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Informal Report

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GEOTHERMAL MATERIALS PROJECT INPUT FOR CONVERSION TECHNOLOGY TASK ANNUAL OPERATING PLAN FY 1992

Lawrence E. Kukacka

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April 1991

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

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CONSERVATION DIVISION
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

MASTER

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U.S. DEPARTMENT OF ENERGY
FIELD WORK PROPOSAL

1. B&R No:	2a. CONTRACTOR NO:	2b. REV. NO:	3. DATE PREPARED:	4. IS THIS WORK INCLUDED IN THE INST. PLAN?	5. TASK TERM:
AM-10-01	AS-17-EECD	0	02/20/91	X Y ___ N	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
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17. WORK PROPOSAL DESCRIPTION (Approach, anticipated benefit in 200 words or less):

This ongoing laboratory-based high risk/high payoff R&D program has already yielded several durable cost-effective materials of construction which are being used by the geothermal energy industry. In FY 1992, R&D in the following areas will be performed: (1) advanced high-temperature (300°C) CO_2-resistant lightweight well-cementing materials, (2) high-temperature chemical systems for lost-circulation control, (3) thermally conductive composites for heat exchange applications, (4) corrosion mitigation at The Geysers, and (5) high-temperature chemical coupling materials to bond elastomers to steel substrates. Work to address other materials problems will commence in FY 1993, as their needs are verified. All of the activities 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.

18a. PRINCIPAL INVESTIGATOR(S):

Lawrence E. Kukacka — 02/20/91

Signature(s) — Date

18b. CONTRACTOR WORK PROPOSAL MANAGER:	19. OPERATIONS OFFICE REVIEW OFFICIAL:
John W Andrews — 02/20/91 Signature — Date	Signature — Date

20. DETAIL ATTACHMENTS: (See Instructions) Task Proposals Attached.

- X a. Facility requirements
- X b. Publications
- X c. Purpose
- X d. Background
- X e. Approach
- X f. Technical progress
- X g. Future accomplishments
- X h. Relationships to other projects
- X i. Environmental assessment
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I. INTRODUCTION

The Geothermal Materials Project is an important part of the Geothermal Division's (GD) Hydrothermal Category, and it has an impact on two tasks, Conversion Technology and Hard Rock Penetration. The objective of the project is to provide information to industry which will result in reduced costs of geothermal well-field and power-plant 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. Specific goals to be achieved in realizing the objectives are to (1) reduce costs associated with lost circulation episodes by 30 percent in the near term, (2) reduce the costs of deep wells and directionally drilled wells by 10 percent in the near term, (3) reduce well-cementing problems for typical hydrothermal wells by 20 percent in the near term, and (4) reduce the cost of binary power cycles by development of a corrosion-resistant and low-fouling heat exchanger tube material costing no more than three times the cost of carbon steel in the near term.

Although the Materials Project is structured as a project within the Conversion Technology Task, it is also making major contributions to the Hard Rock Penetration Task. Future commercialization within the Geopressured-Geothermal, Hot Dry Rock, and Magma Categories will also be highly dependent upon materials development.

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 BNL materials project is focused on meeting these objectives. Currently, research and development work is in progress on 1) advanced high temperature (300°C), lightweight (~1.1 g/cc), CO_2-resistant well-cementing materials, 2) high temperature chemical systems for lost circulation control, 3) thermally conductive composites for heat exchanger tubing, 4) high temperature chemical coupling materials to bond elastomers to steel substrates, and 5) corrosion mitigation at The Geysers. In addition, high temperature elastomer technology developed earlier in the project is being transferred for use in the Geothermal Drilling Organization (GDO) programs on drillpipe protectors and rotating head seals. BNL serves as technical consultants for these efforts. All of these activities are coordinated with the Hard Rock Penetration Task at Sandia National Laboratories (SNL) and the Conversion Technology Task at the Idaho National Engineering Laboratory (INEL) and is the subject of cost-shared activities with U.S. industrial firms and the New Zealand Department of Scientific and Industrial Research (DSIR). Work on all of these activities will be continued in FY 1992. Contingent upon the results, laboratory R&D work on cements and lost circulation control materials will be completed in FY 1992. Activities 4 and 5 will be continued in FY 1993. Work to address other materials needs will commence in FY 1993.

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 1990, the project consisted of work on several activities: 1) advanced high temperature lightweight cements, 2) chemical systems for lost circulation control, 3) thermally conductive composites for heat exchanger tubing, and 4) corrosion mitigation at The Geysers. In addition, liaison responsibilities for high temperature elastomer work being sponsored by the GDO were continued. In FY 1991, the initiation of an activity on high temperature chemical coupling materials was authorized. Work on this subject is underway. Funding and manpower summaries for FY 1990 and 1991 are given in Table 1. Activity Descriptions and Accomplishments for both years follow.

Table 1. Prior Year Funding and Manpower Levels

	FY 1990	FY 1991
Total obligation, $K	395	600
Total year end cost, $K	395	600
Equipment, $K	0	30
Staffing, staff yr.		
Scientific	2.2	3.4
Other direct	1.1	1.8
Total direct	3.3	5.2

ACTIVITY 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 in the near term, 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

CO_2-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 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.

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. Chemical Systems for Lost Circulation Control

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. As a result, GD Level III Objectives include 1) reduction of costs associated with lost circulation eposides by 30 percent in near-term, and 2) reduction of the costs of deep well's and directionally drilled wells by 10 percent in the near-term. The most significant cost reduction in lost circulation control would be accrued if an advanced high temperature chemical system that can be introduced through the drillpipe into the lost circulation zones is developed. Elimination of the need to remove the drill string will not only greatly reduce down time, but it will also aid in the location of fractured zones.

The emphasis of the work is to formulate and characterize advanced chemical systems that can be placed using conventional practices into lost circulation zones and which will rapidly cure in a controllable way to yield properties sufficient to meet API specifications.

3. Thermally Conductive Composites for Heat Exchanger Tubing

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 activity 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, and measurements of the physical and mechanical properties after exposure to hot brine under laboratory and field conditions.

4. Corrosion Mitigation at The Geysers

Increased HCl concentrations in the steam produced from some geothermal wells at The Geysers have resulted in severe corrosion problems in the upper regions of the well casing where some condensation occurs, and in the steam collection piping. In some cases, this has resulted in the shutdown of wells causing reduced steam supply and, therefore, decreases in electric power generation. Increased operating costs and safety and environmental concerns have also resulted. The work consists of optimization of previously developed polymer cement formulations for use in highly acidic environments at high temperature, cost-shared field testing, and contingent upon these results, development and testing of methods for joining lined components.

5. Geothermal Drilling Organization Elastomer Activities

BNL provides liaison services to SNL and the GDO in order to enhance the transfer of completed GD-sponsored high temperature elastomer technology to industry so that it can be utilized in equipment needed by the GDO. Such needs include drillpipe protectors, rotary head seals, blow-out protectors, and Moineau stators for downhole drillmotors.

6. High Temperature Chemical Coupling Systems

The need for hydrolytically stable chemical coupling systems to bond elastomers to metal reinforcement used in a variety of geothermal tools was first identified in an earlier BNL program. This need has subsequently been verified in an ongoing GDO-sponsored program on drillpipe protectors, and it is expected to severely constrain the future development of blow-out preventors and downhole drill motors. Since the availability of high-temperature drilling tools is essential if GD's Level I objectives are to be met, BNL has commenced 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.

FY 1990 ACCOMPLISHMENTS

1. Advanced High Temperature Lightweight Cements

Work to formulate and test lightweight CO_2-resistant cements continued. In addition to resistance to CO_2 attack at high temperature, other property criteria are as follows: slurry density < 10 lb/gal, pumpability for a minimum of 4 hr at 150°C, compressive strength > 1000 psi at an age of 24 hr, water permeability < 0.1 m Darcy, and a bulk density < 62.4 lb/ft^3.

The results from the laboratory studies performed during the year first confirmed that all calcium silicate hydrate-based well cements undergo carbonation reactions when exposed to hydrothermal fluids containing CO_2. The carbonation rates are strongly dependent on CO_2 concentration, temperature and pressure. The presence of sodium cations in the fluid was found to result in alkali metal-catalyzed hydrolysis of the cement hydrates, thereby increasing the carbonation and subsequent deterioration rate.

The most promising CO_2-resistant formulation identified at BNL is a phosphate modified calcium aluminate cement. The cements yield compressive strengths far in excess of the criterion. For example, curing in air for 24 hr produces a strength of 4000 psi. Curing in hydrothermal environments at 150°C and 200°C for 20 hr yields strengths of 4740 and 10500 psi, respectively.

The formulation can meet API pumpability standards by the incorporation of conventional organic-type retarders such as gluconic acid or glucuronic-6,3 lactone. Unfortunately, these retarding materials undergo reactions with CO_2 leading to carbonation. Inorganic acid-type additives such as boric acid and sodium tetraborate decahydrate are not as effective in retarding the curing rate, but they are not susceptible to carbonation. Studies to explore other methods for extending the pumpability are planned for FY 1991.

The cost-shared cooperative program with the DSIR in New Zealand was continued. Series of calcium aluminate cements were sent to DSIR who installed them in a well where they are being exposed to CO_2-containing brine at 320°C and pH ~2.2. After only 3 months in this environment, conventional well cements had volume reductions of up to 20% and were completely carbonated. At years end, none of the BNL-supplied samples had been removed for evaluation.

The results from the FY 1990 studies can be summarized as follows:

1. Phosphate-bonded calcium aluminate cement showed great promise as a CO_2-resistant binder.
2. Calcium aluminate cements are not pumpable without the addition of retarders.
3. Conventional organic-type retarders yield pumpable slurries but are susceptible to carbonation.
4. Inorganic acid additives (boric acid, borax) are not as effective retarders, but they are not subject to carbonation.
5. Initial downhole test data for conventional portland-based cements received from DSIR.

Planned FY 1990 milestones for this activity are listed below.

- o Identify best candidate cement
- o Complete pumpability tests
- o Perform long-term durability testing in autoclaves
- o Commence downhole testing
- o Peer-review publication

Milestones 1, 4 and 5 were completed, one set of autoclave exposures (Milestone 3) was completed and another is in progress. Pumpability testing (Milestone 2) was initiated and is an ongoing effort during the evaluation of retarding admixtures. The following peer-reviewed publications were prepared.

Sugama, T., Kukacka, L. E. and Carciello, N. Cement hydrate catalyzed hydrolysis of polyimide lightweight materials. BNL 43270, Jan. 1989; J. App. Poly. Sci., 40, 1857-70 (1990).

Sugama, T., Gray, G., and Carciello, N. R. Influences of set-retarding admixtures on alkali carbonation of calcium aluminate cements under hydrothermal conditions. J. Mat. Sci. and Tech., in press.

Sugama, T., and Carciello, N. R. The development of strength in phosphate bonded calcium aluminate cements. J. Am. Ceramics Soc., in press.

Sugama, T., Gray, G., and Carciello, N. R. The interface between zinc phosphate-deposited steel fibers and cement paste. BNL 44759, July 1990; J. Mat. Sci., in press.

2. Chemical Systems for Lost Circulation Control

During FY 1990, R&D work was continued as a cooperative effort with SNL. Experiments were performed with a previously identified bentonite-ammonium polyphosphate-borax-magnesium oxide system to determine methods for controlling the curing rates and, therefore, pumpability. Microencapsulation of the magnesium oxide in organics was determined to be an effective method for controlling pumpability. The formulations were then optimized with respect to placement and formation temperatures and the resultant mechanical properties of the cured cements.

The work was reviewed at the SNL-organized Hard Rock Penetration Task Industrial Review Panel meeting held in San Diego, California, on February 7-8, 1990. The need for the work and the technical approach for meeting the goals were endorsed by the Panel.

Six potential methods for placement of the advanced chemical systems into fractured zones were identified by SNL. These are listed below: (1) pumped through open drill pipe, (2) pumped through drillable straddle packer, (3) pumped through bit using encapsulated accelerator, (4) pumped through bit using downhole injector, (5) pumped through wireline-deployed porous poker, and (6) pumped through drillstring-deployed porous poker. For each of these methods the pumpability requirements, material quantities, setting times, and operating temperatures were estimated and these needs were then matched with the laboratory identified materials characteristics. Advanced high temperature rapid setting materials suitable for placement using methods 1 and 2 appear to be available today, and they will be tested on a larger scale by SNL in prototype placement equipment in FY 1991. Materials for use with methods 3-5 require additional optimization in FY 1991, but should be ready for prototype testing in FY 1992, in time to meet the Level III Objective.

Planned FY 1990 milestones for this activity are listed below.

- o Selection of material
- o Complete mud displacement tests

Milestone No. 1 was completed although work to optimize the formulation for use with the six potential placement techniques listed above is continuing. Mud displacement tests (Milestone No. 2) were performed in small-scale laboratory equipment, and larger scale testing will be performed in conjunction with SNL in FY 1991.

3. <u>Thermally Conductive Composites for Heat Exchanger Tubing</u>

Milestones planned for FY 1990 are listed below.

- o Issue interim report for Heat Exchanger Test No. 1
- o Selection of modified surface formulation
- o Complete autoclave evaluation of surface-modified formulation
- o Initiate and complete field testing of Heat Exchanger No. 2

Milestones 2 and 3 were completed, the other two delayed. In order to meet these milestones, both required the selection of a field test site and award of a contract by DOE/IDO to the commercial operator of that site (Red Hill Geothermal, Inc.). Both were completed late in FY 1990, but start-up of the field testing of the prototype shell and tube heat exchanger containing 80 ft of lined tubing was delayed until FY 1991. The unit was assembled and installed at the site by INEL. The fluid to be used in the test is at a temperature of 183°C, and has a salt content of ~275,000 ppm. Under heat exchange operations, its scaling and silica deposition rate is 5 in./yr.

Prior to assembly at the Red Hill Geothermal site, INEL performed "base line" testing at the Geothermal Test Facility (GTF). A non-scaling brine was used in this test in order to obtain heat transfer and fluid flow information for a clean tube. The results from these tests which were performed at an inlet temperature of 170°C, indicate that compared to a AL-29-4C tube, the polymer cement lined tubing had a lower heat transfer coefficient and a higher pressure drop. Both characteristics would be expected to improve when industrial-scale fabrication methods are utilized.

4. Corrosion Mitigation at The Geysers

In mid FY 1990, based upon an industrial request to DOE/GD, BNL initiated cost-shared work with the Coldwater Creek Operator Company to determine the technical feasibility for the use of previously developed polymer cement composites for corrosion protection. Two BNL-supplied test sections were installed at the Geysers at locations where failure of 0.5 in. thick wall steel casing generally occurs within 5 weeks. Neither test section failed during a five week test, but some chemical attack on the liners was apparent. The probable cause of this attack was the presence of an excessive amount of portland cement in the formulation and the presence of a significant amount of laitance on the liner surface. Normally, the hydrothermal stability of polymer cements is improved by the addition of insoluble forms of calcium-containing compounds found in portland cement, but acid resistance is decreased. Therefore, for use in a high temperature (170° to 200°C) highly acidic (pH 2-4) environment, an optimization of the formulation with respect to fluid temperature and pH is required. This study is scheduled to be made early in FY 1991 and it will be followed by the field testing of coated test coupons and lined 8-in. diameter x 12-in. long wellhead sections.

In addition to the Coldwater Creek Operator Company, Unocal and the Northern California Power Authority indicated a desire to participate in this program, the results from which should help to mitigate corrosion, thereby making the use of many marginal production wells cost effective while enhancing safety.

5. Geothermal Drilling Organization Elastomer Activities

Work on the development of advanced high temperature drillpipe protectors was essentially completed by the GDO-selected contractor, Regal International. Based upon laboratory and field testing conducted in FY 1989, and a FY 1990 field test, it was concluded that the unavailability of a hydrothermally stable chemical coupling system, needed to bond the elastomers to steel reinforcement, prevented the development of a tool which met the GDO requirements. However, the program increased the operating capability for oil and gas applications, and the tool is being commercialized for those uses.

Development of advanced rotary head seals was continued by A-Z Grant International under contract with the GDO. Two promising elastomers and a bonding system were identified and laboratory tested, a sealing configuration designed, and full-scale seal units fabricated. Large-scale laboratory and field testing will commence in FY 1991.

EXPECTED ACCOMPLISHMENTS IN FY 1991

1. Advanced High Temperature Lightweight Cements

The R&D phases of work on advanced, high temperature (~300°C), lightweight CO_2-resistant cements will be completed. Testing in laboratory autoclaves in which phosphate-modified calcium aluminate cements made pumpable by the addition of either organic or inorganic-type admixtures, are exposed to Na_2CO_3 will be completed. Contingent upon DSIR's ability to successfully remove previously installed samples from their test well, several series of modified calcium aluminate cement samples will be evaluated after a 1 yr exposure to a high CO_2-containing brine at pH ~2.2 and 320°C. Based upon all of the laboratory and field test results, a cement formulation and retarding admixture will be identified for use in larger-scale field tests planned for FY 1992. All results will be published in a peer-reviewed journal.

2. Chemical Systems for Lost Circulation Control

The cooperative effort with SNL and private industry to develop advanced high temperature chemical systems for lost circulation control will be continued. Small-scale laboratory flow tests under simulated downhole placement conditions will be completed. These tests will result in optimization of the previously identified magnesium oxide-borax-bentonite system with respect to placement method, placement and formation temperatures, and the resulting properties when cured. Based upon these data, plans for larger-scale drilling fluid displacement tests which will be performed at SNL will be made.

3. Thermally Conductive Composites for Heat Exchanger Tubing

Work to develop advanced heat exchanger materials for use in binary power cycles will be continued. Field testing by INEL in hypersaline brine of a prototype single-tube shell and tube heat exchanger containing an unmodified surface thermally conductive polymer cement liner will be completed. Contingent upon the results, tubing with a liner modified to enhance the resistance to scale accumulation will be prepared. Field testing will occur in early FY 1992. All results will be documented in a joint INEL/BNL report. Testing of tubing with enhanced heat transfer surfaces (fins, etc.) will commence in FY 1992.

4. Corrosion Mitigation at The Geysers

Ongoing cost-shared activities with private companies at The Geysers focused on the mitigation of HCl-initiated corrosion, will be continued. Laboratory work to select a polymer cement formulation will be completed and field testing of coated test coupons and lined 8 in.-diam x 12-in. long wellhead sections started by Coldwater Creek Operators. Contingent upon the results from these tests, several 10 to 12 ft lengths of 16-in. diam well casing will be lined and installed at the top portion of Coldwater Creek wells. The work will then be expanded to include the installation of lined casing to depths of several hundred feet in FY 1992. The emphasis of this portion of the program will be on the development of techniques for lining 20 to 30 ft sections of casing and for joining lined sections.

Field testing of lined above ground components will also be started. Tees, elbows, flanges and other components subject to erosion as well as corrosion will be lined and placed in test. If successful, the results from this work could be widely applied at The Geysers in FY 1992.

5. High Temperature Chemical Coupling Systems

R&D to develop advanced high temperature hydrolytically stable chemical systems for use in bonding elastomers to steel substrates will commence. The work 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. Work in each element will be performed concurrently.

6. Geothermal Drilling Organization Elastomer Activities

Liaison activities will be continued with SNL and the GDO to transfer GD-sponsored high-temperature elastomer technology to industry so that it can be used for rotating head seals. Key activities that will be monitored in FY 1991 will be the performance in the laboratory of full-size tests on redesigned seals which incorporate the advanced elastomer, and contingent upon these results, the performance of field tests in steam and/or brine.

III FUNDING YEAR RESEARCH PLAN

Descriptions of each of the activities in the Materials Development Project and the FY 1990 and expected FY 1991 accomplishments in each, were given in Section II. Work to be performed in FY 1992, milestones, deliverables, and manpower/funding requirements are summarized below.

1. Advanced High Temperature Lightweight Cements

a. Work Statement

The technology transfer phase of the work on advanced high temperature (~300°C) lightweight CO_2-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 SNL and will be cost-shared with industry. BNL will identify the cement formulation and supply the chemical constituents. SNL will design and supply any specialized placement equipment required; and industry the test well, conventional placement equipment, and field personnel. Laboratory work to develop cements and retarding admixtures for operation at temperatures up to 600°C will continue.

b. Milestones and Deliverables

Accomplishments	Date of Accomplishment
Peer-review publication of FY 1991 work.	12/91
Complete planning for cost-shared field demonstration.	04/92
Placement of cement in demonstration well.	07/92
Peer-review publication.	09/92

c. Funding and Manpower Requirements

The funding level (BA) for FY 1992 required to perform the work outlined above is $150,000. A total of 1.22 man yr will be committed to this Project Activity. These are summarized in Table 2.

2. Chemical Systems for Lost Circulation Control

a. Work Statement

Work on advanced chemical systems for lost circulation control will be completed with the performance of cost-shared efforts with SNL and private industry. Drilling fluid displacement tests will be conducted using SNL-defined injection techniques and placement parameters. If successful, the formulations and injection techniques will be tested in a demonstration well.

b. Milestone and Deliverables

Accomplishment	Date of Accomplishment
Complete mud displacement test with SNL and industry.	10/91
Complete planning for cost-shared field demonstration.	03/92

Complete cost-shared field test.	05/92
Peer-review publication.	08/92

c. Funding and Manpower Requirements

The funding level (BA) for FY 1992 required to perform the work described above is $150,000. A total of 1.22 man yr will be committed to the Project Activity. These are summarized in Table 2.

3. Thermally Conductive Composites for Heat Exchanger Tubing

a. Work Statement

Laboratory R&D efforts focused on improving the operating performance of thermally conductive polymer matrix composites for heat exchange applications will be continued. Based upon experimental data that will be obtained in the FY 1991 field test of a prototype single tube shell and tube heat exchanger, work will be performed to further improve the thermal and fluid flow properties of centrifugally cast composite lined tubing. Work to reduce scale accumulation on tubing surfaces by the addition of anti-oxidants will also be conducted. Contingent upon the results from these studies, a field test of tubing lined in accordance with the improved materials and fabrication procedures defined above, will be performed as a cooperative effort with INEL.

b. Milestone and Deliverables

Accomplishment	Date of Accomplishment
Issue interim report on HX-1	10/91
Complete thermal conductivity measurements for centrifugally-cast liners	2/92
Identification of optimized formulation	5/92
Fabrication of tubing for HX-2 field test	6/92
Initiate field test for HX-2	8/92
Issue interim report	9/92

c. Funding and Manpower Requirements

The funding level (BA) for FY 1992 required to perform the work described above is $165,000. A total of 1.34 man yr will be committed to the Project Activity. These are summarized in 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 Coldwater Creek Operators, the downhole testing of prototype sections of polymer cement-lined 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.

Work with NCPA to evaluate the use of errosion/corrosion-resistant liners on wellhead and other above-ground components will also be continued.

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

Accomplishment	Date of Accomplishment
Installation of lined casing string for downhole evaluation.	10/91
Installation of lined above ground components.	02/92

Commence downhole testing of CO_2-resistant well cements.	05/92
Issue interim report.	09/92

c. Funding and Manpower Requirements

The total funding level (BA) for FY 1992 required to perform the work described above is $110,000. It is assumed that the funding source for this activity will be Reservoir Technology (AM-10-03). A total of 0.90 man yr will be committed to the Project Activity. These are summarized in Table 2.

5. Advanced High Temperature Coupling Systems

a. Work Statement

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

b. Milestones and Deliverables

Accomplishment	Date of Accomplishment
Complete characterization of metal/ bonding agent/elastomer interfaces.	10/91
Initiate long-term autoclave testing.	11/91
Identification of most promising bonding system.	05/92
Cost-shared testing for drill pipe protector applications.	08/92
Peer-review publication.	09/92

c. Funding and Manpower Requirements

The funding level (BA) for FY 1992 required to perform the work described above is $175,000. A total of 1.43 man yr will be committed to the Project Activity. These are summarized in Table 2.

6. Geothermal Drilling Organization Elastomer Activities

a. Work Statement

Liaison activities will be continued with SNL and the GDO to transfer GD-sponsored elastomer technology to industry so that it can be utilized in a variety of advanced geothermal tools. This linkage will also be used to initiate the transfer of high temperature chemical coupling system technology developed in Activity 5 which was described above.

b. Milestones and Deliverables

Accomplishment	Date of Accomplishment
Commercial availability of advanced rotating head seal	4/92

c. Funding and Manpower Requirements

Funding to cover BNL liaison activities is not included in the Geothermal Materials Project budget but is provided by SNL. The estimated cost at BNL will be $10,000. The estimated manpower requirement for the Project Activity will be 0.08 man yr.

Table 2. Summary of FY 1992 Funding and Manpower Requirements

	Activity	Funding, $K	Manpower Man-yr
1.	Advance High Temperature Lightweight Cements	150	1.22
2.	Chemical Systems for Lost Circulation Control	150	1.22
3.	Thermally Conductive Composites	165	1.34
4.	Corrosion Mitigation at The Geysers	110[a]	0.9
5.	GDO Elastomer Activities	[b]	
6.	High Temperature Chemical Coupling Systems	175	1.43
	Total	750[c]	6.1

a, Funding source, Reservoir Technology
b, SNL funded, $10K. Not included in total given below
c, Materials Project $640K, Reservoir Technology $110K

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.

Fical 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.

EXHIBIT I

BROOKHAVEN NATIONAL LABORATORY

Organizational Description

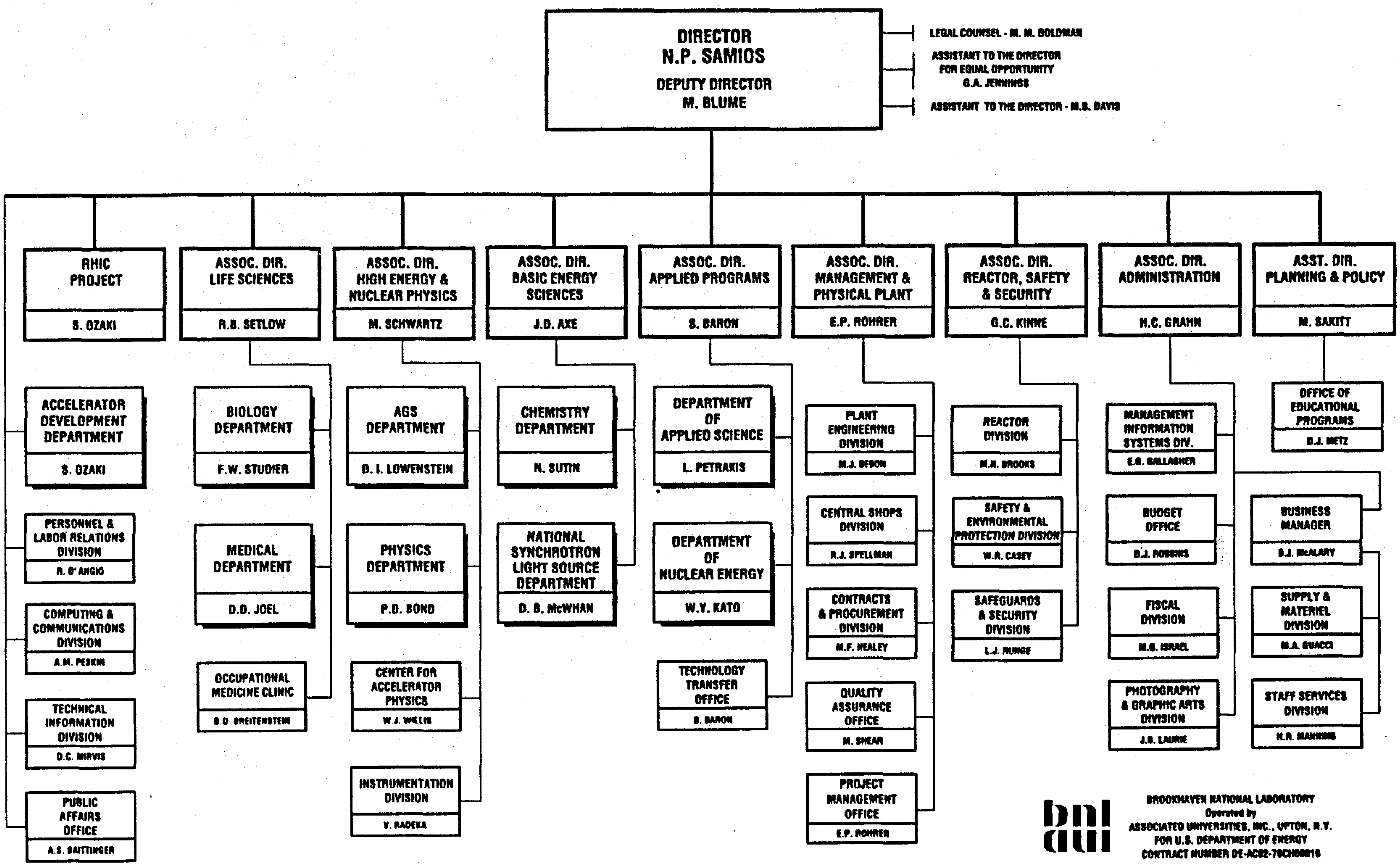
Brookhaven National Laboratory is Operated by Associated Universities, Inc. under contract with the United States Department of Energy. Nine northeastern universities sponsor Associated Universities, Inc. The Board of Trustees consists of the President *ex officio* and two individuals from each university, 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. McAlary, Business Manager, Brookhaven National Laboratory.

EXHIBIT II

BROOKHAVEN NATIONAL LABORATORY



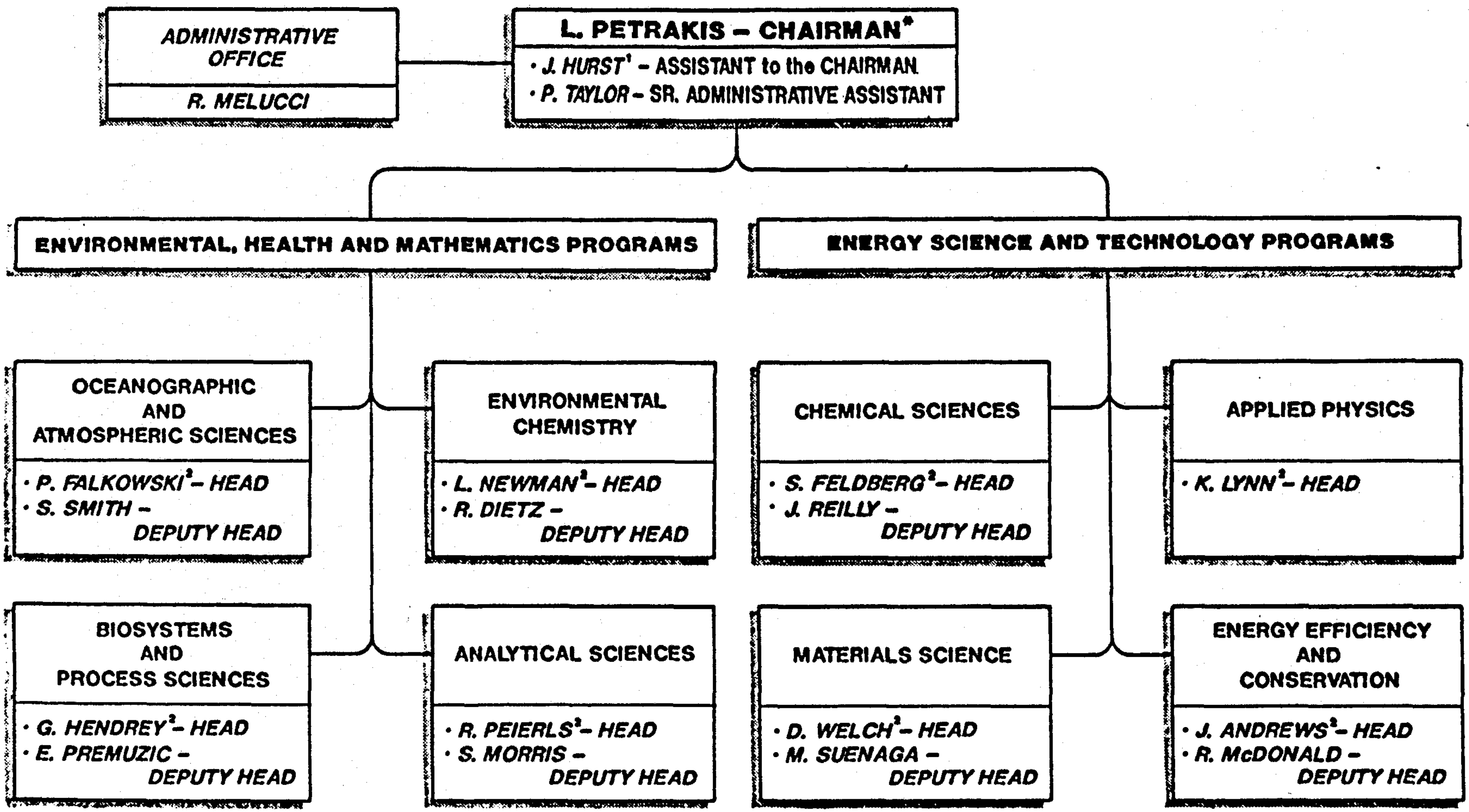
BROOKHAVEN NATIONAL LABORATORY
Operated by
ASSOCIATED UNIVERSITIES, INC., UPTON, N.Y.
FOR U.S. DEPARTMENT OF ENERGY
CONTRACT NUMBER DE-AC02-76CH00016

N.P. Samios

APRIL 1, 1991

EXHIBIT III

DEPARTMENT OF APPLIED SCIENCE



10/1/90

L Petrakis

(1) *Safety and Quality Assurance*

(2) *Departmental Council Members*

**Reports to S. Baron, Assoc. Dir., Applied Programs*

Taylor of the Idaho Falls Operations Office (IDO) (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. Safety and Environmental Protection Management

Safety requirements and procedures for the Materials Project are as defined in the BNL Safety Manual. The primary responsibility for assuming that these requirements are met lies with the Principal Investigator. Assurance that compliance is occurring results from quarterly safety and environmental protection inspections conducted by the Department of Applied Science safety coordinators and members of the BNL Safety and Environmental Protection Division. Summaries of their findings and the corrective measures taken are reviewed by the Division Head and Department Chairman.

DOE/GD review of the project safety procedures is provided by inspections made by Kenneth J. Taylor of IDO and/or his authorized representative from the DOE Brookhaven Area Office.

4. 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 1992 of $40,000 is requested. Equipment needed, the purpose, and the cost for each item are summarized below.

A mechanical testing machine capable of measuring the compression, tensile and flexural properties of inorganic and organic matrix composites is needed to replace an old obsolete machine. Replacement is necessary to meet quality assurance criteria. The cost of this unit is $20,000.

A Vicat apparatus is needed for use in measurements of the setting times of well cements, advanced lost circulation control materials and pre-ceramic coating systems. This equipment costs $5,000.

A new electron collector unit for an existing X-Ray Photoelectron Spectrometer is needed to replace an obsolete one. This will improve sensitivity by 2 to 3 times thereby enhancing our ability to study the interfaces in cement matrix composites and for the bonding of elastomers to steels. The cost for the equipment is $15,000.

No additional project management resources are required at BNL. GD and IDO requirements have not been defined.

5. Procurement Plan Summary

The three pieces of capital equipment described above will be ordered as soon as FY 1992 funding authorization is received. Other than normal materials and supplies, no other major procurements are planned.

6. Subcontracting Plan

No subcontracts are anticipated.

7. Schedules of Conferences and Technical Review

Three 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. A second will be held at BNL. Participation in the Annual GD Program Review is also planned. Other review meetings will be held with GD Staff at their convenience.

8. 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 Council[1], 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. This will be done by the continued utilization of industry advisory panels, professional societies, and government-industry cooperative groups such as the 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

During the period FY 1993 - 1997, emphasis will be placed upon the development and field demonstration of the following (1) high temperature (~600°C) cements, (2) lost-circulation control materials, (3) metallic and composite liners for mild steel well casing, (4) elastomeric and castable

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

ceramic well lining materials and (5) hydrolytically stable chemical bonding ceramic well lining materials and (5) hydrolytically stable chemical bonding systems for downhole tools and safety devices. Materials needs constraining operations at The Geysers will also be addressed.

The work will be coordinated with SNL and performed as cost-shared activities with geothermal energy producers and companies supplying equipment and services to those companies.

Milestones	FY 93	FY 94	FY 95	FY 96	FY 97
High temperature cements	1			2	
Advanced lost-circulation control	3		4		
Well liner materials		5			6
Well drilling and safety device elastomers	7		8		9

1,2 Complete cost-shared field placements of advanced CO_2-resistant lightweight cements for 300° and 600°C aplications.

3,4 Complete cost-shared demonstrations of materials in hydrothermal and magma well drilling operations.

5,6 Complete downhole testing of composite, elastomeric and ceramic well liner systems.

7 Identification of advanced chemical bonding systems.

8,9 Field testing of elastomer/bonding systems in downhole drillmotors and blow-out preventors.

Resource Plan ($ in Thousands)	FY 93	FY 94	FY 95	FY 96	FY 97
Operating Budget	$755	$800	$800	$800	$850
Capital Budget	50	30	30	30	0