Received by OSTI

JAN 02 1991

das

GEOTHERMAL MATERIALS PROJECT INPUT FOR CONVERSION TECHNOLOGY TASK
ANNUAL OPERATING PLAN
FY 1991

Lawrence E. Kukacka

DO NOT MICROFILM
COVER

August 1990

Prepared for the
Geothermal Division
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D. C. 20585

Energy Efficiency and
Conservation Division

DEPARTMENT OF APPLIED SCIENCE

BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973

bnl

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

BNL--45277

DE91 005502

**GEOHERMAL MATERIALS PROJECT INPUT FOR CONVERSION TECHNOLOGY Task
ANNUAL OPERATING PLAN FY 1991**

Lawrence E. Kukacka

August 1990

**Prepared for the
Geothermal Division
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D. C. 20585**

**ENERGY EFFICIENCY AND
CONSERVATION DIVISION
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.**

**This work was performed under the auspices of the U.S. Department of Energy,
Washington, D.C. Under Contract No. DE-AC02-76CH00016**

MASTER *22*

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

TABLE OF CONTENTS

	<u>Page No.</u>
EXECUTIVE SUMMARY.....	111
I. INTRODUCTION.....	1
II. PRIOR YEAR DATA.....	5
ELEMENT DESCRIPTIONS.....	5
1. Advanced High Temperature Lightweight Cements.....	5
2. Cements for Magma Well Completions.....	6
3. Thermally Conductive Polymer Concrete Liners.....	6
4. Chemical Systems for Lost Circulation Control.....	7
5. Support to Geothermal Drilling Organization Elastomer Programs.....	8
6. Corrosion Mitigation at the Geysers.....	8
7. High Temperature Chemical Coupling Systems.....	8
8. Advanced Elastomers for Downhole Drill Motors.....	10
FY 1989 ACCOMPLISHMENTS.....	10
1. Advanced High Temperature Lightweight Cements.....	10
2. Cements for Magma Well Completions.....	12
3. Thermally Conductive Polymer Concrete Liners.....	12
4. Chemical Systems for Lost Circulation Control.....	13
5. Support to Geothermal Drilling Organization Elastomer Programs.....	14
EXPECTED ACCOMPLISHMENTS IN FY 1990.....	16
1. Advanced High Temperature Lightweight Cements.....	16
2. Thermally Conductive Polymer Concrete Liners.....	16
3. Chemical Systems for Lost Circulation Control.....	17
4. Support to Geothermal Drilling Organization Elastomer Programs.....	17
5. Corrosion Mitigation at the Geysers.....	17
III. FUNDING YEAR RESEARCH PLAN.....	18
1. Advanced High Temperature Lightweight Cements.....	18
a. Work Statement.....	18
b. Milestones and Deliverables.....	18
c. Funding and Manpower Requirements.....	18
2. Thermally Conductive Polymer Concrete Liners.....	18
a. Work Statement.....	18
b. Milestones and Deliverables.....	19
c. Funding and Manpower Requirements.....	19

TABLE OF CONTENTS (cont.)

	<u>Page No.</u>
3. Chemical Systems for Lost Circulation Control.....	19
a. Work Statement.....	19
b. Milestones and Deliverables.....	20
c. Funding and Manpower Requirements.....	20
4. Corrosion Mitigation at the Geysers.....	20
a. Work Statement.....	20
b. Milestones and Deliverables.....	21
c. Funding and Manpower Requirements.....	21
5. High Temperature Chemical Coupling Systems.....	21
a. Work Statement.....	21
b. Milestones and Deliverables.....	21
c. Funding and Manpower Requirements.....	22
6. Advanced Elastomers for Downhole Drill Motors.....	22
a. Work Statement.....	22
b. Milestones and Deliverables.....	22
c. Funding and Manpower Requirements.....	23
 IV. MANAGEMENT PLAN.....	 23
1. Overview of Management System.....	23
2. Management Structure.....	24
Exhibit I.....	25
Exhibit II.....	26
Exhibit III.....	27
3. Management Resource Requirements.....	24
4. Procurement Plan Summary.....	24
5. Subcontracting Plan.....	24
6. Schedules of Conferences and Technical Reviews.....	28
7. Schedule of Planned Foreign Travel.....	28
 V. OUTYEAR RESEARCH PLAN.....	 28
1. Goals/Objectives.....	28
2. Key Issues and Strategy.....	28
3. Broad Task Descriptions.....	29
a. Advanced High Temperature Lightweight Cements.....	29
b. Advanced Elastomers for Downhole Drill Motors.....	29
c. High Temperature Chemical Coupling Systems....	30
d. Corrosion Mitigation at the Geysers.....	30
e. In-Situ Conversion of Drilling Mud Into Cement.....	30
f. Advanced Liners for Well Casing.....	31
4. Outyear Funding Requirements.....	32
5. Outyear Manpower Requirements.....	33

**U.S. DEPARTMENT OF ENERGY
FIELD WORK PROPOSAL**

1. B&R No: AM-10-01	2a. CONTRACTOR NO: AS-17-EECD	2b. REV. NO: 0	3. DATE PREPARED: 02/21/90	4. IS THIS WORK INCLUDED IN THE INST. PLAN? X Y N	5. TASK TERM: BEGIN: Continuing END: Open
6. TITLE: Geothermal Materials Development					
7. PRINCIPAL INVESTIGATORS: Kukacka, Lawrence E. (666-3065)					
8. HEADQUARTERS/OPERATIONS OFC PROGRAM MANAGER: LaSala, Raymond			11. HEADQUARTERS ORGANIZATION: Conservation & Renewable Energy		14. DOE ORG. CODE: CE
9. OPERATIONS OFFICE WORK PROPOSAL REVIEWER:			12. OPERATIONS OFFICE: CHICAGO		15. DOE ORG. CODE: CH
10. CONTRACTOR WORK PROPOSAL MANAGER: Dept. of Appl. Sci.- Andrews, J. (666-7726) Petrakis, L. (666-3037)			13. CONTRACTOR NAME: ASSOCIATED UNIVERSITIES, INC. BROOKHAVEN NATIONAL LABORATORY		16. CODE: 13
17. WORK PROPOSAL DESCRIPTION (Approach, anticipated benefit in 200 words or less): <p>This ongoing laboratory-based high risk/high payoff R&D program has already yielded several durable cost-effective materials of construction for geothermal energy processes. In FY 1991, R&D in the following areas will be performed: (1) development and downhole testing of advanced high-temperature (300°C) CO₂-resistant lightweight (1.1 g/cc) well-cementing materials, (2) high-temperature chemical systems for lost-circulation control, (3) thermally conductive scale-resistant composites for heat-exchanger tubing, (4) high-temperature chemical coupling materials which can be used to bond elastomers to steel substrates, and (5) high-temperature elastomers for use in downhole drill motors. Contingent upon the results, work on heat-exchanger tubing and lost-circulation control materials will be completed in FY 1991 and the other activities will be continued in FY 1992. Work on other materials needs will commence in FY 1992. These include the <u>in situ</u> conversion of drilling fluids into well-completion materials and ceramic-type well casing. All of the subtasks will be performed as cost-shared activities with other National Laboratories and/or industry. Successful developments will significantly reduce the cost of well drilling and completion, and energy-extraction processes.</p>					
18a. PRINCIPAL INVESTIGATOR(S): <div style="display: flex; justify-content: space-between; align-items: flex-end;"> <div style="text-align: center;"> Signature(s) </div> <div style="text-align: right;"> 02/21/90 Date </div> </div>					
18b. CONTRACTOR WORK PROPOSAL MANAGER: <div style="display: flex; justify-content: space-between; align-items: flex-end;"> <div style="text-align: center;"> Signature </div> <div style="text-align: right;"> 02/21/90 Date </div> </div>			19. OPERATIONS OFFICE REVIEW OFFICIAL: <div style="display: flex; justify-content: space-between; align-items: flex-end;"> <div style="text-align: center;"> Signature </div> <div style="text-align: right;"> Date </div> </div>		
20. DETAIL ATTACHMENTS: (See Instructions) Task Proposals Attached.					
☒ a. Facility requirements		☒ e. Approach		☒ i. Environmental assessment	
☒ b. Publications		☒ f. Technical progress		☒ j. Explanation of milestones	
☒ c. Purpose		☒ g. Future accomplishments		☒ k. Patent position	
☒ d. Background		☒ h. Relationships to other projects		☒ l. Capital Equipment	
Explanation of Acronyms					

WORK PROPOSAL REQUIREMENTS FOR OPERATING/EQUIPMENT OBLIGATIONS AND COSTS

CONTRACTOR NAME: ASSOCIATED UNIVERSITIES, INC./BNL			CONTRACTOR NO: AS-17-EECD			REVISION NO: 0		DATE PREPARED: 02/21/90	
TITLE: Geothermal Materials Development							BUDGET & REPORTING CODE: AM-10-01		
21. STAFFING (in staff years)	PRIOR YEARS	FY 1990	FY 1991 PRESIDENT'S REVISED		FY 1992 REQUEST AUTHORIZED		FY 1993	FY 1994	TOTAL TO COMPLETE
a. SCIENTIFIC.....		2.2	2.6	2.9	2.9				
b. OTHER DIRECT.....		<u>1.1</u>	<u>1.1</u>	<u>0.9</u>	<u>0.9</u>				
c. TOTAL DIRECT.....		3.3	3.7	3.8	3.8				
22. OPERATING EXPENSE (in thousands)									
a. TOTAL OBLIGATIONS..		356	550	600	640				
b. TOTAL COSTS.....		372	550	600	640				
23. EQUIPMENT (in thousands)									
a. EQUIP OBLIGATIONS..		0	0	15	40				
b. EQUIP COSTS.....		4	0	10	35				
24. MILESTONE SCHEDULE (Tasks)					PROPOSED SCHEDULE		AUTHORIZED SCHEDULE		
<u>Advanced High Temperature Lightweight Cements</u> 1. Complete downhole testing of best candidate lightweight CO ₂ -resistant cement. 2. Peer-review publication on FY 1990 work.					09/91 12/91				
<u>Thermally Conductive Polymer Concrete Liners</u> 1. Complete field test of HX-2. 2. Initiate field test of HX-3. 3. Issue interim report.					12/90 06/91 11/91				
<u>Chemical Systems for Lost Circulation Control</u> 1. Select material. 2. Complete mud displacement test with industry. 3. Complete field demonstration. 4. Peer-review publication.					09/90 04/91 09/91 12/91				
25. REPORTING REQUIREMENTS									

TITLE:**Geothermal Materials Development**

ASSOCIATED UNIVERSITIES, INC. BROOKHAVEN NATIONAL LABORATORY	DATE PREPARED: 02/21/90	S&R NUMBER AM-10-01	CONTRACTOR NO. AS-17-EECD	REV. NO. 0
---	----------------------------	------------------------	------------------------------	---------------

24. Milestone Schedule cont.**Advanced Chemical Coupling Systems**

1. Identification of metallic surface modification process. 12/90
2. Selection of organic bonding system. 03/91
3. Complete characterization of metal/bonding agent/elastomer interfaces. Initiate long-term autoclave exposure. 08/91
4. Peer-review publication. 10/91

Advanced Elastomers for Downhole Drill Motors

1. Select industrial partner. 12/90
2. Complete stator design and fabrication. 06/91
3. Complete laboratory evaluation. 08/91
4. Issue interim report. 09/91

I. INTRODUCTION

The Materials Development Project is an important part of the Geothermal Division's (GD) Hydrothermal Research Category. Although organizationally it is part of the Conversion Technology Task, the work also significantly impacts the Goals of the Hard Rock Penetration Task. The Level I objective of the Hydrothermal Research Category is to reduce the life cycle cost of producing electricity from liquid-dominated, moderate-and high temperature hydrothermal resources by 25 to 35 percent by 1992. Specific research objectives (Level III) for these tasks include 1) reducing costs associated with lost circulation episodes by 30 percent by 1992, 2) reducing the costs of deep wells and directionally drilled wells by 10 percent by 1992, 3) reducing well-cementing problems for typical hydrothermal wells by 20 percent by 1991, and 4) reducing the cost of binary power cycles by the development of a corrosion-resistant and low-fouling heat exchanger tube material costing no more than three times the cost of carbon steel by 1991.

If the GD program objectives are to be met, it is essential that new materials of construction be available. Advanced technology is required for industry to reduce costs caused by the severe geothermal environments encountered during drilling, well completion and test field development, heat extraction, power production, and reinjection of spent brine. Particular needs are for improved materials and methods to withstand 1) extremely high temperatures encountered in geothermal reservoirs and in energy conversion processes, and 2) severe corrosion and scaling by geothermal brines. Materials needs exist for specific components such as downhole drill motors, pumps, casing, packers, blow-out preventors, drillpipe protectors, rotating head seals, and heat exchangers. In particular, improvements in lost circulation control, lightweight well completion materials, hydrolytically stable chemical systems for bonding high temperature elastomers to steel substrates, and downhole drill motors, would significantly reduce well costs.

As a result of the small and uncertain geothermal market, industry will not develop the special materials required for these critical components. Therefore, the purpose of the Brookhaven National Laboratory (BNL) project is to provide the technical and managerial basis for the performance of high risk/high payoff materials R&D so that the results are available to industry when they commence

development of higher temperature and chemically aggressive geothermal resources. The goal of the project is to provide information to industry which will result in reduced costs of geothermal well-field and powerplant design, construction, and operation by (1) extending the operating range of equipment in terms of temperature limits and tolerance to chemically aggressive fluids, (2) extending equipment life, (3) reducing maintenance and replacement costs, and (4) substitution of lower cost materials.

The BNL materials project is focused on meeting these objectives. Currently, research and development work is in progress on 1) high temperature chemical systems for lost circulation control, 2) advanced high temperature (300°C), lightweight (~1.1 g/cc), CO₂-resistant well-cementing materials, and 3) thermally conductive composites for heat exchanger tubing. Work to address corrosion problems which have recently been detected at the Geysers was started late in FY 1990 as a cost-shared program with operators at that site. The work is coordinated with the Hard Rock Penetration Task at Sandia National Laboratories and the Conversion Technology Task at the Idaho National Engineering Laboratory, and is the subject of cost-shared activities with U.S. industrial firms and the New Zealand Department of Scientific and Industrial Research. This work will be continued in FY 1991. In addition, high temperature elastomer technology developed earlier in the program is being transferred for use in the Geothermal Drilling Organization programs on drillpipe protectors, rotating head seals, and blowout preventors. BNL serves as technical consultants for these efforts.

A schematic of the various phases of the materials development project is given in Figure 1. The first part involves identifying R&D needs. This is accomplished through industrial advisory panels, professional societies such as the American Petroleum Institute, ASTM and the National Association of Corrosion Engineers (NACE), and studies made by the National Research Council.^{1,2} other inputs come from BNL and DOE staff. The second phase of the project is to establish the technical and economic feasibility of solving the various materials

1. Materials Needs for the Utilization of Geothermal Energy, National Materials Advisory Board, Publication NMAB-375, 1981.
2. Geothermal Energy Technology Issues, R&D Needs, and Cooperative Arrangements, National Research Council, 1987.

Materials Development Flow Chart

Figure 1.

problems. This is then followed by either a basic and/or an applied research phase. Dependent upon the results, the development continues with a demonstration mode, which usually involves field testing in collaboration with industry. Working with industry also promotes their interest in the R&D and enhances transfer of the technology to the private sector.

Using the above strategy has resulted in many advances in geothermal materials development. The most significant has been in high temperature elastomers. Developed under GD sponsorship by L'Garde, Inc., the Y-267 EPDM (ethylene, propylene, diene, methylene) elastomer can be classified as a technology breakthrough. Three major U.S. seal manufacturers acquired the technology from the Department of Energy (DOE) in 1982, and molded parts are now commercially available from these and other firms. The elastomers are widely used in well logging tools, packers, valves and other equipment. In FY 1988, GD-sponsored work to modify the Y-267 EPDM to enhance its performance in drillpipe protectors, rotating head seals, and blow-out preventors was completed. These results are currently being utilized in the Geothermal Drilling Organization's programs on these components. However, the lack of hydrolytically stable chemical coupling systems needed to bond the elastomers to steel reinforcing is seriously impeding successful development of these badly needed components.

Another successful materials advance was the development of high-temperature polymer concrete formulations. These materials are now being used commercially as corrosion resistant linings on well casing and on brine collection piping.

Cements represent another area where considerable progress has been made. The results from this effort currently serve as the basis for the selection of cements used for geothermal well completions throughout the world. There is still, however, a major need for improved lightweight CO₂-resistant cements. In addition, deterioration of the cements used at the Geysers is starting to occur, and lifetimes >5 yr cannot be assured.

Handbooks summarizing the performance of materials in above-ground and downhole geothermal environments are other widely used outputs from the materials program.

Current efforts on dynamic seals and lightweight well cements may be used by industry in the very near future. Other efforts on CO₂-resistant cements,

lost circulation control materials, and nonmetallic heat exchanger tubing will require longer development times, but assuming the funding requirements listed in this AOP are authorized, should meet scheduled GD objectives.

II. PRIOR YEAR DATA

The materials development project which organizationally is part of the Conversion Technology Task, is also of extreme importance to the meeting of Hard Rock Penetration objectives. During FY 1989, the project consisted of work on several elements: 1) advanced high temperature lightweight cements for well completions, 2) cements for magma well completions, 3) thermally conductive polymer concrete (PC) liners for heat exchange applications in binary processes, and 4) chemical systems for lost circulation control. Work on element 2 was terminated in FY 1989. Work will be continued throughout FY 1990 on elements 1, 3, and 4. Liaison responsibilities for high temperature elastomer work being sponsored by the Geothermal Drilling Organization is continuing. Funding and manpower summaries for FY 1989 and 1990 are given in Table 1. Descriptions and Accomplishments for both years follow.

Table 1. Prior Year Funding and Manpower Levels

	<u>FY 1989</u>	<u>FY 1990</u>
Total obligation, \$K	495	395
Total year end cost, \$K	495	395
Equipment, \$K	30	0
Staffing, staff yr.		
Scientific	2.1	1.5
Other direct	1.7	1.2
Total direct	<u>3.8</u>	<u>2.7</u>

ELEMENT DESCRIPTIONS

1. Advanced High Temperature Lightweight Cements

In order to meet the GD Programmatic Objectives of reducing well cementing problems for typical hydrothermal wells by 20 percent by 1991, improved well cements must be developed. The R&D strategy seeks to improve the effectiveness of geothermal well completion procedures and to reduce the occurrence of lost circulation problems by the development of CO₂-resistant lightweight high

temperature cements. These improvements will help to transfer well-life limitations from materials to reservoir constraints in a cost effective manner. The work is being performed as a cooperative research effort with the New Zealand Department of Scientific Research (DSIR). BNL develops the cement formulations and performs physical, chemical and mechanical evaluations. DSIR conducts the downhole tests in wells at their Mokai and Rotokawa geothermal fields. Plans are also being formulated for a cost-shared program with Unocal for the downhole testing of cements at the Geysers where cement deterioration problems have recently started to occur.

The emphasis of the BNL effort is on high temperature rheology, phase chemistry, and the mechanical, physical and chemical resistance properties of the cured materials.

2. Cements for Magma Well Completions

Before attempts are made to drill into regions approaching magma bodies, novel cements or ceramic-like materials that can be used as well completion materials at temperatures up to 600°C must be developed. Work to address this need commenced at BNL in FY 1988 in an effort closely coordinated with the Magma Program at Sandia National Laboratories. The work emphasized the high-temperature phase chemistry and rheology of non-portland cement containing systems. Based upon these results, experiments to measure the physical, mechanical, and chemical properties of the cements commenced, but they were terminated late in FY 1989 upon announcement of the planned termination of the Magma Program. However, since all of the binders considered for this application are not subject to reactions with CO₂, the results from this task element are of immediate value since the use of the identified binders with lightweight aggregates should yield excellent lightweight CO₂-resistant cements for hydrothermal wells.

3. Thermally Conductive Polymer Concrete Liners

One of the Level III Goals of the Energy Conversion Task is to reduce the cost of binary power cycles by the development of low cost corrosion and scale resistant materials of construction for heat exchanger tubing. This project investigates the use of thermally conductive composites for this application.

Corrosion of the brine side of tubing in shell and tube heat exchangers can be a major problem in binary plants unless a very expensive high alloy steel (AL 29-4C) is used. Even then, excessive fouling prevents the economic use of binary processes with hypersaline brine reservoirs. Both problems may be solved with the development of thermally conductive corrosion and scale resistant polymer concrete liners for steel tubing. The work consists of determinations of the effects of compositional and processing variables on the thermal and scale-resistance characteristics of the composite, measurements of the physical and mechanical properties after exposure to hot brine, and field testing with hypersaline brines under heat extraction conditions.

4. Chemical Systems for Lost Circulation Control

Currently, the cost of correcting lost circulation problems occurring during well drilling and completion operations constitutes 20 to 30 percent of the cost of a well. The GD Objective is to reduce well drilling costs for typical hydrothermal wells by 10 percent by 1991. Therefore, our goal is to develop advanced high temperature chemical systems that can be introduced through the drill pipe into the lost circulation zones. Elimination of the need to remove the drill string will greatly reduce down time and aid in the location of the fractured zone, resulting in considerable cost savings.

During FY 1984 and 1985, BNL developed two promising chemical formulations, but due to budget constraints, the task was suspended. Work was resumed in FY 1988.

One formulation is composed of bentonite, ammonium polyphosphate (AmPP), borax, magnesium oxide, and water. The appropriate combination of these ingredients results in the formulation of slurries with viscosities and thickening times adequate to allow placement. After curing at elevated hydrothermal temperatures, the cement produced was characterized by a compressive strength >500 psi at 2 hr age, a permeability to water $<2.0 \times 10^{-4}$ darcy, and a linear expansion >15 percent. Consistometer tests performed at Sandia confirmed the pumpability of the material at high temperature and pressure.

The second promising system consists of cement, borax, glass fiber, and bentonite. The system is pumpable at 250°C, and at 2 hr age has a compressive

strength of 400 psi, a water permeability of 2×10^{-3} darcy, and linear expansion of ~2 percent.

5. Support to Geothermal Drilling Organization Elastomer Programs

Elastomers suitable for use in dynamic sealing applications in geothermal environments at temperatures up to ~260°C are not commercially available. Since a successful development could result in substantial reductions in drilling and completion costs, thereby helping DOE/GD to attain its goal of a 10 percent reduction by 1992, GD funded work to meet this need. The work was terminated in FY 1987 due to budgetary constraints. Since then, the Geothermal Drilling Organization (GDO) has sponsored two projects to utilize the results from the previous program in the development of drillpipe protectors and rotary head seals. BNL serves as a technical consultant to Sandia National Laboratories on both of these projects.

6. Corrosion Mitigation at the Geysers

As the steam pressure in the wells at the Geysers decreases, the HCl gas concentrations in the steam increase. This is resulting in rapidly increasing corrosion which is causing well shutdowns for costly repairs, and could lead to the abandonment of wells due to safety concerns. BNL has been asked by industry to participate with them in cost-shared programs aimed at mitigating these corrosion problems.

7. High Temperature Chemical Coupling Systems

A completed GD/BNL-sponsored program at L'Garde, Inc. first indicated the lack of suitable high-temperature chemical coupling systems needed to bond elastomeric materials to metallic substrates. This need has subsequently been confirmed in an ongoing GDO-sponsored program on drillpipe protectors, and it may severely limit the service temperature for rotating head seals and downhole drill motors. For drillpipe protectors, a 280°C hydrothermally stable bond between a modified Y-267 EPDM elastomer and steel reinforcement is required to meet the specified 48-hr service life of the component. All attempts by the GDO contractor (Regal International) to find a suitable commercially available or experimental coupling system have been unsuccessful, and it appears that the chances of meeting the GDO criteria for drillpipe protectors are very small. Similar problems may occur when field-testing of rotating head seals currently

under development at Drilex commences. Although the specified service-temperature (215°C) and service-life requirements (22 hr) are less stringent and the design of the component may minimize the stress at the interface, preliminary coupon tests indicate a bond loss of >50% within 22 hr in an unstressed condition.

Since the availability of high-temperature drilling tools is essential if GD's Level I objectives are to be met, BNL proposes to commence R&D directed toward the development of hydrothermally stable chemical systems and novel surface modification techniques which can be used in combination to enhance bonding at elastomer-metal interfaces.

The effectiveness of polymeric or elastomeric liners as impermeable corrosion-resistant barriers is generally determined by the ability to bond the organics to metallic substrates. For normal temperature applications (appliances, cars, etc.), crystalline zinc phosphate (Zn·Ph) conversion coatings are frequently applied to the steel substrate followed by the application of a polymer topcoating (epoxy, urethane, etc.). The Zn·Ph itself does not provide corrosion protection, but serves as a vehicle to mechanically bond the polymer to the steel.

Under Army Research Office sponsorship, BNL developed a method to modify the Zn·Ph process which results in significant enhancement in coating flexibility, bond strength, and corrosion resistance. The enhancement in properties is due to control of the Zn·Ph crystal size by the addition of polyacrylic acid macromolecules and chemical bonding formed between these reactive groups in the Zn·Ph and the polymers. As a result of these efforts, BNL-developed zinc phosphate technology was selected by Industrial Research Magazine as one of the 100 most significant new technical products of 1987. In addition, a major industrial firm has initiated procedures to license the BNL-patented technology.

For geothermal applications, BNL proposes to increase the operating-temperature capability of the system by altering the conversion coating by the partial replacement of the zinc with cobalt or nickel. This will also enhance the chemical bonding with high-temperature (>300°C) polymer topcoat systems and elastomers.

If successful, the work will find wide application as a corrosion protective system and in geothermal tools, where the current limitation is the ability to chemically bond GD-developed high-temperature elastomers to steel substrates.

8. Advanced Elastomers for Downhole Drill Motors

Based upon the promising results from FY 1984 through FY 1987 subcontracted work at L'Garde, Inc. to develop high-temperature elastomers for dynamic-sealing applications, it is proposed to start the Phase Two portion of the program. In the early stages (January 1984) of the Phase One effort which emphasized generic rotary seal elastomer compound development, elastomeric stators for downhole drill motors were identified as an application that, if successful, would significantly reduce well drilling costs. In addition to uses in conventional and directional drilling, the Moineau pump can be used for slurry service when high pressures are needed. Currently, nonsealed bearing turbines can work at circulating temperatures of -200°C and Moineau's at -120°C .

FY 1989 ACCOMPLISHMENTS

1. Advanced High Temperature Lightweight Cements

Planned FY 1989 milestones for this effort were the completion of laboratory evaluations of lightweight cements after exposure to low CO_2 -containing brines, the performance of pumpability measurements to verify the ability to place the cements, and completion of a 1 year downhole test in New Zealand as part of the ongoing cooperative effort with DSIR. The first milestone was attained and the results were published in three peer-review papers listed below. Another report which summarizes all of the work was prepared as a draft and it will be published in FY 1990.

Sugama, T., Kukacka, L. E., Carciello, N., and Stathopoulos, D. Interfacial reactions between oxidized carbon fibers and cements. Cem. and Conc. Research 19, 355-65 (1989).

Sugama, T., Kukacka, L. E., and Carciello, N. Study of interactions at water-soluble polymer/ $\text{Ca}(\text{OH})_2$ or gibbsite interfaces by XPS. Cem. and Conc. Research 19, 857-67 (1989).

Sugama, T., Kukacka, L. E., and Carciello, N. Cement hydrate catalyzed hydrolysis of polyimide lightweight materials. BNL 43270, J. App. Poly. Sci. (in press).

Sugama, T., Gray, G., and Kukacka, L. E. Alkali carbonation of autoclaved polymer-cement composites in Na_2CO_3 -laden water at 300°C . Draft, Nov. 1989.

The two patent disclosures listed below were also prepared.

Sugama, T. Oxidation of carbon fiber surfaces for improvement in fiber-cement interfacial bond at a hydrothermal temperature of 300°C . Nov. 21, 1988.

Sugama, T. Metal-alkoxide-modified calcium aluminate cements. Nov. 21, 1988.

The results from the laboratory studies to develop cements resistant to CO_2 -containing hydrothermal fluids indicated that all conventional cement systems decompose very rapidly. The most promising advanced formulation developed at BNL consists of calcium aluminate cement modified by the addition of a carboxylated styrene-butadiene copolymer. Upon exposure in an autoclave to Na_2CO_3 -laden water at 300°C , this formulation was found to be the most effective for minimizing strength degradation and carbonation reactions. These improvements are due to the formation of a calcium-complexed polymer structure resulting from the addition of the acrylic polymer. It was also determined that the degradation of cements in geothermal fluids containing CO_2 is not only due to severe carbonation of the hydrated cement products, but also to alkali metal-catalyzed hydrolysis of the cement hydrates caused by the attack of sodium cations present in the brine. The latter results in the formation of a porous microstructure as the CaCO_3 formed by carbonation is converted into water soluble $\text{Ca}(\text{HCO}_3)_2$.

Pumpability tests on these cements in accordance with American Petroleum Institute (API) standards were made. For use in these tests, a high pressure consistometer was obtained on loan from Sandia National Laboratories and installed at BNL.

The cost-shared cooperative program with the Department of Scientific and Industrial Research in New Zealand was continued, and as part of this effort, BNL fabricated and shipped several series of samples to the test site for installation by the well operators. Unfortunately, the downhole testing was delayed for over one year by the failure to the main valve on the well where the cement specimens are to be initially exposed to a low CO_2 content brine at 320°C in the Mokai field. DSIR informed BNL that the valve is jammed in the closed position, and that the well will have to be quenched before the valve can be

replaced. No date for this was established since funds are short and the Ministry of Energy is in the process of selling the wells.

2. Cements for Magma Well Completions

Before attempts are made to drill into regions approaching magma bodies, novel cements or ceramic-like materials that can be used as well completion materials at temperatures up to 600°C must be developed. Work to address this need commenced at BNL in FY 1988 in an effort closely coordinated with the Magma Program at Sandia National Laboratories. The work in FY 1989 emphasized the high-temperature phase chemistry and rheology of several non-portland cement containing systems. Experiments to measure the physical, mechanical, and chemical properties of the cements commenced, but they were terminated late in the year upon announcement of the planned termination of the Magma Program. Since all of the binders considered for this application are not subject to reactions with CO₂, their use with lightweight aggregates should yield excellent lightweight CO₂-resistant cements for hydrothermal wells.

Planned FY 1989 milestones were as follows: (1) identification of best candidate material, (2) completion of pumpability tests, and (3) initiation of long-term durability tests. The most promising binder system identified was a titania-modified calcium aluminate cement.

Tests to measure the mechanical and physical properties under dry and hydrothermal conditions at temperatures of up to 1000°C were made, and the results were documented in the two peer-reviewed publications listed below.

Sugama, T., Kukacka, L. E., and Carciello, N. Effect of aluminum alkoxides on the mechanical properties of calcium aluminate cements at high temperatures. *Advances in Cem. Research*, Vol. 1, 4, 207-214 (Oct. 1988).

Sugama, T., Hocker, N. J., Kukacka, L. E., and Carciello, N. The effects of in-situ sintered titania on the mechanical properties of high temperature calcium aluminate cements. *Cem. and Conc. Research* 19, 747-58 (1989).

3. Thermally Conductive Polymer Concrete Liners

Planned milestones for FY 1989 were as follows: (1) identification of a field test site, (2) completion of the fabrication of a prototype single tube heat exchanger, and (3) commence field testing. Milestones 1 and 2 were

attained. Milestone 3 was delayed as a result of regulatory problems concerning operation of a Puna test site in Hawaii.

Laboratory evaluations of thermally conductive polymer concrete lined tubing in simulated geothermal fluids were continued. After 15 mo in brine at 150°C, liners with a thickness of 0.020-in. provided excellent corrosion protection for the steel substrate. No deterioration or disbondment of the liner was apparent. These tests were to be continued in FY 1990.

For use in the planned field testing of the liner material, an 80-ft long single tube counter-current heat exchanger was constructed. Brine will be the tube side fluid, and water will be on the shell side. BNL fabricated four 20-ft lengths of lined tubing for use in this unit which was designed and assembled by INEL. When operated, measurements of scaling factors, heat transfer rates, and corrosion rates will be made.

In another laboratory effort, basic studies were initiated at BNL in an attempt to modify the surface characteristics of thermally conductive polymer concrete liners to make them less susceptible to scale deposition. It is well known that the deposition of alkali metals such as Na, Ca, and K on polymeric surfaces relates directly to oxidation of the polymer. Oxidation results in the formation of acidic-type pendent groups such as carboxylic acid (COOH) on the polymer surface, and these react preferentially with the alkali metals through acid-base reactions, resulting in the deposition of insoluble alkali metal compounds on the surface.

Experiments conducted in FY 1989 confirmed the technical feasibility of incorporating high temperature anti-oxidants into polymer concrete formulations as a means of reducing scale deposition. Tests were performed on samples after exposure to highly concentrated brines at 150 and 200°C. Contingent upon the results from the field testing of unmodified surfaces, a modified surface will be tested.

4. Chemical Systems for Lost Circulation Control

The most promising formulation identified was composed of bentonite, ammonium polyphosphate (AmPP), borax, magnesium oxide, and water. The appropriate combination of these ingredients resulted in the formation of slurries with viscosities and thickening times adequate to allow placement.

After curing at elevated hydrothermal temperatures, the cement produced was characterized by a compressive strength greater than 500 psi at 2 hour age, a permeability to water less than 2.0×10^{-4} darcy, and a linear expansion greater than 15 percent. Consistometer tests performed at Sandia confirmed the pumpability of the material at high temperature and pressure. It was decided that emphasis be placed on techniques to allow the introduction of the lost circulation control formulation through the drillpipe and the drill nozzle rather than by use of conventional techniques. If successful, the former placement technique will have the greatest impact on reducing cost.

In FY 1989, emphasis was placed on optimizing the bentonite-ammonium polyphosphate (AmPP)-borax-magnesium oxide (MgO) system for use with this placement technique. Since the pumpability and curing times for the system can be closely controlled over a wide temperature range (150°-350°C) by varying the MgO concentration, methods for the microencapsulation of the MgO in epoxies and other polymers were investigated. These MgO-containing capsules can be mixed with the other constituents and pumped down the drillpipe. Depending upon the thickness and thermal stability of the encapsulant, the combination of high temperature and shear forces at the nozzle can be sufficient to rupture the capsule, thereby allowing mixing of the highly reactive MgO with the other materials. Curing can take place within seconds if desired. For use in these experiments, a small bench scale unit which simulates a drillpipe, nozzle and the downhole fluid environment, was designed and constructed by Sandia National Laboratories, and placed in operation at BNL.

5. Support to Geothermal Drilling Organization Elastomer Programs

All of the Materials Program-funded R&D efforts on elastomers were completed in FY 1987 and the final report was published late in FY 1988. At that time, transfer of the technology by application to GDO projects commenced. This work continued throughout FY 1989, and will continue in FY 1990. In order to accelerate the transfer of the technology, BNL was selected by Sandia National Laboratories to serve as technical consultant for GDO sponsored programs on drillpipe protectors, rotating head seals, and blowout preventors. Subsequently, funding limitations resulted in the latter being postponed to an unspecified time.

A GDO contract for the development of advanced high temperature drillpipe protectors was awarded to Regal International. During the fiscal year, Regal confirmed the durability of the elastomer formulation developed by L'Garde for dynamic seals, and determined that conventional fabrication processes could be used to mold the parts. However, no suitable hydrothermally stable chemical coupling system, needed to chemically bond the cured elastomer to the required steel reinforcement, could be identified. Without adequate bonding, a successful drillpipe protector cannot be made. Similar findings had been reported by L'Garde, Inc., and the need for additional work to develop such a coupling system was emphasized in their final report. Unfortunately, budgetary constraints precluded further work.

In an attempt to determine if the results Regal obtained in the laboratory would be reproduced in the field, a field test was performed by Unocal at the Geysers as part of their financial contribution to the program. Compared to the earlier laboratory data, the results from the field test were unexpectedly good. These differences emphasize the uncertainties associated with trying to simulate field conditions in laboratory autoclaves. Excellent bonding between the elastomer and the steel parts was exhibited, but some deterioration of the elastomer occurred, possibly due to erosion. Complete failure of a commercially available drillpipe protector used as a control, occurred. Based upon the unexpected success of the bonding agent, a second field test was scheduled for early in FY 1990. In this test, two elastomers with different hardnesses will be evaluated. Improving the hardness should improve the erosion resistance.

The development of advanced rotating head seals for the GDO was continued by Drilex Systems, Inc. of Houston, Texas. During the fiscal year, laboratory tests were performed to identify promising elastomers and a chemical coupling system. Since the stresses anticipated within the part and the operating temperature are lower than those in drillpipe protectors, the availability of a coupling agent is not considered to be a constraint for this application. Three promising elastomers and a bonding system were selected, and full-size parts molded. Equipment needed to field test the components in steam wells at the Geysers and in hypersaline brine in the Imperial Valley was constructed.

EXPECTED ACCOMPLISHMENTS IN FY 1990

1. Advanced High Temperature Lightweight Cements

The development of advanced, high temperature, lightweight CO₂-resistant cements for well completions will be continued. Emphasis will be given to the phases formed upon exposure to high temperature CO₂-containing brines, the interactions between the cements and lightweight ceramic-type aggregates, and pumpability of the formulations. Downhole testing of the most promising high-alumina cement formulations identified in FY 1989 will commence as part of a continuing cost-shared cooperative effort with the New Zealand DSIR. This testing is contingent upon DSIR's ability to successfully complete repairs to the main valve on the well where the tests will be performed. BNL will fabricate all of the specimens needed for the tests, measure the mechanical and chemical properties of the cements after exposure times of three, six, and twelve months, and document the results. DSIR will furnish the wells, install and remove the samples, and perform some evaluations. If DSIR does not provide access to a well by April 1990, BNL will initiate large-scale in-house autoclave tests in brines at 300°C containing CO₂ concentrations sufficient to rapidly deteriorate conventional portland cement-based formulations.

2. Thermally Conductive Polymer Concrete Liners

Laboratory and field studies to evaluate the effectiveness of the use of thermally conductive polymer-concrete liners as a low-cost method for improving the corrosion and fouling resistance of heatexchanger tubing used in binary processes will be continued. During FY 1990, BNL will assist IDO/INEL in the identification of an alternate field site for the testing of a small prototype shell-and-tube heatexchanger containing thermally conductive polymer-concrete lined tubes. INEL will install and operate the test equipment. Measurements of the scaling factors, heat transfer coefficients, and corrosion rates will be made. Based upon these data, BNL and INEL will design and estimate the cost for full-sized units, and document the results.

Contingent upon the above results, BNL will supply to INEL four 20-ft long tubes containing a polymer-concrete formulation modified by the addition of high-temperature antioxidants to make them less susceptible to scale deposition.

Field testing of this unit will be initiated by INEL, and the results compared with those from the unmodified surfaces tested previously.

3. Chemical Systems for Lost Circulation Control

The cooperative effort with Sandia National Laboratories to develop advanced high-temperature chemical systems for lost-circulation control will be continued. Small-scale flow tests under simulated downhole placement conditions will be performed in order to optimize the compositions of the formulations with respect to their pumpability characteristics at various placement temperatures and the resultant mechanical and chemical properties after curing. Contingent upon the results, Sandia and BNL will make arrangements for the performance of drilling fluid displacement tests. These will be cost-shared efforts with private industry.

4. Support to Geothermal Drilling Organization Programs

Liaison activities will be continued with Sandia National Laboratories and the GDO to transfer completed GD-sponsored high-temperature elastomer technology to industry so that it can be used for drillpipe protectors and rotating head seals.

5. Corrosion Mitigation at the Geysers

BNL was asked by Geothermal Resources International (GEO), a steam producer at the Geysers, to participate in a DOE/GEO co-funded program to determine the suitability of polymer cement liners for protecting steel components from corrosion. When the corrosion resistance has been confirmed in field tests, methods for joining sections of lined well casing will then be developed.

Work on the project started in May 1990. To date, a polymer cement formulation suitable for centrifugal casting onto 16-in. diam. well casing has been selected, and small sections of 16 and 8-in. diam. casing lined for use in preliminary field tests. Exposures to the well-head fluids were started. BNL will assist GEO personnel in the preparation of additional test sections.

Deterioration of well cements used to complete the wells at the Geysers is starting to occur as downhole temperatures above 260°C are being encountered. Lifetimes of less than 5 years are being projected. As a result of this serious problem, BNL expertise in developing advanced high temperature cements has been

requested, and plans for a cost-shared program with industry to address this problem are being formulated for implementation in FY 1991.

III. FUNDING YEAR RESEARCH PLAN

Descriptions of each of the task elements in the Materials Development Project and recent and expected accomplishments in each, were given in Section II. Work to be performed in FY 1991, milestones, deliverables, and manpower and funding requirements are summarized below for each part of the project.

1. Advanced High Temperature Lightweight Cements

a. Work Statement

The R&D phases of work on lightweight CO₂-resistant cements for hydrothermal well completions will be completed. Exposure testing for one year in laboratory autoclaves and in New Zealand wells will be completed, all of the cements characterized, and the results published in peer-reviewed journals. Contingent upon these results, plans for a cooperative cost-shared demonstration effort with Sandia National Laboratories and a private company which would take place in FY 1992, will be made.

b. Milestones and Deliverables

<u>Accomplishment</u>	<u>Date of Accomplishment</u>
1. Complete downhole testing of best candidate lightweight CO ₂ -resistant cement	09/91
2. Peer-review publication on FY 1991 work	12/91

c. Funding and Manpower Requirements

The funding level (BA) for FY 1991 required to perform the work outlined above is \$150,000. A total of 0.95 man years will be committed to the work. This is summarized in Table 2.

2. Thermally Conductive Polymer Concrete Liners

a. Work Statement

Work to develop advanced heat-exchange materials for use in binary power cycles will be completed. Field testing of the prototype single-tube shell-and-tube heat exchangers containing unmodified and surface-modified, thermally

conductive polymer concrete-lined tubes will be completed. In these tests, brine will be the tube-side fluid and water will be on the shell side. Contingent upon these results, testing in a higher salinity brine or with a binary fluid will commence. Measurements to determine scaling factors, heat-transfer coefficients, and corrosion rates will be repeated. Tubing with enhanced heat-transfer surfaces (fins, etc.) will also be evaluated. INEL will conduct the field tests. Based upon these results, designs and potential costs for full-sized units will be determined. BNL and INEL will document and publish the results.

b. Milestones and Deliverables

<u>Accomplishment</u>	<u>Date of Accomplishment</u>
1. Complete field test of HX-1	10/90
2. Issue interim report	12/90
3. Initiate field test of HX-2	12/90
4. Complete field test of HX-2	04/91
5. Initiate field test of HX-3	06/91
6. Complete field test of HX-3	10/91

c. Funding and Manpower Requirements

The total FY 1991 BA required to perform this project element is \$50,000. The manpower assigned to the project will 0.31 man-yr (see Table 2).

3. Chemical Systems for Lost Circulation Control

a. Work Statement

The cooperative effort with Sandia National Laboratories and private industry to develop advanced high-temperature chemical systems for lost-circulation control will be completed. Contingent upon the results from FY 1990 tests, drilling fluid displacement tests will be performed as a cost-shared effort with private industry. The work will culminate with the performance of a field demonstration. BNL will supply the formulation and chemical constituents; Sandia will design and supply any specialized placement equipment required; and industry the test well, conventional placement equipment, and field personnel.

b. Milestones and Deliverables

<u>Accomplishment</u>	<u>Date of Accomplishment</u>
1. Selection of material.	09/90
2. Complete mud displacement test with industry.	04/91
3. Cost-shared field test.	09/91
4. Peer-review publication.	12/91

c. Funding and Manpower Requirements

The BA and BO required in FY 1991 to perform the BNL portion of the work outlined above is \$125,000. Approximately 0.80 man-year of BNL Scientific and Professional Staff time will be assigned to the effort (see Table 2).

4. Corrosion Mitigation at the Geysers

a. Work Statement

Ongoing cost-shared efforts with geothermal steam producers at the Geysers focused on the mitigation of hydrochloric acid initiated corrosion will be continued and new projects will be initiated as their needs are identified. With respect to the ongoing effort with Geothermal Resources International, the downhole testing of prototype sections of polymer cement well casing will be continued. Contingent upon the results from these tests, techniques for joining sections of lined casing will be developed and utilized in the fabrication and installation of several hundred feet of casing. Technical assistance for the protective lining of well-head and other above ground components will also be provided.

R&D efforts with Unocal to solve well cement placement and deterioration problems will be planned and the work implemented. The work will include the downhole testing of advanced cements developed at BNL but as yet untested in the fluids presently encountered at the Geysers, and based upon these results, the modification of existing or the development of new cements.

Technical assistance for materials-related problems will be provided to other operators and electric power producers upon their request.

b. Milestones and Deliverables

<u>Accomplishment</u>	<u>Date of Accomplishment</u>
1. Completion of preliminary testing of lined casing section.	10/90
2. Complete development of method for joining lined casing sections.	03/91
3. Install lined casing string for downhole evaluation	08/91

c. Funding and Manpower Requirements

The FY 1991 funding required for this project element is \$50,000. Any BNL costs above this amount which are incurred due to cement R&D with Unocal will be paid for by Unocal. The manpower allocation for the project is initially 0.31 man-yr (see Table 2).

5. High Temperature Chemical Coupling Systems

a. Work Statement

The work to be performed in FY 1991 will be separated into three elements: (a) elemental alteration and transformation of zinc-phosphate crystal coatings for use as high-temperature protective coatings on steel and to enhance bonding with the coupling system, (b) coupling polysiloxane and polysilane pretreatments for hydroxylated metal surfaces to produce hydrothermally stable polymer-metal interfaces, and (c) characteristics of polymer-elastomer interfaces after exposure to hydrothermal environments.

b. Milestones and Deliverables

<u>Accomplishment</u>	<u>Date of Accomplishment</u>
1. Identification of metallic surface modification process.	12/90
2. Selection of organic bonding system.	03/91

3.	Complete characterization of metal/bonding agent/elastomer interfaces. Initiate long-term autoclave exposure.	08/91
4.	Peer-review publication.	10/91

c. Funding and Manpower Requirements

The FY 1991 funding required to initiate this new project element is \$125,000. A total of 0.80 man-yr will be spent on the project this fiscal year (see Table 2).

6. Advanced Elastomers for Downhole Drill Motors

a. Work Statement

Based upon the promising results from FY 1984 through FY 1987 subcontracted work at L'Garde, Inc. to develop high-temperature elastomers for dynamic-sealing applications, it is proposed to start the Phase Two portion of the program. In the early stages (January 1984) of the Phase One effort which emphasized generic rotary seal elastomer compound development, elastomeric stators for downhole drillmotors were identified as an application that, if successful, would significantly reduce well drilling costs. In addition to uses in conventional and directional drilling, the Moineau pump can be used for slurry service when high pressures are needed. Currently, nonsealed bearing turbines can work at circulating temperatures of ~200°C and Moineau's at ~120°.

It is proposed that the Phase Two effort consist of a BNL subcontract to L'Garde, Inc. to cooperate with a drilling-equipment company on a cost-shared basis, to construct and laboratory-test a prototype Moineau stator containing the best high-temperature elastomer developed in Phase One. L'Garde, Inc. will supply the elastomer and necessary processing equipment. The private firm will supply the stator design, molds, and testing services. L'Garde will document all phases of the work and prepare an interim report which will be published by BNL.

b. Milestones and Deliverables

<u>Accomplishment</u>	<u>Date of Accomplishment</u>
1. Select industrial partner.	12/90
2. Complete stator design and fabrication.	06/91

3. Complete laboratory evaluation. 08/91
4. Issue interim report. 09/91

c. Funding and Manpower Requirements

The FY 1991 funding required to initiate this new project element is \$100,000, approximately \$75,000 of which will be used to start a subcontracted effort with L'Garde, Inc. BNL manpower on this project in FY 1991 will be 0.15 man-yr. Approximately 0.50 man-yr of subcontracted labor will also be utilized. These are summarized in Table 2.

Table 2. Summary of FY 1991 Funding and Manpower Requirements

<u>Task Element</u>	<u>Funding. \$K</u>	<u>Manpower Man-yr</u>
1. Advance High Temperature Cements	150	0.95
2. Thermally Conductive Polymer Concrete Liners	50	0.31
3. Chemical Systems for Lost Circulation Control	125	0.80
4. Corrosion Mitigation at the Geysers	50	0.31
5. High Temperature Chemical Coupling Systems	125	0.80
6. Advanced Elastomers for Downhole Drill Motors	100	0.63
Total	600	3.80

IV. MANAGEMENT PLAN

1. Overview of Management System

The technical and administrative management of the R&D phases of this project are under the direction of BNL with project policy established by the GD Task Manager, Raymond LaSala.

Fiscal control will be exercised in the form of monthly comparisons, over the project term, of actual costs incurred against corresponding line items of the budget. Technical results shall be monitored through a periodic review, by the Contractor Task Manager, of accomplishments by measuring actual performance as compared to expected progress. All work shall be conducted in conformance with generally accepted standards for R&D and other investigative or analytic

procedures, as observed by universities and large independent research facilities including BNL.

2. Management Structure

The GD Manager of the Geothermal Materials Project is Raymond LaSala (FTS 896-4198). Field level program monitoring is provided by Kenneth J. Taylor of the Idaho Falls Operations Office (FTS 583-9063). Field level management is by the Contractor Work Proposal Managers at BNL, Leon Petrakis, Chairman, Department of Applied Science (FTS 666-3037) and John Andrews, Head, Energy Efficiency and Conservation Division (FTS 666-7726). The Principal Investigator at BNL is Lawrence E. Kukacka, Leader, Process Materials Group (FTS 666-3065). An organizational description of BNL is given in Exhibit I. Organization charts of BNL and the Department of Applied Science are given in Exhibits II and III, respectively.

3. Management Resource Requirements

The funding levels given in Section III for each of the project elements include all BNL Overhead and Management charges. A capital equipment authorization for FY 1991 of \$15,000 for the purchase of high pressure autoclaves needed to replace existing corroded and obsolete units, is requested. The units are needed to measure the hydrothermal durability of cements, lost circulation control materials and polymer cement composites. No additional project management resources are required at BNL. GD and Idaho Falls Operations Office requirements have not been defined.

4. Procurement Plan Summary

Two high pressure autoclaves will be purchased. No other procurements are planned.

5. Subcontracting Plan

One subcontract for work on advanced elastomers for downhole drill motors is planned. A two or three year effort will be required to complete this project element.

EXHIBIT I

BROOKHAVEN NATIONAL LABORATORY

Organizational Description

Brookhaven National Laboratory is operated by Associated Universities, Inc. under contract with the United States Department of Energy. Nine northeastern universities sponsor Associated Universities, Inc. The Board of Trustees consists of the President ex officio and two individuals from each university, one a principal administrative or corporate officer and the other a scientist, and not more than six Trustees-at-Large selected by the Board. The purpose of the latter is to ensure adequate representation of any scientific discipline in which the corporation may undertake work and to provide general flexibility in methods of operation. Associated Universities, Inc. has appointed six visiting committees to Brookhaven National Laboratory to provide a continuing independent evaluation of the research program. The committees cover the field of energy and environment, nuclear energy, biology, chemistry, medicine, and physics; they report annually to the Board of Trustees.

The site and all facilities at Brookhaven National Laboratory are the property of the United States Government. Associated Universities, Inc. also operates the National Radio Astronomy Observatory under contract with the National Science Foundation.

All administrative arrangements will be handled by Bernard J. Mc Alary, Business Manager, Brookhaven National Laboratory.

Exhibit II

BROOKHAVEN NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY
Operated by
ASSOCIATED UNIVERSITIES, INC., UPTON, N.Y.
FOR U.S. DEPARTMENT OF ENERGY
CONTRACT NUMBER DE-AC02-75CN00016

N.P. Samios

APRIL 1, 1990

DEPARTMENT OF APPLIED SCIENCE

6. Schedules of Conferences and Technical Review

Two major technical reviews are planned. The first will be held in Washington, D.C. at a date to be specified by the GD Program Manager. Participation in the Annual GD Program Review is also planned. Other review meetings will be held with GD Staff at their convenience.

7. Schedule of Planned Foreign Travel

None anticipated.

V. OUTYEAR RESEARCH PLAN

1. Goals/Objectives

The goal of the Materials Program during the period FY 1992-1995, will be to ensure that the ability of GD to meet its Level I objective for hydrothermal research will not be constrained by the availability of economically and technologically viable materials for well drilling and completion, and for the containment and handling of geothermal and associated fluids during production, energy conversion, and disposal.

2. Key Issues and Strategy

In a 1987 DOE-sponsored review conducted by the National Research Council¹, it is stated that technology is the major barrier to growth of the geothermal industry and that improvement and development are necessary in the areas of reservoir technology, instrumentation and drilling technology. With respect to the latter, specific needs such as downhole motors and turbines, open hole packers, high temperature cements, drilling fluids, and lost circulation control materials are listed. If successfully developed, these materials will initially be used in hydrothermal processes, but they will also be needed if longer term resources such as hot dry rock, geopressure and magma are to be utilized commercially.

The strategy of conducting this high risk R&D program will be to maintain a current list of materials related problems impacting the geothermal industry.

¹Geothermal Energy Technology: Issues, R&D Needs, and Cooperative Arrangements, National Research Council, National Academy Press, Washington, D.C., p. 25, 1987.

This will be done by the continued utilization of industry advisory panels, professional societies, and government-industry cooperative groups such as the Geothermal Drilling Organization (GDO) and the Geothermal Technology Organization (GTO). Initial phases of the R&D efforts will be performed using GD funding, but once technical and economic feasibility have been established, cost-shared efforts with the private sector will be established. The latter also maximizes the potential for successful technology transfer. Successful illustrations of the program strategy are the development of high temperature elastomers for static and dynamic seal applications. The former are now commercial items while the latter have reached the stage where they are the subject of GDO-sponsored programs with industry.

3. Broad Task Descriptions

In FY 1992, work will be completed on CO₂-resistant lightweight cements. R&D efforts on advanced high temperature elastomers for use in downhole drill motors, high temperature chemical coupling systems, and the mitigation of corrosion at the Geysers will be continued. Work will commence on the in-situ conversion of drilling muds into well cements, and metallic or ceramic liners for well casing. Element descriptions are given below.

a. Advanced High Temperature Lightweight Cements

The technology transfer phase of the work on advanced high-temperature lightweight CO₂-resistant cements for the completion of hydrothermal wells will be completed with the cementing of a demonstration well. This work will be performed as a cooperative effort with Sandia National Laboratories and will be cost-shared with industry. BNL will identify the cement formulation and supply the chemical constituents; Sandia will design and supply any specialized placement equipment required; and industry the test well, conventional placement equipment, and field personnel.

b. Advanced Elastomers for Downhole Drill Motors

The FY 1991-initiated effort to develop and test advanced high-temperature elastomers for use in the stator of a downhole drill motor will be continued as a subcontracted effort with L'Garde, Inc. and as a cost-shared effort with industry. Contingent upon FY 1991 results, a full-scale Moineau stator will be

fabricated and laboratory tested. All of the test results will be documented and published by BNL. Planning for field testing will commence.

c. High Temperature Chemical Coupling Systems

The FY 1991-initiated effort to develop high-temperature chemical coupling systems to bond advanced elastomers to metals for applications in many geothermal tools will be completed. The most promising system will be identified, and a cost-shared program with companies currently producing drillpipe protectors, rotating head seals, and blow-out preventors will be established for the purpose of building and field testing full-size units.

d. Corrosion Mitigation at the Geysers

Cost-shared work initiated in prior fiscal years to reduce corrosion of well casing, cements and above ground components will be continued and new problems addressed as they are identified.

e. In-Situ Conversion of Drilling Mud Into Cement

Inadequate displacement of drilling fluids from the annulus between the well casing and formation prior to cementing is a principal cause of cement-free regions behind the casing. High pressures resulting from boiling of the fluids entrapped in these regions can cause collapse of the casing, and formation fluids reaching the outer surface of the casing can corrode it. Therefore, the development of high-temperature drilling muds which can be converted in situ into well cements would simplify well-completion procedures and extend well life.

In current BNL work on advanced chemical systems for lost-circulation control, reactions between cementing materials and the constituents of bentonite-based drilling fluids are being studied. Properties suitable for lost-circulation control have been obtained, and the technical feasibility for obtaining properties needed for well completions has been established. The initial work in FY 1992 will emphasize high-temperature-phase chemistry and rheology of several non-portland cement systems. Properties critical for well-cementing applications such as the long-term durability to high-temperature geothermal fluids, the bond strength to steel casing of the cured material, and the pumpability and density of the slurry will be measured.

f. Advanced Liners for Well Casing

Corrosion of well casing and surface components continues to adversely affect the geothermal industry and low-cost substitutes for the currently used high alloy steels are needed. Two potentially lower-cost alternatives, ceramic and metallic liners on mild-steel tubulars, will be developed.

Considerable reductions in the cost of hydrothermal, geopressure and magma-energy processes and increased well life could be accrued if ceramic-type materials that could be cast on the well-bore during the drilling operation were available. These cost reductions would result from the elimination of the metallic casing and well cements, and reduced drilling rig time. Quick setting, castable, strong, and durable ceramic materials that are compatible with drilling fluids and will bond to mud-saturated formations are needed.

Recent work at BNL on calcium-aluminate cement pastes containing hydrous titania sol-gel particles has indicated the feasibility of producing a ceramic material meeting these requirements. Compressive strengths measured at temperatures between 300° and 1000°C exceed the strength requirements and calcium-aluminate cements are known to be resistant to acids and CO₂. Setting times, castability, and compatibility with drilling muds will be determined, and the formulation optimized for this application.

Earlier (FY 1986) BNL studies resulted in the development of a highly corrosion-resistant alloy and the identification of a number of other metallic systems that appeared to have potential as liners for geothermal well casing. Further development of the BNL alloy and detailed corrosion testing of it and the other metals are required before cost-effective processes can be identified.

During the period FY 1993-95, the materials needs constraining the development of geothermal resources will be ascertained annually and R&D efforts initiated. Needs already identified but R&D efforts constrained by current budget limitations include the items listed below. Hopefully R&D on these needs will commence in the FY 1991-1992 timeframe and be completed by 1995.

1. Elastomeric materials for open-hole packers needed for well stimulation operations.

2. High temperature and hydrolytically stable chemical systems to bond elastomers to steel reinforcing substates. Until these systems are perfected, the performance of many well drilling and safety related tools will be compromised.

3. Elastomeric and metallic liners for mild steel well casing as replacements for high alloy steels.

4. In-situ conversion of drilling muds into well cements. A successful development will eliminate mud displacement problems which can lead to poor well cements and subsequent casing failure.

5. Castable ceramic materials which can be applied in-situ as corrosion protective liners on well casing and process piping.

The commercial availability of the above materials would almost guarantee realization of GD's programmatic goals and enhanced development of geothermal energy resources.

4. Outyear Funding Requirements

<u>Task Element</u>	<u>FY 1992</u>	<u>FY 1993</u>	<u>FY 1994</u>	<u>FY 1995</u>
Well cements	150	-	-	-
Advanced elastomers	150	200	-	-
Chemical bonding agents	100	100	-	-
Corrosion mitigation	40	40	50	50
<u>In-situ</u> conversion of drilling muds	100	150	300	275
Advanced liners for well casing	100	160	300	275
Subtotal, \$K	<u>640</u>	<u>650</u>	<u>650</u>	<u>600</u>
Capital Equipment, \$K	40	50	50	50
Total	<u>680</u>	<u>700</u>	<u>700</u>	<u>650</u>

5. Outyear Manpower Requirements

<u>Task Element</u>	<u>FY 1992</u>	<u>FY 1993</u>	<u>FY 1994</u>	<u>FY 1995</u>
Well cements	0.89	-	-	-
Advanced elastomers	0.89	1.2	-	-
Chemical bonding agents	0.59	0.6	-	-
Corrosion mitigation	0.25	0.24	0.3	0.3
<u>In-situ</u> conversion of drilling muds	0.59	0.9	1.8	1.6
Advanced liners for well casing	0.59	0.96	1.8	1.6
Total, man-yr	<u>3.8</u>	<u>3.9</u>	<u>3.9</u>	<u>3.5</u>