Geothermal Materials Program Strategy

Final Report

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF EXHIBITS	iv
ACKNOWLEDGEMENTS	v
EXECUTIVE SUMMARY	vii
I. INTRODUCTION	1
A. Background	1
B. Purpose of Document	2
II. PROGRAM GOAL AND OBJECTIVES	4
A. Goal	4
B. Strategy	4
C. Scope and Definition of Problems	5
D. Rationale	19
E. Objectives	25
III. PROGRAM ORGANIZATION	27
A. Program Structure and Objectives of Program Elements	27
B. Program Priorities and Funding	32
C. Program Management	41
IV. PROGRAM STATUS	43
A. Materials for Borehole Components	43
B. Materials for Energy Conversion Components	63
C. Materials Testing and Corrosion Control	73
D. Technology Transfer	78
APPENDIX A Assumptions Used to Estimate Illustrative Cost Impact of DGE's Geochemical Engineering and Materials Program on Geothermal Electricity Production	82
APPENDIX B Descriptions of Current Program Projects	85

LIST OF EXHIBITS

	<u>Page</u>
1. General Materials Problems in a Steam or Flash Electric Plant	7
2. General Materials Problems in a Binary Electric Plant	8
3. General Materials Problems in a Typical Direct-Use Plant	9
4. Specific Problems Caused by Materials Failures	10
5. Relationship of Components, Environments, and Failure Modes	11
6. Materials Acceptable for Component Service	13
7. Relationship of Materials Testing and Corrosion Control Needs to Geothermal Systems	15
8. System and Component Performance Constraints Being Addressed by Geothermal Materials Program	16
9. Cumulative Cost and GEM Program Savings Data for Geothermal Electric Plants, 1985-2000 (Constant \$)	20
10. Benefit/Cost Ratios for GEM Program R&D	21
11. Installed Component Costs in Percents of Total Plant Cost for a 50 MWe Plant	23
12. Percentage Plant and Component Cost Savings Due to GEM Program	24
13. Geothermal Materials Program Elements and Subelements	29
14. Geothermal Materials Program Element Priorities	34
15. Materials for Borehole Components: Element Priorities and Funding	35
16. Materials for Energy Conversion Components: Element Priorities and Funding	36
17. Materials Testing and Corrosion Control: Element Priorities and Funding	37
18. Technology Transfer: Element Priorities and Funding	38
19. Program Element Funding Requirements 1978-88	39
20. Overall Program Funding Requirements on Yearly Basis	40
21. Matrix of Current Program Projects and Addressed Subelements	44

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EXECUTIVE SUMMARY

The U.S. National Energy Plan foresees a significant contribution to energy needs from geothermal energy—heat extracted from the earth in the form of hot and pressurized fluids.⁽¹⁾ If federally-sponsored efforts to accelerate commercialization of this energy source are successful, geothermal resources could produce 3.5-9.0 quadrillion BTU/year by the turn of the century.⁽²⁾ While this quantity represents only a small part of the nation's overall projected energy consumption, geothermal energy could account for a large fraction of energy use in some regions, particularly the western states.

Practical applications of geothermal energy are electricity generation, direct-heat uses, and production/utilization of methane (from geopressured resources). The economical utilization of geothermal resources in the U.S. requires surmounting a range of technological, environmental, institutional, legal/regulatory, and social problems that are in many instances significantly more complex than those faced in other nations.

Among the most pressing problems constraining the development and expanded use of energy conversion facilities for this resource is the lack of satisfactory component and system reliability. This is due to the unavailability, on a commercial scale, of cost-effective materials that can function in a wide range of geothermal environments and to the unavailability of a comprehensive body of directly relevant test data or materials selection experience. Suitable materials are needed for service in geothermal wells and in process plant equipment. For both situations, this requires materials that can withstand high-temperature, highly-corrosive, and scale-forming geothermal fluids. In addition to requiring a high degree of chemical and thermal resistance, the downhole environment places demands on the physical/mechanical properties of materials for components utilized in well drilling, completion, pumping, and logging.

The Division of Geothermal Energy (DGE) within the Department of Energy (DOE) is addressing these materials-related problems through two separate but interrelated programs: the Geothermal Materials Program and the Geochemical Engineering Program. The Geothermal Materials Program, which is the subject of this document, is designed to enable achievement of national geothermal energy utilization goals by assisting the private sector, as needed, to: (1) provide commercial quantities of materials suitable for geothermal service; (2) develop materials-related technology for geothermal applications; (3) commercialize materials-related developments; and (4) establish a sound and functioning geothermal industry materials-related infrastructure. The Geothermal Materials Program is a very important aspect of DOE's geothermal technology development activities and is, in many respects, a critical step towards establishing geothermal energy as a viable energy alternative. The rationale for this program lies in the expected reduction in costs directly

(1) These fluids may be naturally-occurring heated subsurface fluids or liquids pumped through hot rock formations to recover heat.

(2) National Energy Plan II, Report to Congress, U.S. Department of Energy, May 1979.

and indirectly associated with geothermal energy commercialization resulting from federally-stimulated industrial activity in materials-related fields. The achievement of greater component and system reliability with cost-effective materials will increase industry productivity for both federally-sponsored and private sector geothermal projects and thereby contribute significantly to accelerating national geothermal commercialization. Since "unusual" water chemistries are the norm for geothermal systems, improved materials also have broad application for other energy conversion systems.

DGE directs its Geothermal Materials Program efforts through four program elements:

- (1) materials for borehole components,
- (2) materials for energy conversion components,
- (3) materials testing and corrosion control, and
- (4) technology transfer.

These four elements correspond to the major areas of concern that DGE has identified through assessments of worldwide experience with geothermal projects and other industrial operations having similar materials-related needs. The objective of the borehole materials program element is to evaluate conventional materials and, where needed, to develop cost-effective substitute and/or alternate materials for downhole components. The second element, which concentrates on above-ground process equipment, has a major objective of assembling and assessing information available about conventional energy conversion systems as it relates to geothermal energy utilization; through this evaluative process, specific problem areas requiring attention can be identified. The materials selection, optimization, and development R,D&D supported under these two program elements is supplemented by funding for the development and application of testing procedures intended to improve materials/component failure prevention and for the development of corrosion control and monitoring techniques. Provisions for the transfer of information and technology are an integral part of individual technical projects sponsored by DGE. However, there are special requirements for assessments that address many, or all, aspects of materials-related concerns in geothermal development and also for ongoing interactive programs involving DGE, industry, and professional societies. All of these forms of technology/information transfer are vital for maximizing the impact of the limited funds available through the Geothermal Materials Program.

Each of the four program elements consists of subelements which are the focal points for the R,D&D. These are set out below.

- (1) Materials for Borehole Components - well cements, tubulars, packers, drilling components, pumps, logging components, wellhead components, and cable.
- (2) Materials for Energy Conversion Components - turbines, pressure vessels, steam separators, pumps, piping, valves, heat exchangers, cooling towers, and waste processing equipment.

- (3) Materials Testing and Corrosion Control - non-destructive testing of drill pipe, non-destructive testing of in-situ well materials, non-destructive testing of energy conversion component materials, corrosion inhibitors, corrosion monitors, cathodic and anodic protection, and corrosion field testing.
- (4) Technology Transfer - handbooks, manuals, conferences and workshops, newsletters, professional societies interaction, product technology transfer, and new standards.

Priorities among the subelements and elements have been determined by the application of four evaluation criteria outlined below.

- (1) Cost Impact - a measure of the favorable impact on the economics of geothermal energy development.
- (2) Environmental Concern - a measure of the favorable impact on maintaining control and safety in handling geothermal fluids.
- (3) State-of-Knowledge - a measure of the contribution to existing data and know-how concerning geothermal development.
- (4) Materials Shortfall - a measure of the degree to which expanded markets for geothermal materials and materials-related technology will be identified and exploited.

Estimated federal funding for the Geothermal Materials Program for the period 1978-88 is \$36.5 million. Of this total, approximately 43% is for the support of the borehole program element, 39% for the energy conversion element, 16% for the materials testing and corrosion control element and 2% for technology transfer element.⁽¹⁾ Federal expenditure through the Geothermal Materials Program is expected to continue to increase until fiscal year 1984 and then sharply decrease to a level representing relatively minor government participation in geothermal materials-related R,D&D. This funding schedule reflects the accelerated involvement of the private sector in the development of materials and components for geothermal power systems that will be facilitated by the Geothermal Materials Program.

The DGE program management structure has been designed to ensure the most effective use of available funding. Brookhaven National Laboratory is the designated Technical Coordinator for all the program elements except the technology transfer element, which is coordinated directly by DOE. A large amount of the program R,D&D is conducted or subcontracted by national laboratories, but a significant proportion is also contracted directly to industry and universities. Professional societies and technical advisory groups are actively involved in the processes of problem identification, evaluation of R,D&D, and standards development.

There are currently 25 active projects addressing the entire range of materials-related problems identified in the program. A significant number of high-impact technical and economic achievements have been recorded to date.

(1) The 2% figure for the technology transfer program element does not include funding which is attributable to technology and information transfer activities built into the other three R,D&D program elements.

The future course of the Geothermal Materials Program will be guided by these accomplishments, the results of the program's active projects, periodic determination of industry needs, and the available budget. Very important contributions to the planning effort will be made by a current National Academy of Sciences study of geothermal materials needs through the year 2000, as well as by other selected industrial task groups.

This document presents the R,D&D strategy and status of the DGE Geothermal Materials Program. Included in this document are:

- Program goals, objectives, and scope
- Program R,D&D strategy and rationale
- Program R,D&D elements and subelements
- Program priorities and historical and requested funding
- Program management structure
- Status of ongoing projects
- Major accomplishments to date

Also included is an appendix describing the objectives of the program's active projects.

I. INTRODUCTION

A. BACKGROUND

The United States is committed to a National Geothermal Program aimed at the accelerated use of the country's abundant geothermal resources. It is expected that these resources will make an important contribution to national energy requirements through electric power generation and direct heat applications, with geopressured resources serving also as a supply of methane. Recognizing that realization of this goal requires overcoming a number of serious technological and non-technological problems, Congress enacted the Geothermal Energy Research, Development, and Demonstration Act of 1974. The Act concludes that:

...the Federal Government should encourage and assist private industry through Federal assistance for the development and demonstration of practicable means to produce useful energy from geothermal resources with environmentally acceptable processes.

Federally sponsored research, development, and demonstration (R,D&D) activities to assist in geothermal energy industrialization are authorized by this Act and by the Federal Nonnuclear Energy Research and Development Act of 1974 and the Geothermal Steam Act of 1970. The Department of Energy (DOE) has been designated as lead agency for the federal geothermal energy programs and, as such, its role is to:

- (1) evaluate and characterize geothermal reservoirs,
- (2) conduct R,D&D programs to assist industry in developing the technology necessary for exploitation,
- (3) help establish geothermal utilization as a cost-competitive energy alternative, and
- (4) assess and mitigate regulatory, environmental, institutional, and social barriers to geothermal development.

A major thrust of DOE's geothermal program is to develop economically feasible solutions to technical problems associated with the extraction, handling, and disposal of geothermal fluids that are impeding rapid commercialization. In response to this thrust, the primary goals⁽¹⁾ of the combined Geochemical Engineering and Materials (GEM) Programs within the Division of Geothermal Energy (DGE) are:

- to provide assurance that geothermal fluids sufficient to meet U.S. geothermal energy goals can be produced, contained, utilized, and disposed of in a safe, economic, and environmentally acceptable manner.
- to increase public and industry confidence in the national geothermal energy plan.

The GEM Program addresses these goals by pursuing two separate but inter-related areas of research: (1) development of cost-effective materials durable enough for use in a wide range of geothermal environments, and (2) improvement of geochemical fluid management techniques. Although these two aspects have much in common with regard to specific problem areas, technical program objectives, R&D requirements, and resulting cost reductions, they can be differentiated according to their materials or geochemical engineering orientation. Separation of geochemical engineering and materials R&D into two programs is necessary for precise problem identification and the development of appropriate problem-solving techniques.

B. PURPOSE OF DOCUMENT

This document presents the strategy and status of the Geothermal Materials Program. The purpose of this document is to:

- (1) describe the magnitude and scope of materials-related problems constraining geothermal commercialization;
- (2) define the goals and objectives of the DGE Geothermal Materials Program;

(1) Geothermal Energy Program Summary Document, Assistant Secretary for Resource Applications, DOE, January 1980.

- (3) describe the rationale and strategy of the program;
- (4) delineate the structure, priorities, funding, and management of specific elements within the program; and
- (5) present the status of the overall program.

II. PROGRAM GOAL AND OBJECTIVES

A. GOAL

Within the overall framework of the Geochemical Engineering and Materials effort, the specific goal of the Geothermal Materials Program is to:

Facilitate rapid geothermal energy commercialization by ensuring the commercial availability of economically and technologically viable materials for well drilling and operation, and for the containment and handling of geothermal and associated fluids during production, energy conversion, and disposal.

B. STRATEGY

Achievement of the program goal requires the effective management of a wide range of technological and economic problems. DGE's approach is to optimize the benefits of materials-related R,D&D through the resolution of selected problems. The program strategy outlined below concentrates on developing an optimum balance between (1) problems whose solutions have an immediate impact on the successful operation of large-scale prototype plants, and (2) moderate-term applied R,D&D designed to have significant impacts on industrial viability and productivity through improvements in materials performance and costs. The Geothermal Materials Program Strategy is to sponsor projects that:

- (1) identify materials-related needs constraining commercialization;
- (2) evaluate the applicability of existing materials and technology to geothermal problems;
- (3) develop specific and generic solutions to materials problems that have major impacts on geothermal energy costs and productivity;
- (4) provide appropriate and adequate incentives and mechanisms for the stimulation of industry-sponsored geothermal materials R,D&D;
- (5) provide sufficient incentives for the commercialization of new developments as necessary; and

- (6) identify and help develop essential elements of the materials-related supply/service infrastructure needed to support the geothermal industry.

The overall applied R&D program serves as a focal point for supplier industries to become aware of the scope of geothermal problems at a time when little economic incentive exists for private R&D investments. Some seemingly lower-priority generic applied R&D projects are funded, therefore, in order to stimulate wide private sector industrial activity. These higher risk/higher return projects provide a reasonable combination of foci to ensure the accelerated development of an adequate service and supply infrastructure. This open-forum government/industry/university involvement, which is coordinated through national technical society task groups, also provides the continuous feedback necessary for a sound technical program, as well as creating industry and university awareness of materials, manpower, and research needs and opportunities.

The establishment of a high degree of materials expertise early in the growth period of the geothermal industry provides problem-solving capabilities and preliminary materials test experience that is effective in overcoming larger-scale, costly materials-related problems economically constraining the initial stages of geothermal resource development. No other division within DOE's Assistant Secretary for Resource Applications addresses such applied R&D needs of the National Geothermal Program.

C. SCOPE AND DEFINITION OF PROBLEMS

The technical and economic problems selected for federal support under the Geothermal Materials Program have been identified through assessments of worldwide experience with geothermal operations and associated materials-related equipment failures, of available corrosion information relevant to geothermal conditions, and of the requirements of novel U.S. technology currently under development and demonstration.

Exhibits 1 through 4 summarize the major materials problems that can be expected in electric and direct-use plants. Materials intended for geothermal applications frequently experience a unique operating environment necessitating appropriate materials selection or the development of improved materials to meet diverse chemical and physical demands. Although suitable corrosion-resistant alloy materials are often available for geothermal applications, their high cost may prohibit commercial use. The materials chosen for geothermal service should be carefully matched to the required performance standards and the existing operating conditions. This decision must take account of the suitability of the materials for the particular component under study and, in particular, the failure modes found and/or expected to present actual or potential problems. Exhibit 5 is a matrix which relates components to their working environments and associated failure modes, while Exhibit 6 lists the materials applicable for use in borehole and energy conversion components. These exhibits illustrate the wide range of problems and considerations involved in materials selection or development. General testing and evaluation, monitoring, and protection techniques applicable to major geothermal systems are shown in Exhibit 7. Exhibit 8 outlines the component-specific materials problems being addressed by the Geothermal Materials Program that are impeding rapid progress towards the development and operation of efficient and reliable fluid extraction and utilization systems. Additional difficulties are evident when it is realized that varying combinations and degrees of the identified conditions are encountered at specific geothermal sites.

The failure or expected short service-lives of downhole components are causing drilling and operating costs for geothermal wells to escalate. Geothermal field development costs over the life of a reservoir will be significantly greater than for oil and gas production due to the present lack of comparable

EXHIBIT 1

GENERAL MATERIALS PROBLEMS IN A STEAM OR FLASH ELECTRIC PLANT

EXHIBIT 2

GENERAL MATERIALS PROBLEMS IN A BINARY ELECTRIC PLANT

EXHIBIT 3

GENERAL MATERIALS PROBLEMS IN A TYPICAL DIRECT-USE PLANT

SPECIFIC PROBLEMS CAUSED BY MATERIALS FAILURES

METALLIC MATERIALS

FIRST ORDER

- Well casing failure.
- Increase in component wall thickness to allow for corrosion and erosion.
- Downhole failures in drilling operations of metal seals and drill pipes.
- Downhole pump seal and bearing failures and general corrosion.

SECOND ORDER

- Frequent maintenance and promoting cement failure, safety.
- High capital cost, difficulties in high volume purchase.
- High tripping frequency - high well cost, reduction in resource development.
- Frequent removal of pump for maintenance, high down-time; losses of fluid delivery.

APPROACHES FOR IMPROVEMENT

- Determine properties requirements in terms of strength, fracture toughness, pitting resistance in high temperature corrosive environments.
- Evaluate and develop if necessary metals or alternate materials to meet requirements (performance standards).
- Test metals under field conditions (confirm standards).

NON-METALLIC MATERIALS

FIRST ORDER

Cement

- Improper curing.
- Low strength, low bonding strength.
- Flow properties - incomplete filling of annulus.
- Water loss or free water.
- Lost circulation problems*.

Elastomers

- Seal failures during drilling.
- Seal failures in pumps, downhole drilling motors.
- Packer failures in cementing and stimulation (if applied).
- Drilling fluids*.

SECOND ORDER

- High completion cost. Cement defects unknown until failure during operation.
- Fluid entering areas between casing and cement. Casing failure. Thermal losses. Poor safety.
- Vapor pressure causes collapse of casing.
- Formation damage.
- Low bit life. Frequent tripping. High drilling cost.
- High maintenance cost.
- More than one cement squeeze. High well cost. Possible abandonment.

APPROACHES FOR IMPROVEMENT

- Determine properties requirements in terms of flow behavior, setting time, water loss, etc. in placement, and in terms of strength and durability in high temperature, corrosive environments of geothermal sites.
- Measurement of in-situ properties/performance.
- Evaluate and develop if necessary cements and elastomers or alternate seal materials/concepts to meet requirements (cement and seal material standards).
- Test under field conditions (confirm standards).
- Coatings and surface treatments for pipe.

*These projects are addressed by the DGE Drilling and Completion Program.

EXHIBIT 5

RELATIONSHIP OF COMPONENTS, ENVIRONMENTS, AND FAILURE MODES

COMPONENTS ENVIRONMENTS	BOREHOLE								ENERGY CONVERSION								
	WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING
Production Fluid with H ₂ S, CO ₂	TD,EW CD,PP	GC,EW PC,SSC HE	TD,CD	CC,CF EW,TD SSC,WP	CD,TD EW,CF BF	WS,WP TD,CD	CD,PC TD,CF GVC,EW SSC,HE	SCC,TD PC,BF, CC,CF HE,PP WS,WP CD,SSC	--	GC,SCC CF,PC SSC,EW WS,WP	GC,SCC CF,PC SSC,EW WS,WP	EW,GC PC,CC	GC,PC EW	GC,PC CC,EW	SCC,PC CF,GC CC,HE SSC	--	--
Production Fluid with CO ₂	TD,EW CD,PP	GC,EW PC,HE	TD,CD	PC,CF EW,TD WP	CD,TD EW,CF BF	WS,WP TD,CD	CD,PC TD,CF EW,GVC	SCC,TD PC,BF CC,CF HE,PP WS,WP CD	--	SCC,CF WS,WP CF	SCC,CF WS,WP CF	EW,GC PC,CC	GC,PC EW	--	SCC,PC CF,GC CC,HE	--	--
Production Fluid	TD,EW CD,PP	GC,PC HE,EW	TD,CD	PC,CF EW,TD WP	CD,TD EW,CF BP	WS,WP TD,CD	CD,PC TD,CF EW,GVC	SCC,TD PC,BF CC,CF HE,PP WS,WP CD	--	SCC,CF WS,WP CF	SCC,CF WS,WP CF	EW	GC,PC EW		SCC,PC CF,GC CC,HE	--	--
Steam with H ₂ S, CO ₂	TD,EW CD,PP	GC,PC HE,EW SSC	TD,CD	PC,CF EW,TD SSC,WP	--	WS,WP TD,CD	CD,PC TD,CF EW,GVC SSC	SCC,TD PC,BF CC,CF HE,PP WS,WP CD,SSC	SSC,CF EW,SSC CC,HE PC	SCC, SSC,WS WP,CF	SCC SSC,WS WP,CF	--	GC,PC EW		--	--	--
Steam with H ₂ S	TD,EW CD,PP	SSC	TD	PC,CF EW,WP	--	WS,WP TD,CD	CD,TD CF,SSC SSC	SCC,TD PC,BF CC,CF HE,PP WS,WP CD,SSC	SSC,PC EW	SCC, SSC,WS WP,CF	SCC SSC,WS WP,CF	--	GC,PC EW		--	--	PC,CC WS,WP CF,SSC SSC,CD

(Failure mode abbreviations on following page.)

EXHIBIT 5 (Cont.)

ENVIRONMENTS	COMPONENTS	BOREHOLE								ENERGY CONVERSION								
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING
Steam with CO ₂		TD,EW CD,PP	GC,PC HE,EW	TD,CD	PC,CF EW,TD WP	—	TD,CD	CD,PC TD,CF EW	SCC,TD PC,BF CC,CF HE,PP WS,WP CD	SCC,CF EW,CC HE,PC	SCC,CF WS,WP	SCC,CF WS,WP	—	GC,PC EW		—	—	—
Steam		TD,EW		TD	PC,CF	—	TD	TD	SCC,TD PC,BF CC,CF HE,PP WS,WP CD	SCC,CF EW,HE PC	SCC,CF WS,WP	SCC,CF WS,WP	—			SCC,PC CF,CC CC,HE	—	—
Steam Condensate		CD,PP	—	—	—	GC	—	—	—	—			EW,GC	GC,PC CC		SCC,PC CF,CC CC,HE	GC,PC CD	PC,CC CC,WS WP,CD
Cooling Water		—	—	—	—	GC	—	—	—	—			EW,GC	GC,PC CC		SCC,PC CF,CC CC,HE	GC,PC CD	—
Flashed Brine		—	—	—	—	—	—	—	—	—			EW,GC PC,CC	GC,PC CC			GC,PC CD	PC,CC GC,WS WP,CD
Binary Fluid Contaminated with O ₂ , brine		—	—	—	—	—	—	—	—	GC,PC			EW,GC			SCC,PC CF,CC CC	—	—
Brine Effluent		CD,PP	GC,PC		PC,EW	CD,CC	—	—	—	—			EW,GC PC,CC	GC,PC CC	GC,PC CC,EW		—	PC,CC CC,WS WP,CD

FAILURE MODE ABBREVIATIONS

Galvanic Corrosion	GVC	Stress Corrosion Cracking	SCC	Erosion & Wear	EW
Pitting Corrosion	PC	Brittle Fracture	BF	Dezincification	DZ
Crevice Corrosion	CC	Thermal Degradation	TD	Weld Sensitization	WS
General Corrosion	GC	Sulfide Stress Cracking	SSC	Weld Porosity	WP
Corrosion Fatigue	CF	Hydrogen Embrittlement	HE	Chemical Degradation	CD
				Physical Properties	PP

EXHIBIT 6

MATERIALS ACCEPTABLE FOR COMPONENT SERVICE

COMPONENTS MATERIALS		BOREHOLE								ENERGY CONVERSION							
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS
Carbon Steel		X		X	X		X		X	X	X	X	X	X			X
Low Alloy Steel		X		X	X		X		X	X	X	X	X	X			X
Austenitic Stainless Steels (T304, 316, 321)					X		X		X	X	X	X	X	X		X	X
Exotic Austenitic Stainless Steels (Al 6X, 317LM, 20C63)			X		X	X	X			X	X	X		X	X	X	X
Exotic Ferritic Stainless Steels (29-4, E-Brite, 26-1)			X		X	X		X		X	X	X		X	X		X
Ferritic Stainless Steels			X						X								X
Inconel's (Ni-Cr)			X	X	X	X						X		X	X		X
Hastelloy's (Ni-Cr-Mo)			X	X	X	X		X				X		X	X		X
Titanium Alloys			X		X	X		X	X	X		X		X	X		X
Cobalt Alloys (Stellites, etc.)		X	X	X			X		X					X			X
Tungsten Alloys				X													
Diamond				X													
Ni-Ti Alloys			X	X	X		X					X		X	X		
Ceramics, Cermet's, Powder Metallurgy		X		X	X	X	X	X				X		X			

EXHIBIT 6 (Cont.)

<div>COMPONENTS</div> <div>MATERIALS</div>		BOREHOLE								ENERGY CONVERSION								
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING
Plastics			X	X			X							X			X	X
Modified Portland Cements		X		X													X	X
Polymer Concrete		X	X								X	X		X			X	X
Wood																	X	
Fiber-Reinforced Plastic			X				X				X	X		X			X	X
Elastomers				X	X	X		X	X				X		X	X		X
Coatings and Surface Treatment			X	X	X	X		X		X	X	X	X	X	X	X	X	X

EXHIBIT 7

RELATIONSHIP OF MATERIALS TESTING AND CORROSION CONTROL NEEDS TO GEOTHERMAL SYSTEMS

NEED \ COMPONENTS		BOREHOLE								ENERGY CONVERSION								
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING
Nondestructive Evaluation		X	X		X				X	X	X	X		X		X		
Corrosion Inhibitors			X		X											X	X	X
Corrosion Monitors		X									X	X				X	X	X
Cathodic Protection			X								X			X	X	X	X	X
Anodic Protection											X					X		
Corrosion Field Testing		X	X	X	X	X				X	X	X		X		X	X	X

EXHIBIT 8

SYSTEM AND COMPONENT PERFORMANCE CONSTRAINTS BEING ADDRESSED BY GEOTHERMAL MATERIALS PROGRAM

<u>System or Component</u>	<u>Problem or Need</u>
1. Drill pipe, tool joints, and casing	High wear rates in deviated or directional drilled holes in downhole geothermal environment during drilling. New materials, hardfacing, or surface treatments needed to control wear which do not use Co, W, Cr, or other strategic materials.
2. Drill pipe and tool joints	Corrosion and corrosion fatigue, sulfide embrittlement. Need nondestructive test methods to detect harmful flows (cracks) and crack propagation data to establish inspection intervals to avoid "twist offs."
3. Rock bits and drilling tools	High wear rate of carbide insert and hardfacing materials in downhole geothermal environment, especially in air drilling. New materials or coatings needed for wear control, preferably without W, Co, or Cr. Improved materials suitable for high rpm turbodrills.
4. Seals for rock bits and drilling tools (dynamic seals for rotating parts)	Degradation of elastomers at elevated temperatures in the geothermal chemical environment. Need high temperature elastomer or alternative seal material/concept.
5. Downhole motors	Seal and bearing life limits life between overhauls for turbodrills. High temperature elastomers needed for positive displacement motors which run at lower speeds than turbodrills. Rock bit life is greatly reduced at higher rpm and higher temperatures.
6. Seals for logging tools and measurement-while-drilling tools (static seals)	Degradation of elastomers at elevated temperatures in the geothermal chemical environment. Need high temperature elastomer or alternative seal material/concept.
7. Cement	Flow properties at elevated temperatures, setting characteristics and strength after prolonged exposure to heating in production are unsatisfactory with presently

EXHIBIT 8 (cont)

<u>System or Component</u>	<u>Problem or Need</u>
7. Cement (cont)	available materials. Free water trapped against casing leads to casing collapse after well begins production. Need resistance to chemical degradation.
8. Insulation for logging tools and measurement-while-drilling instruments and cables	Degradation at elevated temperatures and in downhole chemical environments. High cost of cable materials.
9. Packers (also useful in thermal enhanced oil recovery)	Elastomeric seal material or alternative to seal irregular gaps up to 1/4" under pressure. No suitable material or alternate concept exists for the higher range of geothermal temperatures.
10. Corrosion control systems	Widely varied geothermal fluid compositions from site to site.
11. Scale control systems	Acids used for removal of silica scales attack steel casing.
12. Bearing systems	
Rock bits-roller reamers/stabilizers	
Non-sealed roller bearings	Contact fatigue life. Wear rate. Resulting loss of hole size control.
Sealed roller bearings	Contact fatigue life. Seal life/reliability. Short bearing life at high speeds with turbodrills.
Sealed sliding bearings	Load/speed capabilities at geothermal temperatures. Seal life/reliability
Downhole drilling systems	
Turbodrills	Bearing/seal life. Load/speed capabilities. Seal materials/designs.
Positive displacement motors	High temperature. Elastomers for motor elements plus other needs same as turbodrill.
13. Piping	Corrosion resistance. Abrasion resistance. Structural strength. High temperature service. Need alternate materials.
14. Vessels	Corrosion resistance. Abrasion resistance. Structural strength. High temperature service. Need alternate materials.

Adapted From Materials Needs for the Utilization of Geothermal Energy Through the Year 2000, Second Draft, March 1980, National Materials Advisory Board, National Research Council

component and system reliability. Geothermal development must also compete to some degree with the much larger oil and gas industry for similar equipment and specialized services.

In addition to the direct cost constraints imposed on the development of new or improved materials for geothermal applications, there is the problem of generally insufficient market incentive for the development by private industry of cost-effective materials within the time frame required by commercialization goals. The materials supply and related service industries are more geared to meeting the needs of oil and gas producing customers than the emerging geothermal industry. This barrier to commercialization must be addressed by timely and successful federally-sponsored testing of materials in actual and simulated geothermal environments. This will help demonstrate the suitability of these materials for utilization in other applications, such as water treatment, oil and gas production, chemical processing, and solar energy, thus increasing the marketability of such materials. Examples of such transfer of technology include improved steels developed for geothermal brine and H₂S service applicable to sour oil and gas wells, and improved geothermal packer elastomeric materials that have been successfully field tested in oil recovery operations.

To a significant degree, materials and materials-related technology currently employed in oil and gas production cannot be satisfactorily transferred to geothermal situations. Therefore, the range and types of materials-related problems make it imperative that the federal government assume and continue responsibility, on a selective basis, for encouraging and assisting the materials development and commercialization activities necessary to establish geothermal resources as a viable energy alternative.

D. RATIONALE

Since a major cost of geothermal energy production is directly or indirectly materials-related, R,D&D to improve materials performance presents significant opportunities for reducing development and operational costs of energy utilization. For example, it is estimated that a typical geothermal well in the U.S. costs approximately \$1 million. Using simplified assumptions (see Appendix A), it can be calculated that DOE's present⁽¹⁾ goal of 25,000 MWe generating capacity from geothermal resources by the year 2000 would involve the drilling of over 11,000 production wells with existing technology (assuming all plants are 50 MWe units) at a cost of over \$11 billion (see Exhibit 9). Estimating the benefit/cost ratios of the various Geothermal Materials Program activities, some of which are presented in Exhibit 10, there is considerable scope for savings in well costs. Combined geochemical engineering and materials R,D&D may be able to save up to \$1.2 billion in constant dollars by year 2000 on well costs alone (assuming an 11% reduction of well cost⁽²⁾) by favorably impacting downhole seals, drill pipe, cements, wellhead/surface materials, and logging instrumentation. Most of this cost reduction is attributable to materials-related projects. These figures do not include the sizeable cost reductions which should also be obtainable for wells drilled for geothermal direct applications. Injection wells are also excluded, which may number somewhat over one-half of the number of starting production wells; on the basis of the assumptions used here, this could amount to an additional 3,750 wells or more by 2000. The number of wells

(1) As of August 1980. It should be noted that the DOE generating capacity goals used here are in the process of review, and are used mainly for illustrative rather than reporting purposes.

(2) Preliminary Benefit/Cost Analysis of Geothermal Technology R&D, The MITRE Corporation, briefing document, 1980.

EXHIBIT 9

CUMULATIVE COST AND GEM PROGRAM SAVINGS DATA FOR GEOTHERMAL ELECTRIC PLANTS, 1985-2000 (Constant \$)

	1985	YEAR 1990	2000
DOE electric generating goals (MWe)	3,000	7,000	25,000
No. of 30 MWe plants required	60	140	500
No. of production wells required ⁽¹⁾	900	2,730	11,070
Cost of plants @ \$60m/plant (\$m)	3,600	8,400	30,000
Cost of wells @ \$1m/well (\$m)	900	2,730	11,070
GEM reduction of plant cost @ 4.5% ⁽²⁾ (\$m)	162	378	1,350
GEM reduction of well cost @ 11% ⁽³⁾ (\$m)	99	300	1,218
Cost of well components (\$m)			
<u>% of well cost⁽³⁾</u>			
Wellhead/surface mats. 9.4	85	257	1,041
Casing 8.8	79	240	974
Bits 3.7	33	101	410
Cement 3.7	33	101	410
Logging 2.9	26	79	321
Motors 1.4	13	38	155
Drill pipe <u>1.2</u>	<u>11</u>	<u>33</u>	<u>133</u>
31.1	280	849	3,444
GEM reduction of well cost by components (\$m)			
<u>% reduction of well cost⁽³⁾</u>			
Seals 4.8	43	131	531
Drill pipe 4.2	38	115	465
Cement 1.0	9	27	111
Wellhead/Surface mats. 0.9	8	25	100
Logging instrumentation 0.6	5	26	66
Casing (steel) <u>-0.4</u>	<u>-4</u>	<u>-11</u>	<u>-44</u>
11.1	99	303	1,229

(1) Assumes:

Years After Power-on-Line	0	5	10	15	20	25
Cumulative No. of Production Wells	15	25.5	36	46.5	57	67.5

(2) Mean of MITRE estimated savings on steam, flash, and binary plants.

(3) Source: The MITRE Corporation

EXHIBIT 10

BENEFIT/COST RATIOS FOR GEM PROGRAM R&D

R&D Area	Benefit/Cost Ratio ¹	
	Pessimistic	Optimistic
Nondestructive evaluation techniques	50.0	553.9
Seal materials	10.6	77.3
Well cement	36.4	66.7
Casing and drill pipe materials	38.8	55.0
Dynamic component materials	15.2	39.7
Nonmetallic construction materials	21.0	27.2
Pitting and local corrosion resistant materials	19.2	26.5
Materials design handbook	9.8	14.9
Entire GEM Program ²	18.3	39.8

¹Excludes sunk costs.

²Totals are not additive.

Source: Benefit/Cost Analysis of Geothermal Technology R&D, V.T. Nguyen and D.J. Entingh, DGE-4014-10, May 1979.

estimated here may, in fact, be conservative. One study⁽¹⁾ estimated the number of production wells required by 37 identified geothermal sites to be about 4,600 by 1990, with about 2,900 associated injection wells (using an electricity generating goal of about 8850 MWe by 1990).

With regard to total electric plant capital cost, savings resulting from GEM projects are estimated to be 2.2% on a steam plant, 5.5% on a flash plant, and 5.8% on a binary plant.⁽²⁾ This ranges from \$1.3-\$3.5 million for a typical plant cost of \$60 million. This could result in reducing expected plant costs over the next 20 years by \$650-\$1,750 million. (These savings include contributions from above-ground equipment costs benefiting from GEM-funded R,D&D.) The relative costs of the impacted plant components and associated savings are set out in Exhibits 11 and 12, respectively. Specific examples of cost reductions for geothermal electricity production resulting from DOE-funded R,D&D for materials technology include the development of:

- polymer concrete which could reduce the capital cost of steam separators by 80%, supply and injection systems piping by 40%, and plant piping by 29% for the flashed-steam plant design at Heber⁽³⁾;
- high-temperature (> 200°C) well cements which could extend well life by 30%⁽⁴⁾; and
- ceramic and cement casing materials which may effect a 20% reduction in casing costs⁽⁴⁾.

(1) Prospects for Improvement in Geothermal Well Technology and Their Expected Benefits, E.J. Friedman and A. El-Sawy, DGE/4014-4, December 1977.

(2) Preliminary Benefit/Cost Analysis of Geothermal Technology R&D, The MITRE Corporation, briefing document, 1980.

(3) Economic Assessment of Polymer Concrete Usage in Geothermal Power Plants, Burns & Roe Industrial Services Corp., November 1977.

(4) Long-Term Supply Curves for Geothermal Energy - The Impacts of Technology, Pacific Northwest Laboratory, PNL-3072, January 1980.

EXHIBIT 11

**INSTALLED COMPONENT COSTS IN PERCENTS OF TOTAL
PLANT COST FOR A 50 MWe PLANT**

<u>Impacted Cost Item</u>	<u>Steam Plant</u>	<u>Flash Plant</u>	<u>Binary Plant</u>
Heat Exchanger	-	-	12.76
Gathering System	15.04	11.94	10.71
Pressure Vessels	-	0.91	-
Down-Hole Pump	-	-	1.33
Injection Pump	<u>1.19</u>	<u>1.43</u>	<u>1.06</u>
	16.23	14.28	25.86

SOURCE: The MITRE Corporation

EXHIBIT 12

**PERCENTAGE PLANT AND COMPONENT COST
SAVINGS DUE TO GEM PROGRAM**

Reduction of Plant Capital Costs:	<u>Plant</u>	<u>%</u>
	Steam	2.2
	Flash	5.5
	Binary	5.8
Reduction of Component Lifetime Costs:	<u>Component</u>	
	Heat exchanger	12.0
	Pressure vessel	18.7
	Gathering pipelines	28.9
	Down-hole pump	38.3
Reduction of Component Capital Costs:	<u>Component</u>	
	Heat exchanger	9.7
	Pressure vessel	16.0
	Gathering pipelines (F&B plants)	22.2

SOURCE: The MITRE Corporation

It has been estimated⁽¹⁾ that the overall Geochemical Engineering and Materials R,D&D benefit/cost ratio for electricity generation will range from 18.3 in a pessimistic scenario to 39.8 in an optimistic scenario.

The foregoing discussion has been oriented towards the utilization of geothermal resources for the purpose of electricity production since these figures can be readily estimated. There is significant scope for technology overlap between electric and direct applications, but the Geothermal Materials Program is also designed to meet the special generic needs of direct-use development (e.g., corrosion-resistant downhole heat exchangers). Since materials-related costs comprise a greater percentage of the total cost of direct uses (due primarily to the greater requirements for piping and vessels), the benefit/cost ratio and resultant cost savings from the Geothermal Materials Program are expected to be significant, although offset to some extent by the less severe demands placed on materials by the lower temperatures and less hostile environments encountered.

E. OBJECTIVES

In order for DGE to implement its goal-oriented strategy, precise objectives have been developed to guide problem identification, project selection and prioritization, assessment of the need for government involvement, and determination of the amount and distribution of funding. The major objectives are, through support and coordination of private sector projects, to:

- (1) identify materials-related problems impeding near-term geothermal commercialization;
- (2) identify longer-term generic materials-related problems affecting geothermal energy utilization, and plan and coordinate appropriate remedial applied R&D programs;

(1) Benefit/Cost Analysis of Geothermal Technology R&D, V.T. Nguyen and D.J. Entingh, DGE-4014-10, May 1979.

- (3) review materials specifications for major DOE demonstrations and make recommendations as appropriate; and
- (4) disseminate technical information to the geothermal community in a timely manner in order to minimize duplication of effort and maximize the return on R&D investments.

When the need arises, as determined from interaction with industry representatives, the program will assist the private sector with funding to:

- (1) develop, demonstrate, and standardize economic materials for construction and equipment, including alternatives to conventional, standard, and critical materials where needed;
- (2) reduce life-cycle costs related to materials performance;
- (3) develop a collection of standardized and flexible techniques and materials that can be applied to site-specific needs;
- (4) develop and conduct nondestructive tests for detecting incipient materials failure; and
- (5) develop materials-related corrosion control systems.

III. PROGRAM ORGANIZATION

A. PROGRAM STRUCTURE AND OBJECTIVES OF PROGRAM ELEMENTS

The strategy of the Geothermal Materials Program is implemented through an applied R,D&D capability organized according to the four major areas of concern. These areas of concern, or program elements, are:

1. Materials for Borehole Components⁽¹⁾ -- optimizing, developing, and standardizing conventional and alternate materials for wells (cement, casing, packers, and wellhead), pumps, drilling components, logging equipment, and cable.
2. Materials for Energy Conversion Components -- optimizing, developing, and standardizing conventional and alternate materials for energy conversion, fluid disposal, pumping, and waste processing equipment.
3. Materials Testing and Corrosion Control -- developing and conducting non-destructive evaluation techniques for well drill-pipe, casing, cements, and energy conversion components; developing and testing corrosion inhibitors, monitoring systems, and cathodic and anodic protection; and conducting corrosion field testing.
4. Technology Transfer -- preparing and publishing handbooks, technical reports, manuals, and newsletters; organizing conferences and workshops; involving professional societies in standards development; and cooperative programs.

(1) Field and laboratory developments involving drilling muds, lost circulation, completion technology, fracture fluids, and proppants are addressed in DGE's Drilling and Completion Technology Development Program and Stimulation Program.

The four program elements are composed of discrete subelements as detailed in Exhibit 13. This exhibit also highlights the specific areas and/or classes of materials under consideration within each subelement.

The objectives of these four program elements are briefly described below.

1. Materials for Borehole Components

Since existing technology is generally not designed for geothermal applications, the objective of the borehole program element is to evaluate conventional materials and, where needed, to develop cost-effective substitutes and/or alternate materials for downhole components. A major focus of this program element is the timely provision of downhole materials that can meet the reliability and durability requirements for cost-effective extraction of geothermal fluids. Materials problems encountered in downhole applications are related to the high temperatures of the environment, corrosion, wear, erosion, and deterioration of mechanical strength. In addition, there are questions of materials cost, availability, design, fabrication, installation, reliability, and inspection which must be considered. (This program element is complemented by DGE's Geothermal Drilling and Completion Technology Development Program which emphasizes the development of drilling hardware, drilling fluids, completion technology, lost circulation control methods, and advanced drilling systems. This program, which is in part materials-oriented, has as a major goal the development of technology for reducing well costs 25% by 1983 and 50% by 1987 based on costs and the status of technology existing in 1978).

2. Materials for Energy Conversion Components

A great deal of world-wide experience has been gained in the design and operation of conventional energy conversion systems. The prime emphasis of this program element is to assemble and assess, in handbook form, available

EXHIBIT 13

GEOHERMAL MATERIALS PROGRAM ELEMENTS AND SUBELEMENTS

1. MATERIALS FOR BOREHOLE COMPONENTS

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

2. MATERIALS FOR ENERGY CONVERSION COMPONENTS

- (1) Turbines
 - coatings
 - corrosion and erosion
 - fatigue resistance
- (2) Pressure Vessels (metals, non-metals)
 - joining and field repair
 - lining
 - coatings
- (3) Steam Separators (metals, non-metals)
 - joining and field repair
 - lining
 - coatings
- (4) Pumps
 - bearings (metals, non-metals)
 - seals (metals, elastomers)
 - coatings
- (5) Piping (metals, non-metals)
 - welding
 - lining
 - coatings

EXHIBIT 13 (cont)

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

3. MATERIALS TESTING AND CORROSION CONTROL

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

4. TECHNOLOGY TRANSFER

- (1) Handbooks
- (2) Manuals
- (3) Conferences and Workshops
- (4) Newsletters
- (5) Professional Societies Interaction
- (6) Product Technology Transfer
- (7) New Standards

information as it relates to geothermal energy utilization. This has facilitated the identification of specific projects that will result in more efficient plant operations.

3. Materials Testing and Corrosion Control

The objective of the materials testing aspect of this program element is to develop non-destructive evaluation (NDE) techniques for drilling components (especially drill pipes), well completion materials, and energy conversion component materials in order to predict and prevent failure (especially catastrophic). The objective of the corrosion control projects is to study the causes and mechanisms of corrosion by geothermal fluids so that appropriate techniques and systems can be devised to minimize and monitor the impact on construction materials. Corrosion field testing of metallic materials is also undertaken. The NDE and corrosion control activities together will aid considerably in avoiding costly down-time, component replacement, and possible well abandonment.

4. Technology Transfer

The objective of the technology transfer element is to facilitate the rapid and accurate dissemination of relevant project information to all concerned parties within the geothermal, materials, and services/supplier communities. It is imperative that project plans, accomplishments, and products be made available to others involved in geothermal development so that (1) technology already available can be effectively utilized, (2) possible duplication of effort can be eliminated, (3) further R,D&D can build on previous experiences, (4) problem areas requiring particular attention can be readily identified, and (5) technological synergy can be promoted. Explicit channels for technology transfer allow maximization of project impact and efficient formulation of new plans. An important aspect of this element is

the cooperative programs arranged to transmit, in an interactive manner, product technology and new ideas from companies and universities conducting R,D&D to materials suppliers, equipment manufacturers, and geothermal developers. Professional societies are also involved in this area, particularly for the development of new standards. Technology transfer also has an important role to play in stimulating private sector participation in geothermal development, identifying educational and training needs, and building public acceptance and support of geothermal energy.

B. PROGRAM PRIORITIES AND FUNDING

The priorities for each element and subelement in the program were determined by DGE on the basis of four major evaluation criteria:

- (1) Cost Impact -- This is a measure of the favorable impact the subelement can have on the economics of geothermal energy development. Increased materials/component reliability and durability will result in varying reductions in field, development, and operating and maintenance costs compared to currently prevailing estimates and practices.
- (2) Environmental Concern -- Materials serve as a barrier between the system and environment. This criterion is an indication of the degree to which the subelement will address the problems of maintaining control and safety standards when handling fluids and gases at high temperature and pressure.
- (3) State-of-Knowledge -- This refers to the extent to which the subelement will expand existing data and know-how and thereby improve the performance and economics of systems by assuring component or system feasibility, timeliness in problem identification, and complete delineation of all problems that might constrain development.
- (4) Materials Shortfall - In many cases, the growing geothermal industry does not represent sufficient demand for the materials industry to

undertake development of new or improved materials. Therefore, concerted efforts must be made to expand markets for needed geothermal materials by determining their suitability for other applications. The specified subelement will have some impact on providing incentives for suppliers to produce materials meeting geothermal specifications. In addition, critical and strategic materials will also be considered under this criterion.

Exhibit 14 shows the priorities for the program elements as determined by the above criteria, while Exhibits 15 through 18 present the priorities and estimated funding level ranges for each of the subelements.

Estimates for outyear program funding presented here are based upon historical data for related 1977-78 projects, and are not necessarily representative of requirements for specific technical categories. Specific areas may have higher costs due to unforeseen technical difficulties. The figures should be regarded only as a relative guide to areas of funding emphasis within the program. The assumption is made that the totals will provide a reasonable approximation of total program needs. The cumulative 10-year (1978-88) funding requirements for the Geothermal Materials Program total \$36.5 million; this is broken down by program elements in Exhibit 19. Approximately \$8 million have already been committed through fiscal year 1980.⁽¹⁾ Funding levels for the overall program on a yearly basis over the 10-year time period are shown in Exhibit 20. It should be noted that the early period of DGE materials-related R,D&D activity

(1)

The \$900,000 requirement projected for the technology transfer element for these 10 years is predominantly for the support of "special" projects designed solely or to a large extent to facilitate the transfer of technology or information. Significant funding attributable to technology transfer activities is implicit in the figures for the other three program elements due to the built-in nature of technology/information transfer with regard to individual projects.

EXHIBIT 14**GEOHERMAL MATERIALS PROGRAM ELEMENT PRIORITIES**

ELEMENT	EVALUATION CRITERIA				PRIORITY
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF- KNOWLEDGE	MATERIALS SHORTFALL	
Materials for Borehole Components	1	1	2	2	1
Materials for Energy Conversion Components	3	3	2	2	3
Materials Testing and Corrosion Control	1	2	2	2	1
Technology Transfer	1	2	1	3	1

EXHIBIT 15

MATERIALS FOR BOREHOLE COMPONENTS: ELEMENT PRIORITIES AND FUNDING¹

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	MATERIALS SHORTFALL		
Well Cements	1	1	2	2	1	1
Tubulars	1	2	2	1	2	1
Packers	2	2	2	2	2	2
Drilling	1	3	2	2*	1	1
Pumps	1	3	2	1	1	3
Logging	3	3	2	3	3	3
Wellhead	3	1	2	2	2	3
Cable	2	3	2	1	2	2

Funding Level (1978 \$)

1 = High = \$2.0-3.5M

2 = Medium = \$0.8-1.2M

3 = Low = \$0.2-0.6M

¹ Re-evaluations of specific total costs are required after in-depth industry review and analysis.

* Also critical and strategic.

EXHIBIT 16

MATERIALS FOR ENERGY CONVERSION COMPONENTS: ELEMENT PRIORITIES AND FUNDING

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	MATERIALS SHORTFALL		
Turbines	2	3	2	3	3	3
Pressure Vessels	2	2	2	1	2	1
Steam Separators	2	3	1	2	2	2
Pumps	1	3	1	2	1	3
Piping	1	2	2	3	2	1
Valves	3	2	2	3	3	3
Heat Exchangers	1	2	2	2	2	3
Cooling Towers	2	3	2	3	3	3
Waste Processing	1	1	2	2	1	3

Funding Level (1978 \$)

1 = High = \$2.0-3.5M

2 = Medium = \$0.8-1.2M

3 = Low = \$0.2-0.6M

EXHIBIT 17

MATERIALS TESTING AND CORROSION CONTROL: ELEMENT PRIORITIES AND FUNDING

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	MATERIALS SHORTFALL		
Nondestructive Testing of Drill Pipe	1	3	2	2	1	2
Nondestructive Testing of In-Situ Well Materials	1	1	1	2	1	2
Nondestructive Testing of Energy Conversion Component Materials	3	2	2	3	2	3
Corrosion Inhibitors	3	3	2	2	3	2
Corrosion Monitors	1	3	2	2	1	3
Cathodic and Anodic Protection	2	3	2	2	2	2
Corrosion Field Testing	1	2	2	3	1	2

Funding Level (1978 \$)

1 = High = \$2.0-3.5M

2 = Medium = \$0.8-1.2M

3 = Low = \$0.2-0.6M

EXHIBIT 18

TECHNOLOGY TRANSFER: ELEMENT PRIORITIES AND FUNDING

SUBELEMENT	EVALUATION CRITERIA				PRIORITY	FUNDING LEVEL
	COST IMPACT	ENVIRONMENTAL CONCERN	STATE-OF-KNOWLEDGE	MATERIALS SHORTFALL		
Handbooks	1	2	1	2	1	2
Manuals	2	2	2	2	2	2
Conferences and Work-shops	2	3	2	3	2	3
Newsletters	2	3	2	2	2	3
Professional Societies Interaction	2	3	2	3	2	3
Product Technology Transfer	1	3	1	1	1	2
New Standards	2	1	1	2	2	2

Funding Level (1978 \$)

1 = High = \$2.0-3.5M

2 = Medium = \$0.8-1.2M

3 = Low = \$0.2-0.6M

EXHIBIT 19

PROGRAM ELEMENT
FUNDING REQUIREMENTS
1978-1988

EXHIBIT 20

OVERALL PROGRAM
FUNDING REQUIREMENTS
ON YEARLY BASIS

effectively initiated the outreach program with an increasing number of university and industrial contracts vis-a-vis direct national laboratory support projects.

C. PROGRAM MANAGEMENT

The implementation of the Geothermal Materials Program is administered primarily through the Division of Geothermal Energy and its field offices. A Technical Coordinator (from either a national laboratory or an industrial firm) designated by DOE is associated with each program element. The Technical Coordinator exercises overall responsibility for managing and subcontracting the work within his program element. However, not all aspects of a program element may come under the direct control of the coordinator; as for example, Sandia National Laboratories' cable development in the borehole materials element. The coordinator works closely with professional societies or technical advisory groups consisting of university and industrial experts. For the Geothermal Materials Program, Brookhaven National Laboratory (BNL) serves as the Technical Coordinator for all three of the primary program elements while DOE directly manages the technology transfer program element since this function is common to the other activities of the program.

An important aspect of the Geothermal Materials Program is the interaction with geothermal or materials oriented groups and the involvement of professional societies in the R&D evaluation process. The Geothermal Materials Program manager interfaces directly with other concerned offices within DOE and with interagency groups such as the Committee on Materials and Technology (COMAT) through the Energy Materials Coordinating Committee. Professional and trade societies and other parties are brought into consultation by membership in those groups. Organizations taking part in this way include the American

Petroleum Institute (API), American Society for Testing and Materials (ASTM), National Association of Corrosion Engineers (NACE), American Concrete Institute (ACI), National Water Well Association (NWWA), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Geothermal Resources Council (GRC), Society of Petroleum Engineers (SPE), Federation of Materials Societies, and the DOE Consumer Advisory Committee.

IV. PROGRAM STATUS

Specific efforts organized within the Geothermal Materials Program address important technical and economic barriers to commercialization identified earlier in this report. Exhibit 21 lists active projects by title and contractor and indicates the subelements which each project concentrates on or can be expected to affect. Some projects are specific to only one subelement, while others address two or more subelements, especially those concerned with subcomponents or program-wide materials assessments. The relative importance of the individual subelements is not necessarily reflected in the number of projects attributed to them since some of the projects are only of secondary relevance to certain subelements (Exhibits 15-18 should be consulted for a priority ranking of subelements).

The following four subsections list the projects completed and underway, briefly describe significant accomplishments to date, and set out the plans and milestones for each of the program elements. The projects with asterisks are those that appear under more than one program element. Appendix B of this report presents the concise objectives of each of the current materials projects.

A. MATERIALS FOR BOREHOLE COMPONENTS

Completed Projects

(1) Benefit/Cost Analysis of Geothermal Technology R&D:

Geochemical and Materials Engineering

The MITRE Corporation

MTR-7980 Vol. IV, May 1979

Contract No. EG-77-C-01-4014

*(2) Economic Impact of Using Nonmetallic Materials in Low-Intermediate

Temperature Geothermal Well Construction

National Water Well Association

BNL Report No. 51224, December 1979

EXHIBIT 21

MATRIX OF CURRENT PROJECTS AND ADDRESSED SUBELEMENTS

<div>SUBELEMENTS</div> <div>PROJECTS</div>		MATERIALS FOR BOREHOLE COMPONENTS								MATERIALS FOR ENERGY CONVERSION COMPONENTS										
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING	NONDESTRUCTIVE MATERIALS TESTING	CORROSION CONTROL
Development of Geothermal Well Completion Systems (Dowell Div., Dow)		X																		
Geothermal Cement Screening (National Bureau of Standards)		X																		
In-House R&D on Well Cements (Brookhaven National Laboratory)		X																		
International Cooperative Research and Standards (Brookhaven National Laboratory)		X	X								X		X			X				
Localized Corrosion of Casing (Case Western Reserve)			X																	X
Test and Evaluation of API Casing Materials Strings (Lawrence Livermore Laboratory)			X																	X

EXHIBIT 21
(continued)

PROJECTS	SUBELEMENTS	MATERIALS FOR BOREHOLE COMPONENTS								MATERIALS FOR ENERGY CONVERSION COMPONENTS										
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING	NONDESTRUCTIVE MATERIALS TESTING	CORROSION CONTROL
New Fluorocarbon Elastomers for Seals in Geothermal and Other Aggressive Environments (ExFluor Research Corp.)				X	X		X	X				X	X	X	X					
Geothermal Elastomer Materials Technology Transfer (L'Garde, Inc.)				X	X		X	X				X	X	X	X					
Shape Memory Alloy Seals for Geothermal Applications (Rockwell International)						X						X	X	X	X					
ASTM/DOE Geothermal Seals Conferences (Brookhaven National Laboratory)				X	X	X	X	X				X	X	X						
Improved Drill Bit Materials (Terra Tek)					X															

**EXHIBIT 21
(continued)**

PROJECTS \ SUBELEMENTS		MATERIALS FOR BOREHOLE COMPONENTS								MATERIALS FOR ENERGY CONVERSION COMPONENTS											
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING	NONDESTRUCTIVE MATERIALS TESTING	CORROSION CONTROL	
The Application of a Non-Destructive Evaluation Technique Utilizing Internal Friction for Detecting Incipient Failure of Drill Pipes (Daedalean Associates, Inc.)					X														X		
Development of Bushings and Bearings for Use in Hot Brine Pumps (Solar Turbines, Inc.)						X						X									
High Temperature Logging Cable and Cablehead Development (Sandia National Laboratories)						X	X		X												
Static Testing of Geothermal Cables (Aerospace Research Corporation)						X	X		X												

EXHIBIT 21
(continued)

PROJECTS \ SUBELEMENTS	MATERIALS FOR BOREHOLE COMPONENTS								MATERIALS FOR ENERGY CONVERSION COMPONENTS										
	WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING	NONDESTRUCTIVE MATERIALS TESTING	CORROSION CONTROL
Metal Sheath Cable Development (Halpen Engineering, Inc.)						X		X											
Design and Fabrication of Polymer Concrete Pipe for Testing in Geothermal Energy Processes. (Lindsey Industries Inc.)													X						X
In-House R&D on Polymer Concrete Lined Pipe for Electric Generating Purposes (Brookhaven National Laboratory)													X						X
Improved Corrosion Rate Meter (Battelle's Pacific Northwest Laboratory)		X		X	X		X		X	X	X	X	X	X	X	X	X		X
Materials Selection Guidelines for Geothermal Energy Systems - Handbook and newsletter (Radian Corporation)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

EXHIBIT 21
(continued)

PROJECTS	SUBELEMENTS	MATERIALS FOR BOREHOLE COMPONENTS								MATERIALS FOR ENERGY CONVERSION COMPONENTS										
		WELL CEMENTS	TUBULARS	PACKERS	DRILLING	PUMPS	LOGGING	WELLHEAD	CABLE	TURBINES	PRESSURE VESSELS	STEAM SEPARATORS	PUMPS	PIPING	VALVES	HEAT EXCHANGERS	COOLING TOWERS	WASTE PROCESSING	NONDESTRUCTIVE MATERIALS TESTING	CORROSION CONTROL
Assessment of Materials Needs for Utilization of Geothermal Energy Through the Year 2000 (National Research Council)		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Professional Societies Interaction		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Geothermal Seals Screening (National Bureau of Standards)					X	X	X	X					X	X	X	X				
In-House R&D on Pressure Vessels and Steam Separators (Brookhaven National Laboratory)											X	X								X
Environmental Testing Compatibility Program (L'Garde, Inc.)					X								X							

BNL Subcontract No. 485874-S

DOE Contract No. DE-AC02-76 CH00016

- (3) 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

BNL Subcontract No. 483982-S

- (4) ASTM/DOE Geothermal Seals Conferences

June 1978, June 1979, May 1980

Conference Report CONF-7806141, April 1979

- *(5) An Assessment of Non-Destructive Testing of Well Casing, Cement and Cement Bond in High Temperature Wells

Lawrence Livermore Laboratory/GeoEnergy Corporation

Report No. UCRL 15032

LLL Contract No. 4332409

- (6) Cementing of Geothermal Wells

Brookhaven National Laboratory

Periodic progress reports 1-12, 1976-80

Contract No. EY-76-C-02-0016

- (7) New High Temperature Cementing Materials for Geothermal Wells; Stability and Progress

Pennsylvania State University

BNL Report No. 511249, October 1979

BNL Subcontract No. 422272-S

- (8) High Temperature Cementing Materials for Completion of Geothermal Wells

Battelle Columbus Laboratories

BNL Subcontract No. 420825-S

- (9) Hydrothermal Cements for Use in the Completion of Geothermal Wells

Southwest Research Institute

BNL Report No. 51183, September 1979

BNL Subcontract No. 427964-S

- (10) Development of Cement for Geothermal Wells

Colorado School of Mines

BNL Report No. 51024

Contract No. EY-76-C-02-0016

- (11) Cementing of Geothermal Wells: Phosphate-Bonded Cements

University of Rhode Island

BNL Subcontract No. 418691-S

Technical Achievements

Cements

- (1) The Dowell Division of Dow Chemical Co. has completed a state-of-the-art report on well cements: Development of Geothermal Well Completion Systems, Phase I Report C00/4190-1, October 1977.
- (2) Ten cements identified for further testing have exceeded API-approved design criteria in the National Bureau of Standards' testing program.
- (3) An API task group on geothermal well cements was formed in 1978.
- (4) Tentative approval has been received for the initiation of joint U.S./Mexican/Italian testing programs.

Casings

- (1) The feasibility of using alternate materials for casings in low-temperature wells has been established (National Water Well

Association, May 1980).

- (2) Materials screening has been completed by Case Western Reserve/Armco Steel and several improved casing compositions have been identified (Contract No. EY-76-S02-2602).
- (3) Lawrence Livermore Laboratory has conducted field verification studies in Imperial Valley of suitable and improved low-alloy steel casing compositions (UCRL 84489 preprint, February 1980, Contract No. W7405-ENG-48).

Packer and Pump Seals

- (1) Hydrolytic stability test methods for elastomers were developed by the Hughes Aircraft Co.: Development of Improved Gaskets, Sealants, and Cables for Use in Geothermal Well Logging Equipment, Interim Summary Report P78-31, January 1978, Contract No. 17-C-03-1325).
- (2) An ASTM Geothermal Seals Task Group was established in 1977.
- (3) L'Garde, Inc. has developed EPDM materials for 260°C service. Five months' problem-free service at 230°C has been achieved with packer seals in steam injection field tests for secondary oil recovery; the previous best performance was 5 weeks. Inhole logging tests for hot dry rock have been successful at 309°C. (Final Report No. SAN-1308-2, July 1979, Contract No. EG-77-C-03-1308.)

Pump Bearings

- (1) Solar Turbines, Inc. has published two progress reports, including a state-of-the-art report (BNL Subcontract No. 490656).

Drilling

- (1) Terra Tek, Inc. has completed a state-of-the-art report on drill bit components and materials: Support Research for Development of

Improved Geothermal Drill Bits, Annual Report (TR 77-44, June 1977,
ERDA Contract No. E(10-1) 1546).

Cable and Cablehead

- (1) Logging cable screening tests and a state-of-the-art report have been completed by Sandia National Laboratories/Aerospace Research Corp.

Current Projects

- (1) Development of Geothermal Well Completion Systems

Dowell Division, Dow Chemical Co.

Contract No. DE-AC02-77ET28324

- (2) Geothermal Cement Screening

National Bureau of Standards

Contract No. EA-77-A-01-6010

- (3) International Cooperative Research and Standards

Brookhaven National Laboratory

- (4) In-House R&D on Well Cements

Brookhaven National Laboratory

- * (5) Localized Corrosion of Casing

Case Western Reserve

- * (6) Test and Evaluation of API Casing Materials Strings

Lawrence Livermore Laboratory

- * (7) New Fluorocarbon Elastomers for Seals in Geothermal and Other Aggressive Environments

ExFluor Research Corp.

BNL Subcontract No. 486106-S

- * (8) Geothermal Elastomer Materials Technology Transfer

L'Garde, Inc.

BNL Subcontract No. 490316-S

- * (9) Shape Memory Alloy Seals for Geothermal Applications
Rockwell International
BNL Subcontract No. 509927
- *(10) ASTM/DOE Geothermal Seals Conferences
- *(11) Geothermal Seals Screening
National Bureau of Standards
- (12) Improved Drill Bit Materials
Terra Tek, Inc.
BNL Subcontract No. 492267-S
- *(13) The Application of a Non-Destructive Evaluation Technique Utilizing
Internal Friction for Detecting Incipient Failure of Drill Pipes
Daedalean Associates, Inc.
Contract No. EG-77-C-01-4045
- (14) Development of Bushings and Bearings for Use in Hot Brine Pumps
Solar Turbines, Inc.
BNL Subcontract No. 490656-S
- (15) High Temperature Logging Cable and Cablehead Development
In-house R&D, Sandia National Laboratories
- (16) Static Testing of Geothermal Cables
Aerospace Research Corp.
- (17) Metal Sheath Cable Development
Halpen Engineering, Inc.
- *(18) Assessment of Materials Needs for Utilization of Geothermal Energy
through the Year 2000
National Research Council, National Materials Advisory Board
BNL Subcontract No. 494818-S

Planned Initiatives and Timing

See following milestone charts.

MATERIALS FOR BOREHOLE COMPONENTS

(1) Phase I : Cement chemistry and stability to 275°C.

Phase II: Cement chemistry and stability 250-350°C; cement rheology as function of additives.

(2) Primarily Mexico, Italy, and industry funding; API continues long-term effort after 1985.

LEGEND

▽ Begin Task

▲ Completed Task

◁ Decision Point

**MATERIALS FOR BOREHOLE COMPONENTS
(Cont.)**

ACTIVITY: WELL CASINGS (BNL)										
TASK	CY 1980		CY 1981		CY 1982		CY 1983		CY 1984	
	FY 1980	FY 1981	FY 1981	FY 1982	FY 1982	FY 1983	FY 1983	FY 1984	FY 1984	FY 1985
Alternate Materials for Well Casings										
State-of-Art Report										
Materials R&D										
Property Verification										
Downhole Testing (1)										
Demonstration Well (1)										
ASTM/NWWA Standards Development, Program Management										

(1) Assumes major field test costs borne by industry and foreign participants.

**MATERIALS FOR BOREHOLE COMPONENTS
(Cont.)**

ACTIVITY WELL CASINGS (BNL) (Cont.)																											
TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Metallic Materials for Well Casings																											
Alloy Development and Optimization																											
Field Testing (1)																											
ASTM/API/NACE Standards Development, Program Management																											

(1) Assumes major field test costs borne by industry and foreign participants.

**MATERIALS FOR BOREHOLE COMPONENTS
(Cont.)**

ACTIVITY: WELL CASINGS (BNL) (Cont.)

TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Cladding																											
R&D																											
Property Verification																											
Downhole Testing (1)																											
Demonstration Wells (1)																											
API/NACE/ASTM Standards Development, Program Management																											
Problem Identification-Review of Geopressured Well Casing Experience																											

(1) Assumes primary cost borne by industry and foreign participants.

MATERIALS FOR BOREHOLE COMPONENTS (Cont.)

ACTIVITY : PACKER AND PUMP SEALS (BNL)

[illegible]

(1) Assumes field testing cost borne by industry and Sandia National Laboratories' Drilling and Completion Program.

MATERIALS FOR BOREHOLE COMPONENTS (Cont.)

ACTIVITY: PUMP BEARING MATERIALS (BNL)

[illegible]

**MATERIALS FOR BOREHOLE COMPONENTS
(Cont.)**

60

⁽¹⁾ Primarily cost-shared by industry and Sandia National Laboratories.

**MATERIALS FOR BOREHOLE COMPONENTS
(Cont.)**

ACTIVITY : CABLE AND CABLEHEAD																											
TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Screening Tests																											
Pump				▽			▲																				
Development																											
Cablehead																											
Mono																											
Multi																											
Pump																											
Logging																											
Monoconductor Prototype																											
Multiconductor Prototype																											
Pump																											
Final Report																											
Materials Screening																											
Logging																											
Multiconductor																											

**MATERIALS FOR BOREHOLE COMPONENTS
(Cont.)**

ACTIVITY: CABLE AND CABLEHEAD (Cont.)																											
TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Field Tests																											
Logging																											
Pump																											
API/ASTM Standards Development, Program Management																											

B. MATERIALS FOR ENERGY CONVERSION COMPONENTS

Completed Projects

- (1) Economic Assessment of Polymer Concrete Usage in Geothermal Power Plants, Final Report

Brookhaven National Laboratory

BNL Report No. 50777, November 1977

BNL Subcontract No. 417259-S

- (2) Economic Assessment of Using Nonmetallic Materials in the Direct Utilization of Geothermal Energy, Final Report

Burns and Roe Industrial Services Corp.

BNL Report No. 51112, February 1979

BNL Subcontract No. 44252-S

- *(3) Piping Materials Field Testing

Lawrence Livermore Laboratory

- *(4) ASTM/DOE Geothermal Seals Conferences

June 1978, June 1979, May 1980

Conference Report CONF-7806141, April 1979

- *(5) Materials Selection Guidelines for Geothermal Power Systems, First Edition (Handbook)

Radian Corporation

ALO-3904-1, September 1978

Contract No. EG-77-C-04-3904

Technical Achievements

- (1) Brookhaven National Laboratory has developed polymer concrete pipe that will resist 150°C geothermal fluid.
- (2) Burns and Roe Industrial Services Corp. has published two reports on the economic analysis of polymer concrete pipe and polymer concrete vessels in which cost-effectiveness is established.

- (3) Successful field tests of laboratory-produced polymer concrete pipe and polymer concrete lined pipe have been carried out at a variety of geothermal sites: Alternate Materials of Construction for Geothermal Applications, Progress Reports 1-20 (see, for example, BNL 50699 no. 13).
- (4) Calcium carbonate scale resistance of polymer concrete pipe has been demonstrated during an 18-month test at East Mesa.
- (5) Lindsey Industries has established the feasibility of commercial-scale manufacturing of polymer concrete piping.
- (6) Radian Corporation has reviewed the latest information on relevant materials for specific U.S. geothermal site chemistries and conversion technologies, including an assessment of the localized corrosion problems of metallic pipe: Materials Selection Guidelines for Geothermal Power Systems, ALO-3904-1, September 1978, Contract No. EG-77-C-04-3904.
- (7) Three ASTM/DOE workshops have been held on geothermal seals needs and performance requirements.

Current Projects

- (1) International Cooperative Research and Standards
Brookhaven National Laboratory
- * (2) New Fluorocarbon Elastomers for Seals in Geothermal and Other Aggressive Environments
ExFluor Research Corp.
BNL Subcontract No. 486106-S
- * (3) Geothermal Elastomer Materials Technology Transfer
L'Garde, Inc.
BNL Subcontract No. 490316-S

(4) Environmental Testing Compatibility Program

L'Garde, Inc.

BNL Subcontract No. 511198

***(5) ASTM/DOE Geothermal Seals Conferences**

(6) Design and Fabrication of Polymer Concrete Pipe for Testing in Geothermal Energy Processes

Lindsey Industries, Inc.

BNL Subcontract No. 486337-S

(7) Polymer Concrete Lined Pipe for Electric Generating Purposes

In-house R&D, Brookhaven National Laboratory

(8) Geothermal Seals Screening

National Bureau of Standards

(9) Pressure Vessels and Steam Separators

In-House R&D, Brookhaven National Laboratory

***(10) Assessment of Materials Needs for Utilization of Geothermal Energy Through the Year 2000**

National Research Council, National Materials Advisory Board

BNL Subcontract No. 494818-S

***(11) Materials Selection Guidelines for Geothermal Energy Systems**

Radian Corporation

Contract No. EG-77-C-04-3904

***(12) Shape Memory Alloy Seals for Geothermal Applications**

Rockwell International

BNL Subcontract No. 509927

Planned Initiatives and Timing

See following milestone charts.

MATERIALS FOR ENERGY CONVERSION COMPONENTS

ACTIVITY: PIPING (BNL)										
TASK	CY 1980		CY 1981		CY 1982		CY 1983		CY 1984	
	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984	FY 1985	FY 1986	FY 1987	FY 1988	FY 1988
R&D										
Polymer Concrete Liners		▲								
Metallic Pipe		▲								
Scale Control				▲	▲	Final Report Phase II	▼		▲	Final Report Phase II
Property Verification		▲	▼						▲	
Field Demonstration (1)					▲	Field Test Support				
Prototype(2)										
Polymer Concrete Pipe		▲					▲			

(1) Major field costs borne by user and industry.

(2) Includes connections and field installation procedures.

**MATERIALS FOR ENERGY CONVERSION COMPONENTS
(Cont.)**

ACTIVITY: PIPING (BNL) (Cont.)

TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Field Demonstrations (cont.)																											
Prototype (cont.)																											
Polymer Concrete Liners			▽																								
Metallic Pipe			▽																								
Scale Control																											
Commercial																											
Polymer Concrete Pipe			▽																								
Polymer Concrete Liners																											
Metallic Pipe																											
Scale Control																											

(Cont.)

ACTIVITY : PIPING (BNL) (Cont.)

[illegible]

**MATERIALS FOR ENERGY CONVERSION COMPONENTS
(Cont.)**

ACTIVITY: PRESSURE VESSELS & STEAM SEPARATORS (BNL)

**MATERIALS FOR ENERGY CONVERSION COMPONENTS
(Cont.)**

ACTIVITY: PRESSURE VESSELS & STEAM SEPARATORS (BNL) (Cont.)

TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Property Verification (cont.)																											
Clad Vessels																											
Technology Transfer																											
ASME/ACI Code Certification and Commercial Demonstration, Program Management																											
Polymer Concrete Vessels																											
Clad Vessels																											

**MATERIALS FOR ENERGY CONVERSION COMPONENTS
(Cont.)**

ACTIVITY : HEAT EXCHANGERS																											
TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980			FY 1981			FY 1982			FY 1983			FY 1984			FY 1985			FY 1986			FY 1987			FY 1988		
Problem Identification																											
Binary Plant Materials Screening																											
Elastomeric																											
Metallic																											
Field Tests																											
Elastomeric																											
Metallic																											

MATERIALS FOR ENERGY CONVERSION COMPONENTS (Cont.)

ACTIVITY : HEAT EXCHANGERS (Cont.)

[illegible]

C. MATERIALS TESTING AND CORROSION CONTROL

Completed Projects

- *(1) An Assessment of Non-Destructive Testing of Well Casing, Cement, and Cement Bond in High Temperature Wells

Lawrence Livermore Laboratory/GeoEnergy Corp.

Report No. UCRL 15032

LLL Contract No. 4332409

- *(2) Piping Materials Field Testing

Lawrence Livermore Laboratory

Technical Achievements

- (1) An assessment has been completed by Lawrence Livermore Laboratory/GeoEnergy Corp. of nondestructive testing of well casing, cement, and cement bonding in high temperature wells.
- (2) Successful laboratory and limited field tests have been completed for NDE techniques developed by Daedalean Associates, Inc. for drill pipe.
- (3) Battelle's Pacific Northwest Laboratory has completed laboratory testing of corrosion monitors.

Current Projects

- *(1) Localized Corrosion of Casing

Case Western Reserve

- *(2) Test and Evaluation of API Casing Materials Strings

Lawrence Livermore Laboratory

- *(3) The Application of a Non-Destructive Evaluation Techniques Utilizing Internal Friction for Detecting Incipient Failure of Drill Pipes

Daedalean Associates, Inc.

Contract No. EG-77-C-01-4045

(4) Improved Corrosion Rate Meter

Battelle's Pacific Northwest Laboratory

Planned Initiatives and Timing

See following milestone charts.

MATERIALS TESTING AND CORROSION CONTROL

ACTIVITY: NONDESTRUCTIVE TESTING AND WELDING TECHNIQUE DEVELOPMENT

TASK	CY 1980		CY 1981		CY 1982		CY 1983		CY 1984		CY 1985		CY 1986		CY 1987		CY 1988	
	FY 1980		FY 1981		FY 1982		FY 1983		FY 1984		FY 1985		FY 1986		FY 1987		FY 1988	
Drill Pipe																		
Field Test & Final Report	▽		▲															
In-Situ Well Materials Assessment (complete 1979)																		
Upgrade Existing Tools (1)		▽			▲													
R&D New Systems					▽				▲	▲								
Field Test & Final Report									▽			▲						
Pressure Vessels																		
Problem Identification					▽													
Testing					▲	▽												

- (1) Existing tool upgrading will be carried out under Sandia National Laboratories' Logging Instrumentation Development Program.

MATERIALS TESTING AND CORROSION CONTROL
(Cont.)

ACTIVITY: CORROSION CONTROL																											
TASK	CY 1980			CY 1981			CY 1982			CY 1983			CY 1984			CY 1985			CY 1986			CY 1987			CY 1988		
	FY 1980	FY 1980	FY 1980	FY 1981	FY 1981	FY 1981	FY 1982	FY 1982	FY 1982	FY 1983	FY 1983	FY 1983	FY 1984	FY 1984	FY 1984	FY 1985	FY 1985	FY 1985	FY 1986	FY 1986	FY 1986	FY 1987	FY 1987	FY 1987	FY 1988	FY 1988	
Corrosion Inhibitors																											
Problem Identification																											
R&D																											
Field Tests (1)																											
Corrosion Monitors																											
Upgrade Existing Technology																											
Field Tests (1)																											

(1) In conjunction with industry, foreign governments, and other DGE programs such as conversion technology, project branch, etc.

MATERIALS TESTING AND CORROSION CONTROL (Cont.)

ACTIVITY: CORROSION CONTROL (Cont.)

[illegible]

(1) In conjunction with industry, foreign governments, and other DGE programs such as conversion technology, project branch, etc.

D. TECHNOLOGY TRANSFER

Technology transfer is an activity built into the major technical and economic projects in the Geothermal Materials Program. Generally, specific projects aimed at transferring technology are not initiated. However, there is a number of special program projects and activities intended to disseminate information relating to general materials assessments, problem identification, and other evaluative processes.

Completed Projects

***(1) Economic Impact of Using Nonmetallic Materials in Low-Intermediate Temperature Geothermal Well Construction**

National Water Well Association

BNL Report No. 51224, December 1979

BNL Subcontract No. 485874-S

DOE Contract No. DE-AC02-76 CH00016

***(2) ASTM/DOE Geothermal Seals Conferences**

June 1978, June 1979, May 1980

Conference Report CONF-7806141, April 1979

***(3) Materials Selection Guidelines for Geothermal Power Systems, First Edition (Handbook)**

Radian Corporation

ALO-3904-1, September 1978

Contract No. EG-77-C-04-3904

Achievements

- (1) In the elastomer technology transfer project of L'Garde, Inc., three of 34 industrial applicants were selected for direct technology transfer, and the results will be transmitted to the others at the end of the project.

Current Projects

- * (1) Geothermal Elastomer Materials Technology Transfer

L'Garde, Inc.

BNL Subcontract No. 490316-S

- * (2) ASTM/DOE Geothermal Seals Conferences

- * (3) Materials Selection Guidelines for Geothermal Energy Systems

Radian Corporation

Contract No. EG-77-C-04-3904

- * (4) Assessment of Materials Needs for Utilization of Geothermal Energy Through the Year 2000

National Research Council, National Materials Advisory Board

BNL Subcontract No. 494818-S

- (5) Professional societies interaction (ongoing)

Planned Initiatives and Timing

See following milestone chart.

TECHNOLOGY TRANSFER

[illegible]

APPENDICES

APPENDIX A

ASSUMPTIONS USED TO ESTIMATE ILLUSTRATIVE COST IMPACT OF DGE'S GEOCHEMICAL ENGINEERING AND MATERIALS PROGRAM ON GEOTHERMAL ELECTRICITY PRODUCTION

Certain assumptions were made to simplify the illustrative calculations of the estimated cost and savings figures for geothermal electric plants presented in the rationale section of this document, and a number of MITRE Corporation figures were also used in these calculations. These assumptions are set out below.

- (1) Present DOE cumulative electric generating capacity goals for geothermal resources are 3,000 MWe by 1985, 7,000 MWe by 1990, and 25,000 MWe by 2000; these goals are the subject of current DOE review.
- (2) All plants are 50 MWe units.
- (3) Operational plant life is 25 years.
- (4) The cost of each plant is \$60 million.
- (5) The cost of each production well is \$1 million.
- (6) Initial plant operation utilizes 15 production wells, increasing linearly to 4.5 times this number (67.5) after 25 years.
- (7) MITRE Corporation based data used are as follows.
 - (i) Estimated impacts of GEM R,D&D on the capital cost of a 50 MWe plant are reductions of 2.2% for a dry-steam plant, 5.5% for a flashed-steam plant and 5.8% for a binary plant. The average of these figures (4.5% reduction) was used as the cost reduction for a "typical" plant.
 - (ii) Estimated reduction of well cost by the GEM Programs is 11%.
 - (iii) Estimated costs of well components as a percentage of well cost are:

	<u>% of well cost</u>
Wellhead/surface materials	9.4
Casing	8.8
Drill bits	3.7
Cement	3.7

	<u>% of Well Cost</u>
Logging	2.9
Motors	1.4
Drill pipe	<u>1.2</u>
	31.1

- (iv) Estimated reduction of well component costs by the GEM Programs as a percentage of well cost are:

	<u>% reduction of well cost</u>
Wellhead/surface materials	0.9
Casing (steel)	-0.4
Cement	1.0
Logging instrumentation	0.6
Drill pipe	4.2
Seals	<u>4.8</u>
	11.1

APPENDIX B

DESCRIPTIONS OF CURRENT PROGRAM PROJECTS

(1) Title: Development of Geothermal Well Completion Systems

Contractor: Dowell Division, Dow Chemical Co. (July 1977 - July 1980).

The objective of this project is to develop and evaluate a suitable geothermal well cementing material through stability, placement, and chemical measurements. Work will center around 3 areas: portland and modified portland systems, silica and/or aluminate systems, and polymer systems.

(2) Title: Geothermal Cement Screening

Contractor: National Bureau of Standards (October 1977 - September 1981).

The objective is to develop a laboratory testing program for screening candidate cementing materials that are to be used in the finishing operations of geothermal well holes. This project will provide government and industry with technical data necessary for an evaluation of the structural integrity of these cements. In particular, an assessment will be made as to whether these materials satisfy certain minimum physical requirements prior to costly field testing in downhole facilities.

(3) Title: In-House R&D on Well Cements (not contract)

Contractor: Brookhaven National Laboratory

Work continues to be performed to evaluate and select high-temperature well cementing materials. Tests are in progress to ensure their mechanical, physical, and chemical resistance properties, including pumpability.

(4) Title: Localized Corrosion of Casing

Contractor: Case Western Reserve (October 1979 - September 1981)

The project aims to reduce localized corrosion of geothermal casing by composition and heat treatment. The goal is to eliminate incipient corrosion centers without large increases in materials and fabrication costs. Suitable specimens for testing will be prepared under simulated geothermal conditions using new techniques to reduce tedious evaluation of samples.

(5) Title: Test and Evaluation of API Casing Materials Strings

Contractor: Lawrence Livermore Laboratory

The objective is to determine the API grade of carbon steel best suited for well casing, and to determine the composition-dependent variations within API specifications that influence corrosion lifetime. This will lead to API specifications for maximum well casing lifetime. This will involve analysis of the corrosion performance in a well of a casing string comprised of sections of different grades of carbon steel.

(6) Title: New Fluorocarbon Elastomers for Seals in Geothermal and Other Aggressive Environments

Contractor: ExFluor Research Corp. (September 1979 - November 1980)

The objective of the project is to increase the operating capabilities of elastomers in geothermal environments to greater than 300°C. These sealing materials are needed in drill-bit seals, packers, logging equipment, and blow-out preventors.

(7) Title: Geothermal Elastomer Materials Technology Transfer

Contractor: L'Garde, Inc.

The objective is to transfer to industry the elastomer technology developed under an earlier DGE contract.

(8) Title: Shape Memory Alloy Seals for Geothermal Applications

Contractor: Rockwell International (April 1980 - April 1981)

The objective is to develop metal seal materials that can provide long-term service in geothermal downhole environments. The intention is to upgrade or modify existing oil, gas, and chemical use seals as appropriate.

(9) Title: ASTM/DOE Geothermal Seals Conferences

Contractor: Brookhaven National Laboratory

There have been 3 such conferences so far and a fourth is scheduled. These conferences bring together research groups, major industrial suppliers, and

users of geothermal seal materials. Proceedings are published as DOE/ASTM reports.

(10) Title: Improved Drill Bit Materials

Contractor: Terra Tek, Inc. (September 1979 - September 1981)

The objective of this program is to optimize alloys and the heat treatment of candidate alloys in order to ensure longer life of geothermal drill bits and reamers. In pursuing this work, close liaison will be maintained with interested bit manufacturers.

(11) Title: The Application of a Non-Destructive Evaluation Technique Utilizing Internal Friction for Detecting Incipient Failure of Drill Pipes

Contractor: Daedalean Associates, Inc. (1977 - October 1980)

The objective of this project is to develop internal friction NDE drill string technology for field testing drill pipe used in geothermal wells. An integral part of the program would use analytical and data processing techniques to enable the operator to distinguish the various modes of drill pipe failure.

(12) Title: Development of Bushings and Bearings for Use in Hot Brine Pumps

Contractor: Solar Turbines, Inc. (November 1979 - November 1981)

The objective of this program is to develop durable materials that will resist wear and deterioration when used as bearings in pumps for geothermal fluids. The resistance to galling, corrosion, wear, and localized attack is being developed. The goal is to improve pump lifetimes and increase the efficiency of heat extracted from geothermal wells. Materials will be developed and laboratory tested to determine the best candidates for field testing in components under separate contracts.

(13) Title: In-House R&D on High Temperature Logging Cable and Cablehead Development (not contract)

Contractor: Sandia National Laboratories (October 1979 - October 1983)

Geothermal cable development by industry will be funded to stimulate commercial application of new materials and fabrication techniques, as well as innovative

design with existing materials. Additionally, the program will support industrial development of a promising new cable concept -- an armored cable with a thin-walled metal tube core or impermeable coating, within which high temperature insulators and conductors are protected from the corrosive environment.

(14) Title: Static Testing of Geothermal Cables

Contractor: Aerospace Research Corp.

Under this contract, several new commercial high-temperature cables will be tested in simulated geothermal environments. The test chamber to be used can simulate brine conditions up to 371°C and 10,000 psig and can place the cable under tension.

(15) Title: Metal Sheath Cable Development

Contractor: Halpen Engineering, Inc. (January 1980 - February 1981)

The objective is to develop a metal sheath, single-conductor electro-mechanical logging cable for continuous operation in geothermal wells up to 350°C.

(16) Title: Design and Fabrication of Polymer Concrete Pipe for Testing in Geothermal Energy Processes

Contractor: Lindsey Industries, Inc. (July 1979 - July 1980)

The objective of the project is to design and fabricate full-scale sections of polymer concrete pipe and appropriate joining methods for testing in direct utilization geothermal processes at up to 120°C and 120 psi. The program will expedite the transfer of existing technology from BNL to the private sector and will provide at least one commercial source of PC materials for the geothermal industry. Technological results of the project will be extended to pressure vessels and steam separators.

(17) Title: In-House R&D on Polymer Concrete Lined Pipe for Electric Generating Processes (not contract)

Contractor: Brookhaven National Laboratory (July 1980 - June 1981)

This effort is similar to that above and deals with lined pipe suitable for higher pressures and temperatures. Polymer concrete lined pipe R&D can also be applied to pressure vessels and steam separators.

(18) Title: Improved Corrosion Rate Meter

Contractor: Battelle's Pacific Northwest Laboratory

Work in fiscal year 1979 revealed the limitations of commercial corrosion rate meters when oxygen enters the system. The improved model being developed would result in more accurate corrosion rates measurement under a wider range of conditions.

(19) Title: Materials Selection Guidelines for Geothermal Energy Systems

Contractor: Radian Corporation

The objective of this project is to collect, analyze, and present information relating to materials testing and operating experience at a large number of geothermal sites with existing or potential utilization capabilities in order to aid in identifying potential materials problems and selecting appropriate materials. This contract also includes the publication of a newsletter covering materials-related developments.

(20) Title: Assessment of Materials Needs for the Utilization of Geothermal Energy Through the Year 2000

Contractor: National Research Council, National Materials Advisory Board
(October 1979 - September 1980)

The Board's objectives are to identify the major materials problems that presently limit design and operation of geothermal energy systems, and to formulate recommendations aimed at finding solutions for such problems. Consideration will be given to specific materials development needs and the cost involved, as well as to various other factors (e.g., materials substitutability and

manufacture) affecting the materials problems of geothermal energy systems.

(21) Title: Professional societies interaction

Contractor: Brookhaven National Laboratory

Professional societies involvement is necessary to establish materials standards and to help evaluate and coordinate materials R,D&D. The objective of DGE is to make effective and efficient use of those arrangements where they are needed.

(22) Title: Geothermal Seals Screening

Contractor: National Bureau of Standards (July 1979 - September 1981)

The objectives of the project are to 1) evaluate existing standards for applicability to geothermal uses; 2) develop short-term tests indicative of longer term service life; and 3) screen polymer families for hydrolytic and temperature stability in reductive environments.

(23) Title: In-House R&D on Pressure Vessels and Steam Separators (not contract)

Contractor: Brookhaven National Laboratory (October 1979 - October 1980)

Present in-house BNL research and development is concerned with applying expertise already developed under the Geothermal Materials Program with polymer concrete to the design of polymer concrete pressure vessels and steam separators for geothermal processes.

(24) Title: International Cooperative Research and Standards

Contractor: Brookhaven National Laboratory

A number of international programs have been arranged, particularly with Mexico and Italy, to share the requirements and results of mutually beneficial geothermal materials-related research and testing, including standards development. Components which have been the subject of international study, or which are under consideration for such cooperative efforts, include well cements and tubulars, piping, cooling towers, and steam separators.

(25) Title: Environmental Testing Compatibility Program

Contractor: L'Garde, Inc.

This effort is concerned with testing EPDM rubbers in oils for pump applications.