DOE Contract No. EY-76-C-06-1830

PERIOD OF PERFORMANCE: Terminated in FY 1982

OBJECTIVES:

- Develop and lab test a glass electrode for measuring pH in brines at minimum conditions of 250°C and 5,000 psi in both downhole and above-ground applications.

RESULTS:

- Project terminated because initial test results indicated that the glass electrode would not be successful for high-temperature, corrosive environments.

WORK IN PROGRESS:

PUBLICATIONS:

- "Detailed Conceptual Design of a High Temperature Glass pH Electrode For Geothermal Applications, Final Report, Task 1", D.N. Gray and P.J. Breno, Owens-Illinois, Inc., NTIS No. RLO-1830-T3, May 1979.

PROJECT: Development of High-Temperature Ceramic pH Sensor

CONTRACTOR: General Electric

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Develop and lab test a ceramic sensor for pH measurements over 250°C and 5,000 psi.

RESULTS:

- Probe designed and constructed; autoclave test @ 550°F successful, but some problems @ 200-300°F (perhaps due to manufacturing variances in ceramic tube).

WORK IN PROGRESS:

- Plans to build prototype for testing (funding permitting).

PUBLICATIONS:

- "Development of the Improved Corrosion Rate Meter and Evaluation of Commercially Developed High-Temperature pH Electrodes. Interim Report for Period Ending September 1981", M.J. Danielson, Battelle Pacific Northwest Laboratory, NTIS No. DE82007873, Jan. 1982.

PROJECT: Development of High-Temperature Chemically Sensitive Semiconductor

CONTRACTOR: University of Pennsylvania

CONTRACT NO.:

PERIOD OF PERFORMANCE: Terminated in FY 1982 due to lack of funding.

OBJECTIVES:

- Develop and lab test an advanced, rugged, and small sensor to simultaneously measure several ionic species in brine.

RESULTS:

- Initial work prior to project termination appeared promising.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- Project report has been issued.

PROJECT: Development of High-Temperature CO₂ Sensor

CONTRACTOR: Leeds and Northrup

CONTRACT NO.:

PERIOD OF PERFORMANCE: Terminated in FY 1982 due to lack of funding.

OBJECTIVES:

- Develop and lab test a sensor for in-line measurement of CO₂ at over 250°C and 5,000 psi in both downhole and above-ground applications.

RESULTS:

- Prototype design complete; laboratory confirmation needed (as of Dec. 1980).

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Development of High-Temperature Sulfide Sensor

CONTRACTOR: Beckman Instruments

CONTRACT NO.:

PERIOD OF PERFORMANCE: Terminated in FY 1981.

OBJECTIVES:

- Develop and lab test a sulfide ion sensor for minimum conditions of 250°C and 5,000 psi which will be useful in predicting scaling, probability of atmospheric emissions, and corrosion.

RESULTS:

- Design and preliminary laboratory test complete; laboratory confirmation needed (as of Dec. 1980).
- Project terminated after it was determined that sulfide ion sensors work better in alkaline environments than in neutral /acidic environments.

WORK IN PROGRESS:

PUBLICATIONS:

- "Detailed Conceptual Design of a High-Temperature Sulfide Ion Sensing Electrode for Geothermal Systems," A. Wielback, et. al., Beckman Instruments, Inc. (to PNL), PNL-3624, Nov. 1980.

PROJECT: Development of Conductivity Probe

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Develop and lab test a conductivity probe to detect flashing in heat exchangers which would reduce system efficiency due to scaling.

RESULTS:

WORK IN PROGRESS:

PUBLICATIONS:

PROJEJCT: Development of Redox Probe

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop and lab test a probe to detect the presence of oxygen in fluid streams to permit the prediction and prevention of corrosion.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Development of the High-Temperature Redox Electrode and Improved Corrosion Rate Meter. Interim Report For Period Ending September 1980", M.J. Danielson and O.H. Koski, Battelle Pacific Northwest Laboratory, NTIS No. DE82000933, September 1981.
- "Development of a High Temperature Redox Electrode", M.J. Danielson, Battelle Pacific Northwest Laboratory, PNL-3377, Aug. 1980.

PROJECT: Development of Corrosion Rate Meter

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop and lab test a device for detecting corrosion and measuring corrosion rates to exercise better process control and prevent corrosion-related failures.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Development of the Improved Corrosion Rate Meter and Evaluation of Commercially Developed High-Temperature pH Electrodes. Interim Report for Period Ending September 1981", M.J. Danielson, Battelle Pacific Northwest Laboratory, NTIS No. DE82007873, Jan. 1982.
- "Development of the High-Temperature Redox Electrode and Improved Corrosion Rate Meter. Interim Report for Period Ending September 1980", M.J. Danielson and O.H. Koski, Battelle Pacific Northwest Laboratory, NTIS No. DE82000933, September 1981.

PROJECT: Sensors and Instrumentation Field Testing

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.: DOE Contract No. DE-AC06-76RLO 1830
(EY-76-06-1830)

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Evaluate in-plant operational performance of specially-developed prototype sensors and instrumentation.
- Design plant-wide process monitoring system.
- Support Heber binary project (with Heber project funding).

RESULTS:

- Completed two-year cooperative monitoring/testing program with Magma Electric at Magma's on-line East Mesa binary-cycle power plant.
- Developed monitoring system for Heber plant, which now duplicated at Magma plant.
- Isobutane corrosion probe installed in conjunction with Barber-Nichols DCHX.

WORK IN PROGRESS:

- Reinstallation of Magma plant monitoring equipment following major shutdown and repair due to condenser failure.
- First-time penetration of isobutane loop for isobutane-side corrosion monitoring and cross-leak detection.
- Continue Magma data analysis and Heber design evaluation to refine geochemical monitoring strategies and technology.

PUBLICATIONS:

- "Monitoring the Chemistry and Materials of the Magma Geothermal Binary Cycle Generating Plant", D.W. Shannon, Battelle Pacific Northwest Laboratory, Geothermal Materials Review newsletter, DOE/SF/11503-03, Vol. 3, No. 4, Winter 1982.

PROJECT: Sensors and Instrumentation Technology Transfer

CONTRACTOR: Battelle Pacific Northwest Laboratories

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Transfer specifications and technology of successfully developed and field-tested monitoring instrumentation to private sector manufacturers and test resulting commercialized products in operational plant.

RESULTS:

- Bidders list of 16 companies in response to PON for redox, corrosion, and conductivity probes.

WORK IN PROGRESS:

- PON response evaluation.
- Planning for field testing of commercialized products in Magma power plant.

PUBLICATIONS:

PROJECT: Sampling and Analysis Methods

CONTRACTOR: Battelle Pacific Northwest Laboratory

CONTRACT NO.: DOE Contract No. EY-76-C-06-1830

PERIOD OF PERFORMANCE: 1975 - Active

OBJECTIVES:

- Develop accurate, reliable, and standardized S&A methods for geothermal fluid characterization and for supporting process monitoring activities.

RESULTS:

- Publication of Geothermal Sampling and Analysis Methods Manual.
- S&A methods developed in conjunction with ASTM are being used by geothermal industry.

WORK IN PROGRESS:

- Development of S&A methods for binary plant leak detection (cross-stream leaks).

PUBLICATIONS:

- "Sampling and Analysis Methods for Geothermal Fluids and Gases", J.C. Watson, Battelle Pacific Northwest Laboratory, PNL-MA-572, July 1978.
- "Appendices - Sampling and Analysis Methods for Geothermal Fluids and Gases", D.W. Shannon, Battelle Pacific Northwest Laboratory, PNL-MA-572, available from NTIS.
- "Field Evaluation of Sampling Methods for Pressurized Geothermal Liquids, Gases, and Suspended Solids", D.W. Shannon, et.al., Battelle Pacific Northwest Laboratory, PNL-3412, January 1980, available from NTIS.
- "Techniques for Geothermal Liquid Sampling and Analysis", C.H. Kindle and E.M. Woodruff, Battelle Pacific Northwest Laboratory, PNL-3801, July 1981, available from NTIS.
- "Standardizing Sampling and Analysis Methods for Geothermal Fluids and Gases", J.C. Watson, Pacific Northwest Laboratory, PNL-6847A, Presented at American Nuclear Society National Meeting, San Diego, CA, June 1978.

- "Round Robin Evaluation of Geothermal Brine Analytical Methods," J.C. Watson, Pacific Northwest Laboratory, PNL-SA-7359A, to be presented at Joint American Chemical Society-Chemical Society of Japan Chemical Congress, Honolulu, HI, April 1979.
- "Geothermal Water and Gas - Collected Methods for Sampling and Analysis; Comment Issue," J.G. Douglas, R.J. Serne, D.W. Shannon, E.M. Woodruff, BNWL-2094, August 1976.
- "1979 Field Test Report - East Mesa, California," D.W. Shannon, et al., to be published August 1980.
- "Geothermal Release Points of Environmental Contaminants," C.H. Kindle, PNL-SA-8501, May 1980.
- "Institutional Standardization of Geothermal Fluid Characterization Techniques," C.H. Kindle, to be published in Geothermal Resources Council Transactions, September 1980.
- "Geothermal Sampling/Analysis: Summary Document on Techniques," C.H. Kindle and E.M. Woodruff, to be published.

PROJECT: Geochemical Engineering Reference Manual

CONTRACTOR: Terra Tek, Inc.

CONTRACT NO.: DOE Contract No. DE-AC-03815F-11520

PERIOD OF PERFORMANCE: 10/81 - Active

OBJECTIVES:

- Consolidate, evaluate, and document geochemical engineering information to assist geothermal industry in optimizing energy utilization efficiency and safety.

RESULTS:

WORK IN PROGRESS:

- Preparation of handbook.

PUBLICATIONS:

PROJECT: Solubility of SrSO_4 in Aqueous Solutions

CONTRACTOR: Vetter Research

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Determine solubility of SrSO_4 in NaCl-free solution of CaCl_2 and MgCl_2 at 75°C and 95°C to identify solubility-temperature trends.
- Determine SrSO_4 solubility in higher-temperature solutions containing NaCl.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Hydrodynamic/Kinetic Reactions in Liquid-Dominated Geothermal Systems

CONTRACTOR: Aerojet Energy Conversion Co.

CONTRACT NO.: DOE/Los Alamos Scientific Laboratory Contract No.
4-X29-9916F-1

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Evaluate hydrodynamic/kinetic mechanisms of geothermal scale buildup.
- Identify methods to control or modify solids deposition.

RESULTS:

- Designed, constructed, and tested a mobile well test unit to collect data on geothermal scale formation and provide power plant design data.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Mobile Well Site Test Equipment to Provide Hydrodynamic/Kinetic Reaction and Power Plant Design Data", J.P. Nesewich, et.al., Geothermal Resources Council Transactions, Vol. 5, 1981.

PROJECT: Calorimetric Determination of the Entropies and Gibbs Free Energies of Formation of Selected Scale-Forming Minerals

CONTRACTOR: U.S. Geological Survey

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Measure heat capacities and enthalpies of selected geothermal minerals which contribute to scale formation.

RESULTS:

- Measured heat capacities (between 5K and 600K) of chalcopyrite (CuFeS_2), siderite (FeCO_3), rhodochrosite (MnCO_3), fayalite (FeSiO_4), and tephroite (MnSiO_4) by combined adiabatic calorimetry and differential scanning calorimetry.
- Measured enthalpies of formation of siderite and rhodochrosite by HCl solution calorimetry.

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Solubility and Kinetics of Precipitation of Minerals of Importance in Geothermal Applications

CONTRACTOR: State University of New York, Buffalo

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Determine the thermodynamic solubilities and kinetics of scale-forming minerals in the presence of potential scale inhibitors.

RESULTS:

- Conducted studies on calcium carbonate polymorphs, calcium sulfate hydrates, barium sulfate, and silicates up to 300°C using a seeded growth technique.
- Influence of trace heavy metal ions on precipitation was also considered.

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Calorimetry of Geothermal Fluids and Related Materials

CONTRACTOR: Arizona State University

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed.

OBJECTIVES:

- Modify and apply an existing high-temperature, high-pressure calorimeter to measure enthalpies of dilution in concentrated NaCl-H₂O solutions and enthalpies of mixing, solution, and precipitation of solid phases in the systems NaCl - CaCl₂ - CaSO₄ - H₂O and NaCl - CaCl₂ - CaCO₃ - H₂O.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Geochemistry of Geothermal Systems

CONTRACTOR: Pennsylvania State University

CONTRACT NO.:

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Collect geochemical data and model chemical systems for improving process engineering of geothermal plants.

RESULTS:

WORK IN PROGRESS:

PUBLICATIONS:

PROJECT: Workshops, Conferences, International Information Exchange.
(See also project no. A-39)

CONTRACTOR: Various

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Facilitate rapid and accurate dissemination of information to the geothermal community and service/supply industries so that adequate technology and methods already available can be effectively utilized, duplication of effort can be avoided, R&D can build on previous experiences, and problems requiring particular attention can be identified.

RESULTS:

- Fluid Management Workshop, 1977
- Mineral Recovery - Fluid Management Coordination Meetings, 1976-77
- Workshop on Scale Control in Geothermal Energy Extraction Systems, Los Alamos Scientific Laboratory, Los Alamos, NM, Oct. 6-7, 1977
- International Symposium on Oil Field and Geothermal Chemistry, Society of Petroleum Engineers, June 1977
- Workshop on Scale Control in Geothermal Systems, 1980
- International Information Exchange: U.S./Italy/Mexico/Iceland
- Workshop/symposium on Materials in Geothermal Energy Systems, Radian Corp., Austin, Texas, May 22-25, 1978.

WORK IN PROGRESS:

- "Applying Current Geothermal Corrosion/Materials Technology to Today's Projects", DOE-sponsored conference to be held in San Diego, CA, Oct. 6-8, 1982.
- National Society Workshops
- International Information Exchange: U.S./Italy/Mexico/Iceland

PUBLICATIONS:

- Proceedings of Workshop on Scale Control in Geothermal Energy Extraction Systems, Conference Proceedings LA-7664-C, Los Alamos Scientific Laboratory, Oct. 6-7, 1977.
- Geothermal Systems Materials: A Workshop/Symposium, Proceedings, NTIS No. COO-3904-1, Radian Corp., Austin, Texas, May 23-25, 1978.

PROJECT: Measurement of Injectability of Brines

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed by 1980.

OBJECTIVES:

- Assess injectability of Imperial Valley brine by measuring the flow of brine through media which simulate downhole injection formations and correlate these measurements, as far as possible, with actual injection performance.

RESULTS:

- On-line field tests of core flooding and membrane filtration with 70-102°C brine showed that injection would not be feasible unless particulates ≥ 1 μ m were removed.
- Brines with pH lowered to retard scale formation not highly injectable without filtration.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- An Experimental Investigation of the Permeability of Kayenta and St. Peter Sandstones to Hypersaline Brine in the Temperature Interval 70-90°C at 10.3-MPa Confining Pressure, A.J. Piwinski and R. Netherton, Lawrence Livermore Laboratory, Rept. UCRL-52382, 1977.
- Predicting the Rate by Which Suspended Solids Plug Geothermal Injection Wells, L.B. Owen, et. al., Lawrence Livermore Laboratory, Preprint UCRL-80529, 1977, presented at the 3rd Ann. Stanford Workshop on Geothermal Reservoir Eng., 1977.
- "Development of Injection Criteria for Geothermal Resources," J.D. Tewhey, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2 (1978) pp. 649-652.
- "Apparatus for the Field Evaluation of Geothermal Effluent Injection," R. Netherton and L.B. Owen, Trans. Geothermal Resources Council Meeting, Hilo, 2 1978 pp.

- "An Automated System for Membrane Filtration and Core Tests," R.T. Hasbrouck, et. al., Trans. Geothermal Resources Council Meeting, Reno, 3 1979, pp. 301-304.
- "Processing of Geothermal Brine Effluents for Injection," R. Quong, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2 1978, pp. 551-554.
- An Assessment of the Injectability of Conditioned Brine Produced by a Reaction Clarification--Gravity Filtration System in Operation at the Salton Sea Geothermal Field, Southern, California, L. B. Owen, et. al., Lawrence Livermore Laboratory, Rept. UCID-18488, 1979.
- Viscosity of Brines from the Salton Sea Geothermal Field, Imperial Valley, California, A. J. Piwinski, et. al., Lawrence Livermore Laboratory, Rept. UCRL-52344, 1977.
- Improving the Performance of Brine Wells at Gulf Coast Strategic Petroleum Reserve Sites, L. B. Owen and R. Quong, Lawrence Livermore Laboratory, Rept. UCRL-52829, 1979.
- "Evaluating Brine Injection for DOE's Strategic Petroleum Reserve Program," Energy and Technology Review, Lawrence Livermore Laboratory Rept. UCRL-52000-79-8, 1979 pp. 1-10.
- "An Evaluation of Geopressured Brine Injectability," L. B. Owen, et. al., presented at the 6th Annual Stanford Workshop on Geothermal Reservoir Engineering, 1980.

PROJECT: Injection Well Stimulation Chemistry

CONTRACTOR: Vetter Research

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Identify chemical procedures and chemicals for reducing or removing scale in injection wells.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

PROJECT: Fluid Modeling for Deposition Prediction

CONTRACTOR: University of California at San Diego

CONTRACT NO.:

PERIOD OF PERFORMANCE: Active

OBJECTIVES:

- Model multi-ion geothermal fluids to predict precipitation products, rates, and locations.

RESULTS:

- Finished effort for SO_4^{2-} , Cl^- , and S^- .

WORK IN PROGRESS:

- Finishing CO_3^{2-} .
- Silicates to be started.

PUBLICATIONS:

PROJECT: Geochemistry Modeling and Fluid Chemistry

CONTRACTOR: Los Alamos Scientific Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Assist DOE in planning and coordination of efforts in geothermal fluid chemistry and computer modeling of scaling, including preparation of codes and comparison of prediction with experimental data.

RESULTS:

- Developed and modified computer code to predict locations of deposition of various chemical species in geothermal systems. Although techniques for sampling did not yield sufficiently accurate measurements, empirical data were consistent with general predictions.

WORK IN PROGRESS:

PUBLICATIONS:

- "LASL's Relationships to the Modeling of Geochemical Systems", T. J. Merson, Los Alamos Scientific Laboratory, Workshop on Scale Control in Geothermal Energy Extraction Systems, Los Alamos, N.M., Oct. 6, 1977.

PROJECT: Geothermal Brine Modeling

CONTRACTOR: University of California, La Jolla

CONTRACT NO.:

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Develop an activity coefficient model for geothermal fluids and determine the single electrolyte parameters for binary aqueous solutions of NaOH, KOH, Mg(OH)_2 , and Ca(OH)_2 .

RESULTS:

WORK IN PROGRESS:

PUBLICATIONS:

PROJECT: Hydrodynamic/Kinetic Reactions and Morphology Changes of Scale-Forming Materials

CONTRACTOR: University of Delaware

CONTRACT NO.: 29-9916F-2

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Examine hydrodynamic effects on scale formation kinetics and morphology with scales produced in the lab at atmospheric pressure, low shear stresses, and temperatures from 26-100°C.

RESULTS:

- Electron microanalysis shown to be a sensitive method to determine composition of scale deposits.
- Seems possible to modify scale structure by changing the fluid mechanics of the brine.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Application of a Rotating Disc Contactor To Scale Deposition", A.B. Metzner, et. al.
- "Microanalysis and Electron Microscopy of Geothermal Scale", F.D.S. Marques and J.U. Edington, Proceedings of the 7th Congress on Electron Microscopy.
- "Microstructure of the Scale Formed in a Geothermal Well in the Salton Sea", F.D.S. Marques and J.U. Edington, Proceedings of the 7th Congress on Electron Microscopy.

PROJECT: Cooling Water Treatment

CONTRACTOR: Idaho National Engineering Laboratory

CONTRACT NO.: DOE Contract No. DE-AC07-76ID01570

PERIOD OF PERFORMANCE:

OBJECTIVES:

- Develop techniques to reduce problem scaling and corrosion in geothermal power plant cooling systems which use geothermal brine as make-up.

RESULTS:

- Short-term investigation led to technically effective SiO₂ removal process, which was recommended for Raft River² plant.
- Short-term investigation led to technically effective treatment for general, but not pitting, corrosion along with inhibitor recovery system; economics uncertain.

WORK IN PROGRESS:

PUBLICATIONS:

- "Zeta Potential Study of the Water Treatment of Geothermal Brines", F. M. Wikoff and D. F. Suciu, Idaho National Engineering Laboratory, NTIS No. DE 82005910, Nov. 1981.
- "Corrosion Testing of Carbon Steel in Aereated Geothermal Brine", D. F. Suciu and P. M. Wikoff, Idaho National Engineering Laboratory, NTIS No. DE 81028653, Feb. 1981.
- "Short-Term Pilot Cooling Tower Tests", D. F. Suciu and R. L. Miller, Idaho National Engineering Laboratory, EGG-FM-5087, Jan. 1980, available from NTIS.

PROJECT: Compilation of Data on Fluids From Geothermal Resources in the U.S.

CONTRACTOR: Lawrence Berkeley Laboratory

CONTRACT NO.: DOE Contract No. W-7405-ENG-48

PERIOD OF PERFORMANCE: Completed 9/77

OBJECTIVES:

- Produce comprehensive, single-source compilation of geothermal fluid characteristics for important U.S. resources, to be stored in computerized database.

RESULTS:

- A report was prepared detailing site-specific information on brine chemical composition.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "A Compilation of Data on Fluids From Geothermal Resources in the U.S.", S. R. Cosner and J. A. Apps, Lawrence Berkeley Laboratory, NTIS No. LBL-5936, May 1978.

PROJECT: Assessment of the Characterization (in situ-Downhole) of Geothermal Brines

CONTRACTOR: National Materials Advisory Board, National Academy of Sciences

CONTRACT NO.: DOE Contract No. E(49-18)2551

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Identify and quantify the physical and chemical properties of geothermal fluids and identify the downhole instrumentation needed to monitor changes in the values of these properties.

RESULTS:

- Number of recommendations made concerning needed R&D in terms of existing and new monitoring instruments, sampling, and geochemical information in the downhole environment.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Assessment of the Characterization (in situ-Downhole) of Geothermal Brines", National Materials Advisory Board, National Academy of Sciences, NMAB-344, Jan. 1978.

PROJECT: Chemical Measurement Techniques Development

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop selected measuring techniques specifically tailored to Salton Sea geothermal brines.

RESULTS:

- Insertable sampling probe developed.
- Developed an anaerobic incubation and analytical technique for following silica precipitation rates @90°C.
- Applied laser particle counting techniques to brine characterization.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- Sampling a Two-Phase Geothermal Brine Flow for Chemical Analysis, J.H. Hill and C. J. Morris, Lawrence Livermore Laboratory, Rept. UCRL-77544, 1975.
- Sampling and Characterization of Suspended Solids in Brine from Magmamax No. 1 Well, J. H. Hill and C. H. Otto, Jr., Lawrence Livermore Laboratory, Rept. UCRL-79007, 1977.
- Apparatus and Techniques for the Study of Precipitation of Solids and Silica from Hypersaline Geothermal Brine, J. H. Hill, et. al., Lawrence Livermore Laboratory, Rept. UCRL-52799, 1979.
- Preliminary Tests Using a Laser Particle-Size Analyzer on Geothermal Brine, J. Z. Grens, Lawrence Livermore Laboratory, Rept. UCID-17637.

PROJECT: Precipitation and Scale Control for Salton Sea Brines

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Test available chemical additives (both commercial antiscalants and other selected chemicals not specifically intended for precipitation/scale control) and other approaches in order to identify effective or promising additives for the predominantly SiO_2 precipitation in Salton Sea brines.

RESULTS:

- Brine acidification (HCl) found to significantly reduce S^- and siliceous scales (acidification only chemical method to reduce rate of high-temperature S^- scaling).
- Silica seeding shown to be effective in reducing level of SiO_2 supersaturation and retarding scale formation.
- 9 commercial proprietary organic antiscalants and 8 potential SiO_2 precipitation inhibitors tested, with no successes.
- 120 generic organic compounds tested for SiO_2 control, with certain functional groups identified as active; best formulation probably a mixture of an organic SiO_2 precipitation inhibitor, small amount of HCl , and a phosphonate crystalline deposit inhibitor.
- Patent application (No. 159,313) for SiO_2 precipitation and scaling inhibition with cationic N^- containing compounds (particularly polymeric imines, polymeric amines, and quaternary ammonium compounds).

WORK IN PROGRESS: N/A

PUBLICATIONS:

- J. Z. Grens and L. B. Owen, "Field Evaluation of Scale Control Methods: Acidification," Trans. Geothermal Resources Council Meeting, San Diego, 1, 1977 pp. 119-121.

- Determination of the Rate of Formation of Solids from Hypersaline Brine as a Function of pH, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-17596, 1977.
- Studies of Brine Chemistry, Precipitation of Solids, and Scale Formation at the Salton Sea Geothermal Field, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCRL-52640, 1979.
- Corrosion Sci. J. E. Harrar, et. al., 19, 819 1979.
- On-Line Tests of Organic Additives for the Inhibition of the Precipitation of Silica from Hypersaline Geothermal Brine III. Scaling Measurements and Tests of Other Methods of Brine Modification, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-18238, 1979.
- "Processing of Geothermal Brine Effluents for Injection," R. Quong, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2 1978, pp 551-554.
- Preliminary Results of Tests of Proprietary Chemical Additives, Seeding, and Other Approaches for the Reduction of Scale in Hypersaline Geothermal Systems, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-18051, 1979.
- Final Report on Tests of Proprietary Additives as Antiscalants for Hypersaline Geothermal Brine, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-18521, 1980.
- "Effects of Organic Additives on the Formation of Solids from Hypersaline Geothermal Brine," J. E. Harrar, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2, 1978, pp. 259-262.
- "Field Tests of Organic Additives for the Control of Scale at the Salton Sea Geothermal Field," J. E. Harrar, et. al., Trans. Geothermal Resources Council Meeting, Reno, 3, 1979, pp. 295-298.
- "Silica Control and Materials Tests at the Salton Sea Geothermal Field," R. Quong, et. al., Proc. 3rd Ann. Geothermal Conf. and Workshop, Monterey, CA, 1979, EPRI, pp. 4-21 to 4-27.
- On-Line Tests of Organic Additives for the Inhibition of the Precipitation of Silica from Hypersaline Geothermal Brine, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-18091, 1979.
- On-line Tests of Organic Additives for the Inhibition of the Precipitation of Silica from Hypersaline Geothermal Brine II. Tests of Nitrogen-Containing Compounds, Silanes, and Additional Ethoxylated Compounds, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-18195, 1979.

- On-Line Tests of Organic Additives for the Inhibition of the Precipitation of Silica from Hypersaline Geothermal Brine IV. Final Tests of Candidate Additives, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Rept. UCID-18536, 1979.
- Field Tests of Organic Additives for the Control of Scale at the Salton Sea Geothermal Field, J. E. Harrar, et. al., Lawrence Livermore Laboratory, Preprint UCRL-84227, 1980.
- "Controlling Scale Formation in Geothermal Brines," Energy and Technology Review, Lawrence Livermore Laboratory, Rept. UCRL-52000-80-5, May 1980, pp. 1-7.
- Progress and Future Directions in Chemical Methods for the Control of Scale at the Salton Sea Geothermal Field, J. E. Harrar, Lawrence Livermore Laboratory, Preprint UCRL-84222, 1980, presented at Workshop on Scale Control and Related Topics, Los Alamos, NM, 1980.

PROJECT: Precipitation and Scaling in Dynamic Geothermal Systems

CONTRACTOR: Oak Ridge National Laboratory

CONTRACT NO.: DOE Contract No. W-7405-ENG-26

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Collect basic scaling data for model development
- Develop scaling models for application in pilot plants

RESULTS:

- 100 gpm Ti corrosion test loop modified to provide dynamic facility for studying formation of SiO_2 deposits, their properties, and fates as a function of brine composition, temperature, and flow conditions.
- Scale formation studied in segmented HX under realistic conditions.
- Project terminated after minimal progress.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Silica Scaling in Simulated Geothermal Brines", E.G. Bohlmann, et. al., Oak Ridge National Laboratory, April 1981, available from NTIS.
- "Silica Precipitation and Scaling in Dynamic Geothermal Systems", E.G. Bohlmann, et. al., Oak Ridge National Laboratory, Workshop on Scale Control in Geothermal Energy Extraction Systems, Los Alamos, NM, Oct. 6, 1977.

PROJECT: Silica Scaling Study

CONTRACTOR: EIC Corp.

CONTRACT NO.: DOE Contract No. EY-786-C-02-2607

PERIOD OF PERFORMANCE: Completed 4/78

OBJECTIVES:

- Collect data and prepare models for SiO₂ scaling and kinetics in geothermal brines.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Study of Silica Scaling From Geothermal Brines", Final Report, EIC Corp., Report No. COO-2607-5.
- "Condensation of Silica From Supersaturated Silicate Acid Solutions", Journal of Colloid Interface Science.

PROJECT: Scale Formation and Suppression

CONTRACTOR: Dow Chemical Co.

CONTRACT NO.: DOE Contract No. DE-AC0879ET27255

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Evaluate scale control methods for heat exchangers.
- Provide experimental testing of fluid chemistry models developed by LASL to identify R&D needs for scale inhibitors.
- Provide quantitative data on scaling and scaling rates in pilot-plant size equipment.

RESULTS:

- Lowering pH of simulated brine to pH 6 or less found to be effective in S&T HX; not economic approach, though, due to increased corrosion.
- Calgon CL-165 and Monsanto Dequest 2060 found to be promising and deserving further testing.
- Experiments with seeding, turbulence promotion, and electrostatic and electromagnetic devices were unsuccessful.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Study on Scale Formation and Suppression in Heat Exchange Systems for Simulated Geothermal Brines", Final Report, J. S. Wilson, et. al., Dow Chemical Co., COO/2833-1, Final Report for Period 1/12/76 - 3/5/78.

PROJECT: Silica Scale Kinetics

CONTRACTOR: Lawrence Berkeley Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Study and document the kinetics of SiO_2 scaling in geothermal conditions to enhance understanding² and control of the scaling process.

RESULTS:

- Large amount of high-quality experimental data generated over 23-100°C temperature range.
- SILNUC computer code developed which quantitatively models and extrapolates to untested conditions the nucleation and growth of colloidal SiO_2 particles.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Kinetics of Silica Polymerization", O. Weres, et. al., Lawrence Berkeley Laboratory, LBL-7033, May 1980, available from NTIS.

PROJECT: Scale Inhibition in Geothermal Operations

CONTRACTOR: Vetter Research

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Test commercially-available scale control additives for CaCO_3 at the East Mesa geothermal site to evaluate the additives' technical effectiveness, any undesirable side effects, and economics of use at that site.

RESULTS:

- Monsanto's Dequest 2060 product identified as very effective carbonate scale inhibitor.
- Estimated cost of use determined to be on the order of .3 mills/kWhr.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Scale Inhibition in Geothermal Operations-Experiments with Dequest 2060 Phosphonate in Republic's East Mesa Field", O. J. Vetter and D. A. Campbell, Vetter Research, VR Report No. 79-5-27, May 27, 1979.

PROJECT: Research and Development of Cavitation Descaling Techniques for Heat Exchanger Tubes Used in Geothermal Energy Plants

CONTRACTOR: Daedalean Associates, Inc.

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed

OBJECTIVES:

- Develop and field-test cost-effective means of cavitation descaling for above-ground plant equipment.

RESULTS:

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Development of a Cavitating Descaling Technique for Geothermal Scale Removal", A. A. Hochrein, Jr. and F. Graham, Daedalean Associates, Inc., Geothermal Systems Materials: A Workshop/Symposium, Proceedings, NTIS No. COO-3904-1, Radian Corp., Austin, Texas, May 23-25, 1978.

PROJECT: Study of Using Surface Waters to Supplement Injection

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed by 1980

OBJECTIVES:

- Evaluate feasibility of using local surface waters as make-up water for injection at the Salton Sea geothermal resource.

RESULTS:

- 3 local sources of water (Salton Sea, New River, Alamo River) evaluated.
- Direct injection of make-up not feasible because of high suspended-solids levels and because mixing of make-up with geothermal brine resulted in additional precipitation.
- Mixtures of ambient temperature make-up and higher-temperature (80-90°C) brine effluent in a 1:4 mass ratio found to be potentially injectable following processing by reaction clarification and granular media filtration.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Using Surface Waters for Supplementing Injection at the Salton Sea Geothermal Field, Southern, California," E. Raber, et. al., Trans. Geothermal Resources Council Meeting, Reno, 3, 1979, pp. 561-564.

PROJECT: Processing of Brines for Injection

CONTRACTOR: Lawrence Livermore Laboratory

CONTRACT NO.:

PERIOD OF PERFORMANCE: Completed by 1980

OBJECTIVES:

- Develop and demonstrate a process for treating Salton Sea brine effluents to produce wastes with high injectability.

RESULTS:

- Process developed and bench-scale tested based on solids contact clarification (enhanced with an anionic coagulant) followed by polishing by sand or precoat pressure filtration.
- Injectability tests indicated resulting effluents could be injected without significantly impairing injection wells.

WORK IN PROGRESS: N/A

PUBLICATIONS:

- "Processing of Geothermal Brine Effluents for Injection," R. Quong, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2, 1978, pp. 551-554.
- "Geothermal Brine Injection Evaluation Methodology," Proceedings Second Invitational Well-Testing Symposium, Berkeley, CA, R. Quong, et. al., Lawrence Berkeley Laboratory, Rept. LBL-8883, 1978, pp. 78-80.
- Conditioning of Geothermal Brine Effluents for Injection -- Use of Coagulants, R. Quong, et. al., Lawrence Livermore Laboratory, Rept. UCID-17716, 1978.