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GEOTHERMAL LOGGING INSTRUMENTATION DEVELOPMENT PROGRAM PLAN (U)

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Sandia Laboratories

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GEOTHERMAL LOGGING INSTRUMENTATION

DEVELOPMENT PROGRAM PLAN

SAND78-0316

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Abstract

This Geothermal Logging Instrumentation Development Program Plan outlines a nine-year, industry-based program to develop and apply high temperature instrumentation technology which is needed by the borehole logging industry to serve the rapidly expanding geothermal market. Specifically, this program will upgrade existing materials and sondes to improve their high-temperature reliability. To achieve this goal specialized equipment such as high temperature electronics, cables and devices for measuring formation temperature, flow rate, downhole pressure, and fractures will be developed. In order to satisfy critical existing needs, the near-term (FY80) goal is for operation at or above 275°C in pressures up to 48.3 MPa (7,000 psi). The long-term (FY84) goal is for operation up to 350°C and 138 MPa (20,000 psi). This program plan has been prepared for the Department of Energy's Division of Geothermal Energy (DGE) and is a portion of the DGE long-range Geothermal Well Technology Program.

GEOTHERMAL WELL TECHNOLOGY

Logging Instrumentation Development Program Plan
(FY78 to FY86)

FIGURES

TABLES

GEOTHERMAL WELL TECHNOLOGY
LOGGING INSTRUMENTATION DEVELOPMENT PROGRAM PLAN

I. INTRODUCTION

Development of the earth's geothermal resources as a significant alternative source of energy requires well logging to obtain borehole measurements of those physical and chemical properties required for geothermal reservoir evaluation and production. Together with suitable interpretation, logging data provides a primary source of information for the following key areas of geothermal energy development:

1) Exploration
2) Well testing for reservoir assessment and confirmation
3) Reservoir development and management
4) Environmental, legal and institutional problems

Well logging is indispensable for determining reservoir rock and fluid properties in order to assess the size and production potential of a geothermal resource. Well logs also provide vital information for decisions regarding location of wells as a field is developed and for decisions concerning drilling and completion techniques. In addition, well logging provides important information required for quantitative reservoir modeling and may provide valuable data bearing on environmental, legal and institutional problems, such as information needed to preclude inadvertant thermal and chemical pollution of potable ground water.

Methods for obtaining borehole measurements and making the appropriate interpretations are limited at present by technical deficiencies in that logging tools developed for the oil and gas industry rarely encounter temperatures above 150°C. In geothermal wells, temperatures frequently range up to 350°C, but most of the logging tools, cables and seals are rated only to 180°C. Above their temperature rating in the corrosive "hostile" environment of a geothermal well, logging tools and cables have significantly reduced reliability and life expectancy. These deficiencies, as well as the less than satisfactory results obtained through the use of existing "hostile" environment logging tools in geothermal wells, were confirmed by the 1975 Geothermal Workshop hosted by Sandia Laboratories and reported in Reference 1.

Industries that are expected to make major financial investments in geothermal power plants, space heating or process heating are not inclined to risk large sums on development without confidence that geothermal resources exist with temperatures, flow rates and production longevity sufficient for long-term commericial operation. It is the purpose of the Geothermal Logging Instrumentation Development Program to provide the means to establish that confidence with information from new and improved borehole logging tools which operate in hot, corrosive geothermal reservoirs.

The existing highly developed hydrocarbon and mineral logging instrumentation services and their interpretation procedures form the basis for the technical developments in this program. Research in geothermal reservoir engineering and log interpretation is being pursued by the evolving geothermal production industry. In addition, the logging service companies are conducting in-house R&D to correct technical deficiencies so they may adequately serve the geothermal market. The technical impediment they face involves special technologies which are not normally required in their trade. These technologies are precisely those which will be developed by this program.

Specifically, this program will upgrade existing materials and sondes for improved high-temperature reliability, as well as develop more specialized equipment such as high temperature electronics, cables and devices for measuring formation temperature, flow rate, high resolution downhole pressure, and fracture mapping. Our strategy emphasizes direct cooperation with the geothermal production and logging service industries where the technology needs and applications exist.

In establishing its design goals and overall direction, the Geothermal Logging Instrumentation Development Program will address the needs of geothermal reservoir engineering through formal participation in the Reservoir Engineering Management Program under the responsibility of the Lawrence Berkeley Laboratory (LBL). Also, the borehole measurements obtained in this program's geothermal well field tests will contribute to the data base of the Geothermal Log Interpretation Program underway at the Los Alamos Scientific Laboratory (LASL). Geothermal logging was determined to be the highest priority R&D item for both the Well Testing and Borehole Geophysics Tasks in the Second Task Force Meeting of the Reservoir Engineering Management Program August 4-5, 1977, at LBL.

II. PROGRAM SUMMARY

A. Scope

Sandia Laboratories will organize and operate an industry based program in geothermal logging to provide logging instrumentation technology capable of obtaining the required borehole measurements so that the characteristics of geothermal reservoirs can be reliably assessed. The program's technical developments and field test activities will also be directed toward fulfilling the requirements of geothermal reservoir engineering for logging systems for both open and cased hole services. Much of the development and service activity will be contracted to industry with work done by Sandia and other DOE laboratories to expedite the industry effort with complementary or supportive research, development and testing. Specific program goals for technical development, application and commercialization are set forth by a steering committee with members from geothermal production and operation industries, the well logging service companies, universities, DGE and DOE laboratories.

This program also provides for the technical management by Sandia Laboratories of on-going DGE logging instrumentation development contracts with industry and universities. This management responsibility includes project reviews and recommendations for broadening the scope, expediting, redirecting and terminating support of program elements as indicated by the program's goals and priorities, available funds, development schedules and project performance. Consistent with this plan and within existing budget constraints, new projects will be initiated as necessary to achieve the program's goals.

Overall programmatic responsibility will be with DGE's Geothermal Well Technology Program Manager. Sandia will be responsible for conducting this logging instrumentation program with appropriate management and fiscal authority and approval from DGE.

B. Objective

The primary objective of this program is to accelerate the near-term commercial development of the nation's geothermal resources by providing reliable logging technology for industrial operation in geothermal boreholes. The near-term performance goals include operation at temperatures at or above 275°C in pressures up to 48.3 MPa (7,000 psi) by the end of FY80. Eventual goals for this program include operational temperatures up to 350°C and pressures up to 138 MPa (20,000 psi) by the end of FY84. A list of borehole parameters desired for open borehole exploration and reservoir evaluation is given in Table II-1 in the order of their priority. This list was compiled by the 1975 Geothermal Workshop and updated by the steering committee at their June 28, 1977, meeting. The repertoire of tools, their development priority and performance requirements are described below under Program Task 2.

C. Strategy

In order to achieve the objective of this program, the logging needs of the geothermal community must be identified and addressed in a manner which will lead to early use by industry.

1. Establishing Needs for Logging Instrumentation

Making measurements in geothermal wells is the final step in a process that begins with the needs of reservoir assess-

Table II-1. Borehole Parameter Priorities

Priorities may vary among resource types. However, certain parameters are essential for evaluation of most geothermal resources. These are arranged to indicate ranking and importance.

1. Formation Temperature
2. Formation Pressure
3. Flow Rate
4. Hole Geometry (may be critical in log interpretation)
5. Fracture System (location, orientation, permeability, etc.)
6. Fluid Composition (pH, dissolved solids and gases)
7. Permeability
8. Porosity (interconnected and isolated)
9. Formation Depth and Thickness

Other parameters which are important but which may not need to be measured in every well or which may be reliably predicted or calculated from other physical parameters include:

1. Thermal Conductivity
2. Electrical Conductivity or Resistivity
3. Heat Capacity
4. Lithology and Mineralogy
5. Acoustic Wave Velocity

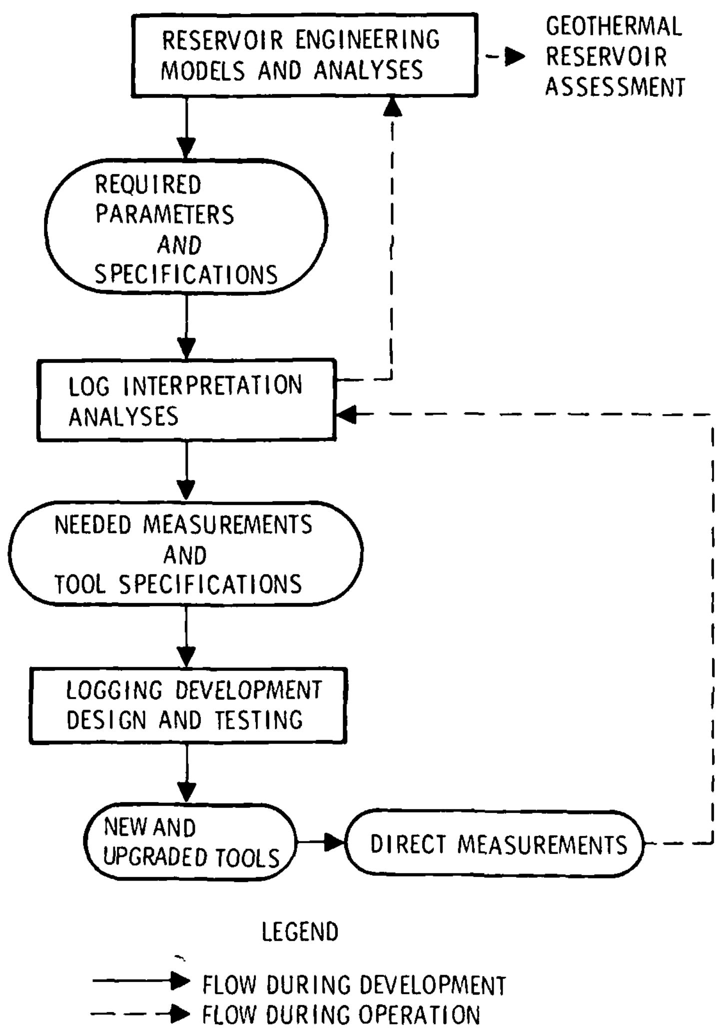
ment. Figure II-1 is a schematic of this process. Reservoir engineers develop models to aid in resource assessment. The result of analysis of these models is a list, such as Table II-1, of important parameters that must be determined in the well bore. A set of specifications which accompanies the parameters list contains the accuracy and tolerances to which the parameters must be known. The function of log interpretation is to deduce the desired parameters from those physical properties that can be directly measured in the well. The result of this interpretation analysis is a list of needed direct measurements with specifications. It is the task of logging instrumentation development to provide tools capable of making the desired direct measurements to the needed specifications.

In the oil and gas industry, the reservoir needs, interpretation techniques and tools required are well defined and highly developed. This is not the case in the infant geothermal industry, however. Reservoir models are not well developed, interpretation of even standard logs is not well understood and deficiencies exist in the capability to make most direct measurements.

2. Program Approach

The approach taken in this program has begun with establishing the logging needs of geothermal reservoir engineering through the auspices of the Geothermal Logging Instrumentation Steering Committee, logging workshops and direct contacts with geothermal producers, logging service companies, DGE's Reservoir Engineering Management Program, DGE's Geothermal Log Interpretation Program and DGE's Regional Program Managers. After the instrumen-

FIGURE II-1. GEOTHERMAL LOGGING ACTIVITIES FLOWCHART



tation needs are identified, industry's ability to fulfill these needs will be assessed to identify key technological deficiencies, such as temperature limited cables, electronics, and elastomeric seals. Finally, specific program elements will be directed toward correcting these deficiencies with emphasis on extensive industry participation in development and field demonstration. Periodic reviews of each program element are scheduled to assure that these logging needs are adequately addressed, refined and revised during the course of the program.

3. <u>Acceleration of Technical Developments</u>

The activities of the Geothermal Logging Instrumentation Development Program will be directed to stimulate and accelerate the rate of technical development in geothermal logging to support near-term goals of the federal geothermal program. This will be accomplished by (a) testing and evaluation of existing devices, materials and components in prototype systems for suitability to geothermal logging applications, and making these test results available to the logging industry; (b) doing prototype circuit and system development to exploit unique capabilities that exist at certain private companies and the national laboratories; and (c) testing and evaluating logging systems to prove out designs and provide an organized, standardized framework for calibration and normalization of logging tools.

All of these activities will provide direct input to the research that is underway in the logging industry and will accelerate, complement, and enhance the technological developments now occurring.

4. Integration of Technical Participants

Although the logging tool development and serive companies possess the requisite technical competence to address the many technical deficiencies in the present state of the goethermal logging art, much the needed basic technology is already available through industries unrelated to logging, as well as through DOE laboratories. This program's approach is to combine the know-how of logging tool development and service companies with specific technical abilities in other unrelated companies and the components, materials science and system integration capabilities of Sandia and other DOE laboratories. These technical resources will be directed to addressing key technical deficiencies, demonstrating prototype hardware solutions, transferring the technology to industry and stimulating commercial geothermal logging services.

Experimental prototypes will be tested in appropriate geothermal boreholes. Early tests will be conducted by Sandia with service industry representatives in attendence. To stimulate a market for geothermal logging services, other tests will be contracted to industry through Sandia. The results of these experimental tests will be made available to log interpreters both in industry and in DOE laboratories. Sandia will coordinate its efforts with all participants to assure this programmatic integration.

D. Schedule and Budget

Figures II-2 and II-3 indicate the schedule and Level A zero based minimum budget necessary to sustain an effective development program. The schedule and Level B zero based budget required to achieve the program's goals for both 275°C and 350°C developments are shown in Figures II-4 and II-5, respectively. Table II-2 lists the program milestones shown in Figures II-2 and II-4. Detailed descriptions of these development activities are given in the Technical Plan, Section IV-B.

As shown in Figure II-4, most of the 275° activities are planned to yield maximum results in the period FY79 to FY82. From FY82 to FY85, the program emphasizes field testing, evaluation, commercialization and technology transfer along with continued advanced development such as fracture mapping.

FY80 will mark the beginning of strong efforts to achieve capability up to 350°C. Most of the supporting device and component developments will be completed before the end of FY84, but prototype design and testing will continue through FY86 with follow-on activities needed to carry these projects to completion.

With the Level A minimum budget, funds are allocated toward the highest priority program elements: 275°C components development, design and fabrication of a minimum number of critically needed prototype sondes, and field tests to verify the performance of the new technology and commercialize the high temperature electronics. Program elements that are not critical to achieving 275°C capability for basic temperature, pressure, and flow tools are delayed or dropped entirely. Comparison of Figures II-2 and II-4 shows that the minimum budget significantly delays the development of prototype instruments. Such a delay will adversely affect other DGE programs in reservoir engineering and log interpretation. In addition, the minimum budget will result in at

FIGURE II-2. GEOTHERMAL WELL TECHNOLOGY LOGGING INSTUMENTATION PROGRAM SCHEDULE WITH LEVEL A BUDGET

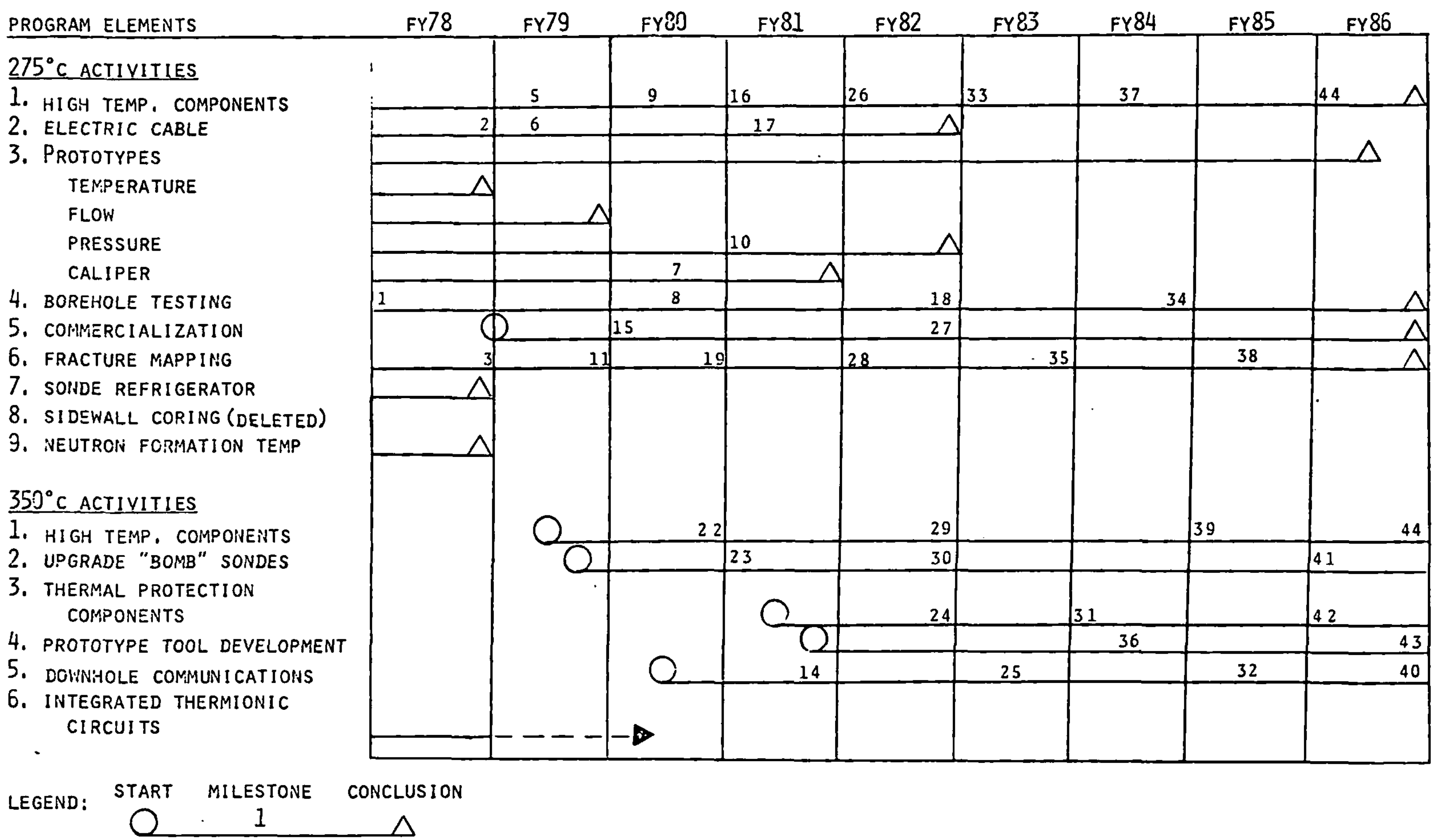


FIGURE II-3. TOTAL PROGRAM COSTS - LEVEL A BUDGET (CONSTANT FY78 DOLLARS IN THOUSANDS)

PROGRAM ELEMENTS	ACTUAL FY77	BUDGETED FY78	EST. FY79	EST. FY80	EST. FY81	EST. FY82	EST. FY83	EST. FY84	EST. FY85	EST. FY86	PROGRAM TOTALS
275°C ACTIVITIES											
1. HIGH TEMPERATURE COMPONENTS	427	359	400	450	400	200	200	150	150	150	2886
2. ELECTRIC CABLE TESTS & DEVELOPMENT	159	60	95	125	100	100	0	0	0	0	9 639
3. PROTOTYPE TOOL DEVELOPMENTS	708	195	250	300	155	100	100	100	100	50	2058
4. BOREHOLE TEST & EVALUATION	88	75	70	100	155	175	225	225	225	275	1613
5. COMMERCIALIZATION	0	0	75	125	175	175	125	100	50	50	875
6. FRACTURE MAPPING	97	123	200	250	375	375	350	325	325	275	2695
7. SONDE REFRIGERATOR	121	145	0	0	0	0	0	0	0	0	266
8. SIDEWALL CORING	0	0	0	0	0	0	0	0	0	0	0
9. NEUTRON FORMATION TEMP TOOL	86	45	0	0	0	0	0	0	0	0	131
SUBTOTAL	1686	1002	1090	1350	1360	1125	1000	900	850	800	11163
350°C ACTIVITIES											
1. HIGH TEMPERATURE COMPONENTS	0	0	150	200	370	450	550	600	650	650	3620
2. UPGRADE "BOMB" TYPE SONDES	0	0	50	125	160	225	250	250	250	250	1560
3. THERMAL PROTECTION COMPONENTS	0	0	0	0	80	175	175	175	175	175	955
4. PROTOTYPE TOOL DEVELOPMENT	0	0	0	0	80	200	250	300	300	300	1430
5. DOWNHOLE COMMUNICATIONS	196	0	0	100	200	300	300	300	300	300	1996
6. INTEGRATED THERMIONIC CIRCUITS	220	225	0	0	0	0	0	0	0	0	445
SUBTOTAL	416	225	200	425	890	1350	1525	1625	1675	1675	10006
PLANNING & MANAGEMENT	40	190	210	225	250	275	275	275	275	275	2290
TOTAL COSTS	2142	1417	1500	2000	2500	2750	2800	2800	2800	2750	23459

FIGURE II-4. GEOTHERMAL WELL TECHNOLOGY LOGGING INSTRUMENTATION PROGRAM SCHEDULE WITH LEVEL B BUDGET

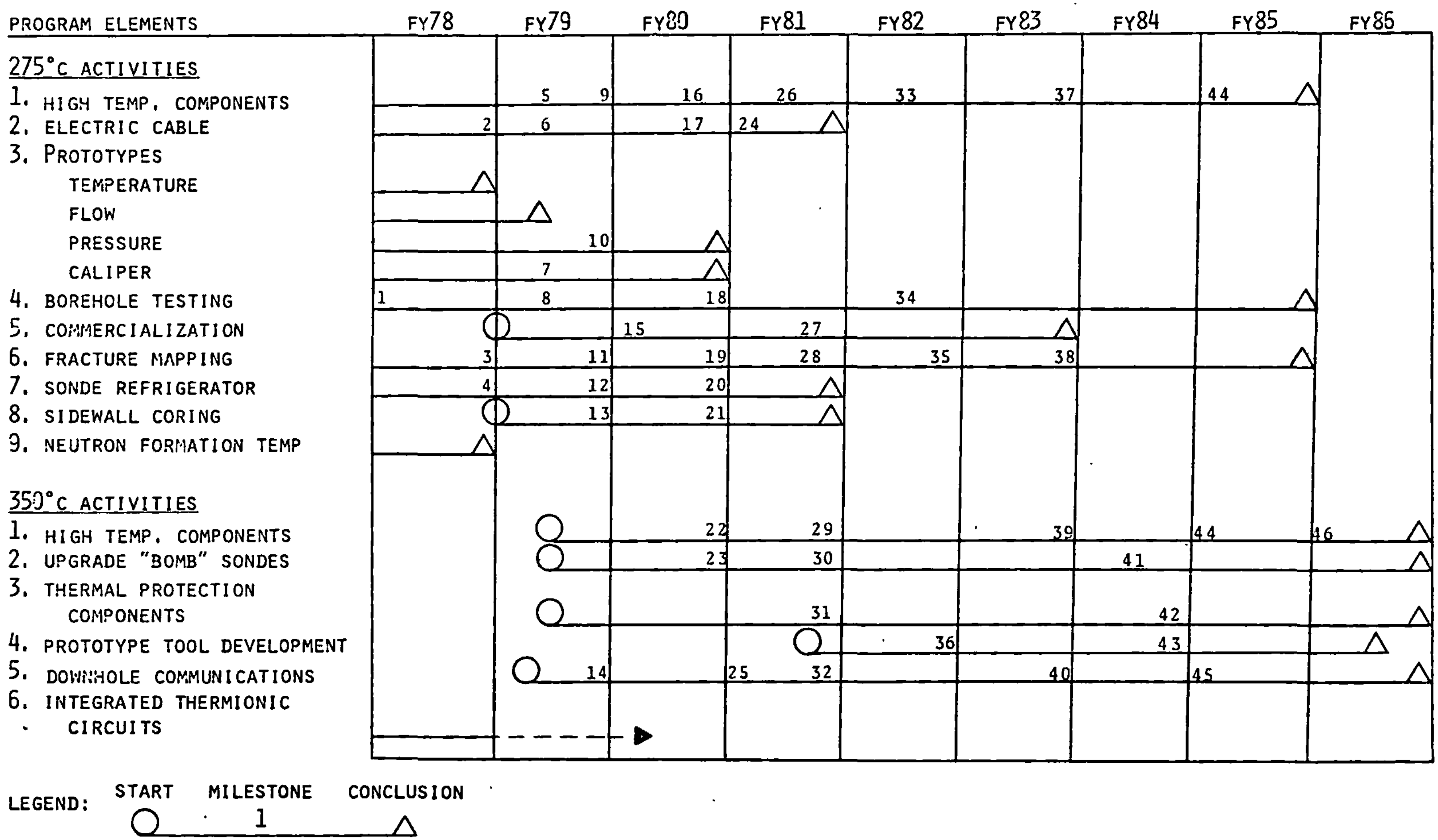


FIGURE II-5. TOTAL PROGRAM COSTS - LEVEL B BUDGET (CONSTANT FY78 DOLLARS IN THOUSANDS)

PROGRAM ELEMENTS	ACTUAL FY77	BUDGETED FY78	EST. FY79	EST. FY80	EST. FY81	EST. FY82	EST. FY83	EST. FY84	EST. FY85	EST. FY86	PROGRAM TOTALS
275°C ACTIVITIES											
1. HIGH TEMPERATURE COMPONENTS	427	359	450	450	400	250	150	150	150	0	2786
2. ELECTRIC CABLE TESTS & DEVELOPMENT	159	60	175	175	75	0	0	0	0	0	644
3. PROTOTYPE TOOL DEVELOPMENTS	708	195	250	375	125	125	75	0	0	0	1853
4. BOREHOLE TEST & EVALUATION	88	75	175	225	300	325	275	175	175	0	1813
5. COMMERCIALIZATION	0	0	125	175	200	175	125	0	0	0	800
6. FRACTURE MAPPING	97	123	275	325	450	450	400	350	175	0	2645
7. SONDE REFRIGERATOR	121	145	150	150	200	0	0	0	0	0	766
8. SIDEWALL CORING	0	0	125	125	175	0	0	0	0	0	425
9. NEUTRON FORMATION TEMP TOOL	86	45	0	0	0	0	0	0	0	0	131
SUBTOTAL	1686	1002	1725	2000	1925	1325	1025	675	500	0	11863
350°C ACTIVITIES											
1. HIGH TEMPERATURE COMPONENTS	0	0	200	250	400	600	650	600	500	375	3575
2. UPGRADE "BOMB" TYPE SONDES	0	0	100	100	200	250	250	250	200	150	1500
3. THERMAL PROTECTION COMPONENTS	0	0	75	75	125	225	175	175	150	150	1150
4. PROTOTYPE TOOL DEVELOPMENT	0	0	0	0	150	300	250	250	175	175	1300
5. DOWNHOLE COMMUNICATIONS	196	0	125	175	275	350	400	350	275	200	2346
6. INTEGRATED THERMIONIC CIRCUITS	220	225	0	0	0	0	0	0	0	0	445
SUBTOTAL	416	225	500	600	1150	1725	1725	1625	1300	1050	10316
PLANNING & MANAGEMENT	40	190	275	300	325	350	350	300	200	200	2530
TOTAL COSTS	2142	1417	2500	2900	3400	3400	3100	2600	2000	1250	24709

TABLE II-2. PROGRAM MILESTONES

(REFER TO FIGURES II-2 AND II-4 FOR PROGRAM SCHEDULE)

NUMBER	MILESTONE
1.	FIRST FIELD TEST OF TEMPERATURE SONDES
2.	START OF CABLE TESTING
3.	REVIEW ACOUSTIC FRACTURE MAPPING DEVELOPMENTS, START NEW CONTRACT
4.	SONDE REFRIGERATOR DEVELOPMENT REVIEW & CONTRACT DECISION
5.	PUBLISH PROPOSED INDUSTRY STANDARD FOR HYBRID THICK FILM TECHNOLOGY
6.	CABLE TESTING DOCUMENTED & R&D STARTED
7.	4-ARM CALIPER COMPLETED, 6-ARM DESIGN REVIEW & DECISION
8.	INTERIM FIELD TEST REPORT PUBLISHED
9.	CONDUCT HIGH TEMPERATURE ELECTRONICS WORKSHOP
10.	FIELD TEST HIGH RESOLUTION PRESSURE SONDE UP TO 275°C
11.	FIELD TEST UPGRADED BOREHOLE TELEVIEWER
12.	FIELD TEST SONDE REFRIGERATOR
13.	SIDEWALL CORING DESIGN REVIEW
14.	FIBER OPTIC CABLE DESIGN REVIEW
15.	REVIEW COMMERCIALIZATION RESULTS, EVALUATE PRODUCTS & TESTS, INITIATE NEW CONTRACT
16.	SEMICONDUCTOR DEVICE DEVELOPMENT REPORT PUBLISHED
17.	FIELD TEST ELECTRIC CABLE
18.	FIELD TEST REPORT PUBLISHED COVERING 275°C SONDES
19.	FRACTURE MAPPING ALTERNATIVE TECHNIQUES STUDY DOCUMENTED
20.	ALTERNATE REFRIGERATOR WORKING FLUID INVESTIGATION COMPLETED
21.	FIELD TEST SIDEWALL CORING TOOL
22.	CANDIDATE ALLOY SEMICONDUCTOR INVESTIGATION DOCUMENTED
23.	TEMPERATURE & LOW RESOLUTION PRESSURE SONDES UPGRADED
24.	INTERIM REPORT PUBLISHED ON MATERIALS APPLICATIONS

NUMBER	MILESTONES
25.	LAB TEST FIBER OPTIC CABLE, REVIEW INTERFACE DESIGNS
26.	275°C PASSIVE ELECTRONICS DEVELOPMENT COMPLETED
27.	"TYPICAL" 275°C PASSIVE CIRCUIT TECHNOLOGY COMMERCIALIZED
28.	INTERIM REPORT PUBLISHED ON BOREHOLE TELEVIEWER EVALUATION
29.	COMPLEMENTARY METAL OXIDE SEMICONDUCTOR (CMOS) CIRCUIT OPERATED TO 350°C
30.	BOMB SONDES FIELD TEST TO 275°C
31.	FIELD TEST ADVANCED THERMAL PROTECTION TO 300°C
32.	FIELD TEST FIBER OPTIC BOREHOLE COMMUNICATION SYSTEM
33.	HYBRID THICK FILM & JUNCTION FIELD EFFECT TRANSISTOR DEVELOPMENT COMPLETED
34.	INTERIM FIELD TEST REPORT PUBLISHED
35.	BOREHOLE TELEVIEWER DEVELOPMENT COMPLETED
36.	FIELD TEST 350°C TEMPERATURE & LOW RESOLUTION PRESSURE TOOLS
37.	275°C SEMICONDUCTOR INTEGRATED CIRCUIT INTERIM REPORT
38.	ACOUSTIC FRACTURE MAPPING DEVELOPMENT COMPLETED, ALTERNATE TECHNIQUE INTERIM REPORT DOCUMENTED
39.	FIELD TEST CMOS SONDE
40.	FIELD TEST FIBER OPTIC LOGGING SYSTEM
41.	FIELD TEST BOMB SONDES TO 350°C
42.	FIELD TEST DEWAR-HEAT SINK SYSTEM TO 350°C
43.	FIELD TEST 350°C HIGH RESOLUTION PRESSURE TOOL
44.	ELECTRONICS WORKSHOP
45.	FIELD TEST MULTIPLEXER OPERATED SYSTEM
46.	350°C PASSIVE ELECTRONICS & PACKAGING DEVELOPMENT COMPLETE

least a one year delay in the program's 275°C activities, cancellation of further sonde refrigerator development after FY78, and elimination of sidewall coring tool development. The 350°C activities are delayed at least two years along with a cutback in fiber optics development. Commercialization of new technology will, of course, also be delayed.

Figure II-6 lists presently funded projects for which Sandia accepted technical management responsibility beginning in FY78. Expiration times are shown as well as the related major program task from Section IV-B. Anticipated contract activities over the next five years are shown in Figure II-7. Each project is listed with its associated program priority. Priority definitions are as follows:

1. Projects which are critically important to satisfy immediate needs at 275°C for temperature, pressure, flow, and caliper measurements. These projects can be accomplished relatively quickly or with moderate expenditures at low risk.
2. Projects which are important to satisfy other needs at 275°C or above. The development cycle is longer, funding requirements are greater, or the risk is higher than for priority 1.
3. Projects which may be important to satisfy needs up to 350°C. The development cycle is longer, high levels of funding will be required, and the risk is high.

E. Activities Summary

The following are brief descriptions of the program activities

FIGURE II-6. PRESENTLY FUNDED CONTRACTS

Contract Subject (Contractor)	Related Program Task
1. Passive Devices (U of Arizona)	1
2. Sonde Refrigeration (MRI)	2
3. Fiber Optics (SWRI)	1
4. Neutron-Formation Temp. (IRT)	2
5. Passive Sondes (SSS)	2
6. Ceramic Tube Amplifier (MRI)	2
7. Heat Flux and Thermal Conductivity (Geoscience)	2
8. Chemical Temp. Sensor (Spectro Systems)	2
9. Acoustic Tools (Westinghouse)	2

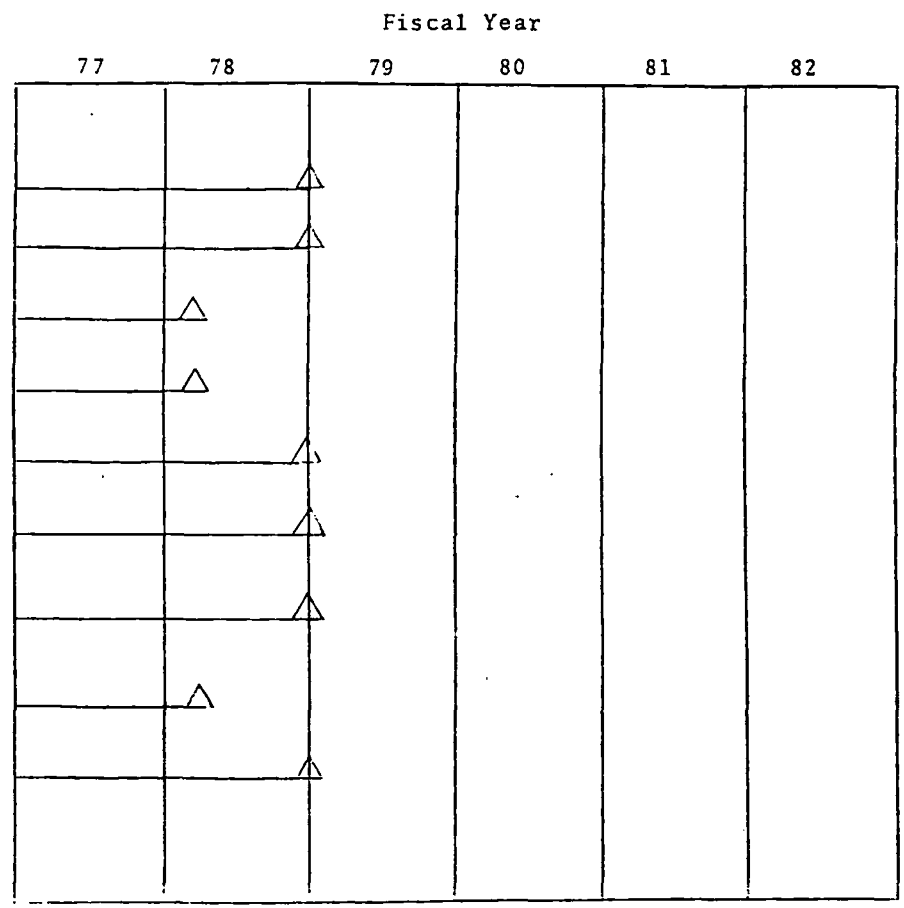
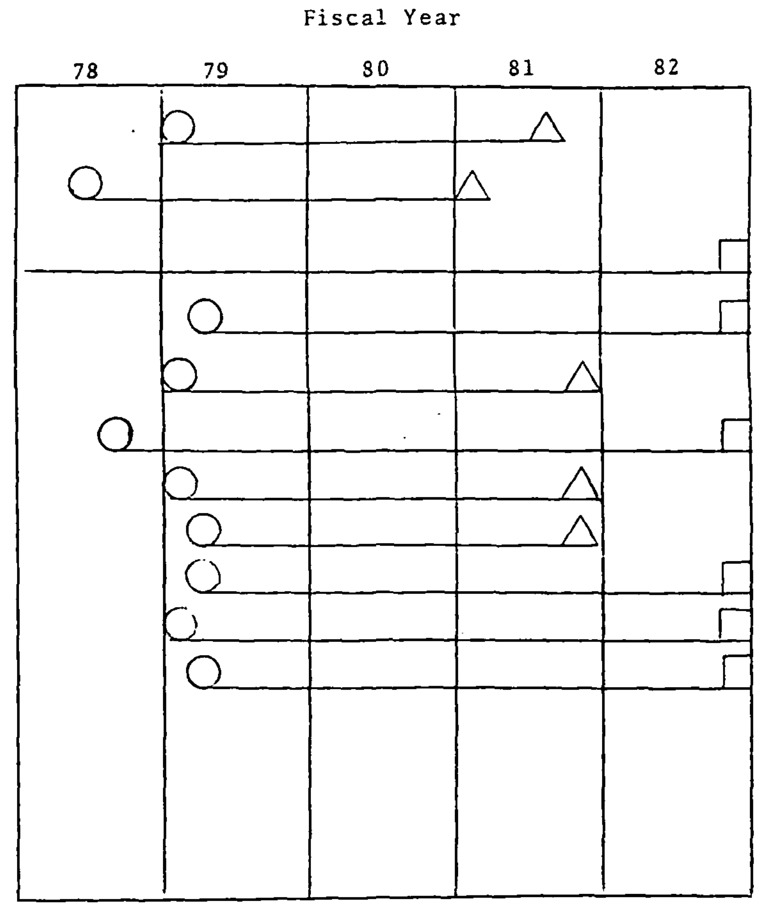


FIGURE II-7, ANTICIPATED CONTRACT ACTIVITIES

Legend: ○ Start
⊓ Decision Points
△ Conclusion

Contract Subject	Program Priority
1. 275°C Electronics	1
2. Electric Cable Tests & Development	1
3. Prototype Tool Development (Temp, Press, Flow, Caliper)	1
4. Borehole Test and Evaluation	1
5. High Temp Circuit Commercialization	2
6. Fracture Mapping	2
7. Sonde Refrigerator	2
8. Sidewall Coring	2
9. 350°C Electronics	3
10. "Bomb" Type Temp. & Press. Sondes	3
11. Fiber Optics	3



listed in Figures II-2 through 7. More detailed descriptions of these activities are given in Section IV-B.

Activites for 275°C Development

1. High Temperature Components -- Screen commercially available hybrid thick film passive electronic components and silicon field effect transistors. Develop high temperature fabrication and packaging techniques. Periodically, publish reports summarizing these component developments for designers of high temperature commercial logging instruments.

2. Electric Cable Testing and Development -- Test commercially available geothermal cable candidates under in situ geothermal conditions. Use the test results to plan the development of new cable configurations and to assess additional cable test facility needs.

3. Prototype Tool Development -- Develop temperature, pressure, flow, and caliper sondes which are vitally needed for reservoir engineering. Use these sondes to confirm component performance and demonstrate the technology in complete systems. Identify technological deficiencies and direct program activities to correct them.

4. Borehole Test and Evaluation -- Field test and evaluate complete systems and confirm results with industry provided services.

5. Commercialization -- Contract for the manufacturing of newly developed high temperature circuits (e.g. multiplexer, line drivers, power supplies and voltage regulators) common to many downhole instruments and for which commercial instrument developers and logging service companies have direct needs.

6. Fracture Mapping -- Upgrade the acoustic borehole tele-

viewer for geothermal fracture mapping. Investigate alternative fracture mapping techniques and select the most promising candidates.

7. Sonde Refrigeration -- Develop an active cooling system which will enable operation of conventional electronics in the hot geothermal environment.

8. Sidewall Coring -- Develop a triangular sidewall coring device to obtain core samples from a desired depth in a geothermal well.

9. Neutron Formation Temperature Tool -- Develop an instrument which can determine the temperature of the rock formation some distance away from the borehole by detecting back scattered, thermally equilibrated neutrons.

Activites for up to 350°C Development

1. High Temperature Components -- Develop hybrid thick film and thin film passive components and packaging. Test commercially available gallium arsenide semiconductors. Develop high temperature device designs, metalization and passivation techniques in order to extend the utility of commercial transistors.

2. Upgrade "Bomb" Type Sondes -- Improve the reliability and measurement resolution/recording of self contained sondes which are run into a borehole on a slickline (i.e. no electric cable). Focus on materials and designs which accommodate thermal expansion and which reduce friction and backlash.

3. Thermal Protection Components -- Upgrade passive, insulated dewars which are currently limited to about 315°C for 10 hours. Investigate alternative insulation materials, coolant

fluids and alternative active cooling systems to increase the downhole operating time to 100 hours or more.

4. Prototype Tool Development -- Design and fabricate temperature and pressure sondes to verify the performance of the above mentioned advanced components in complete operating systems.

5. Downhole Communications -- Develop 350°C fiber optic cables and transducers as higher temperature alternatives to electric cables and downhole electronics. Investigate other approaches to communicate downhole data to the surface.

6. Integrated Thermionic Circuits -- Continue development at LASL of miniature vacuum tube circuits utilizing planar, thin metal film tube elements packaged in ceramic containers. Continue to support these tube circuits as an alternative technology to the 350°C gallium arsenide semiconductors until FY78 when DGE will fund these activities under a separate program.

F. Relationship to Other Geothermal Development Activities

Sandia will closely coordinate the activities of the logging instrumentation program with the geothermal regional development plans, the reservoir engineering program, the log interpretation and the DGE geochemical engineering program. The relationship to interpretation and reservoir engineering has been discussed. The regional development plans focus on demonstration facilities and industry related geothermal developments which may require geothermal logging services. The logging needs of these activities will be reviewed and factored into this program's planning and field testing.

This program relates to the DGE geochemical engineering program in two ways: first, the materials research and development activities in geochemical engineering involve experimentation in geothermal borehole environments. This program's field test equipment and personnel will provide the field test support directly or support the test indirectly by working with DGE to contract for the needed services. Although cost estimates for such activities are included in the budgets given in Figures II-3 and 5, detailed annual budget reviews and updates with DGE will be required to assure adequate planning and support for these commitments. Second, geothermal logging development requires the high temperature qualified materials such as elastomers, which will be developed and tested in the geochemical engineering program. The design application and test evaluation of these new materials in experimental borehole instruments will be closely coordinated with the participants in the geochemical engineering program.

III. BACKGROUND

Geothermal reservoirs commonly occur in fractured igneous or metamorphosed sedimentary formations where fracture permeability predominates, whereas petroleum reservoirs usually occur in sedimentary rocks having mainly inter-granular porosity and permeability. Because of these differences, the lithology and pore structure of geothermal reservoirs are generally unfamiliar to the well logging industry. Also, determination of the size and production potential of these reservoirs requires downhole measurements in environments which are not typical in the oil and gas industry. Among the most important of these are: long duration high temperature, pressure, flow rate, and fracture mapping measurements.

Reliable temperature tools capable of functioning downhole for prolonged periods of time and providing continuous data are currently limited to about 200°C maximum.

For measuring downhole pressure, quartz crystal based instruments are presently available with the necessary 0.01 psi resolution over a range of 0-10,000 psi. However, these instruments cannot tolerate temperatures above 150°C because of degradation of their electronics and crystal parameters. Bourdon tube gauges do not have the required accuracy or resolution. Gas bubbler devices are faster and have about the same resolution as Bourdon tubes, but are prone to pressure perturbations due to temperature expansion of the gas.

In contrast to hydrology and petroleum engineering, geothermal work often involves two-phase flow under nonisothermal conditions in high temperatures and corrosive brines where flow tools and their interpretations have not been perfected. A suitable downhole, two phase flow tool is vital in identifying the presence of production zones, mingling of flow from vertically separated productive layers, and leaky boundaries.

The existing highly developed hydrocarbon and mineral logging instrumentation services and their interpretation procedures form the basis for technical advances in this program. Research is underway in the evolving geothermal production industry to solve the problems in geothermal reservoir engineering and log interpretation. Logging service organizations are actively developing tools for use in hostile environment oil and gas wells. In addition, some industry developments are directed at geothermal applications.

However, industry's level of effort in geothermal logging tools is substantially below that directed toward petroleum logging. Near-term economic incentives in geothermal logging are not sufficient to justify large expenditures in industry to develop tools and techniques solely for use in geothermal fields. DOE's geothermal energy program is intended to provide supplementary and complementary research to develop materials and techniques which can be directly transferred to industry so that near-term availability of advanced geothermal logging methods will be substantially accelerated. Ultimately, this will lead to increased activity in geothermal drilling, reliable reservoir assessment, and sufficient economic incentives to stimulate continued industry development and commercialization of geothermal logging services.

Three major management programs related to geothermal logging have been assigned to national laboratories:

1) Sandia Laboratories -- Geothermal Logging Instrumentation Development Program

2) Lawrence Berkeley Laboratory -- Reservoir Engineering Management Program

3) Los Alamos Scientific Laboratory -- Geothermal Log Interpretation Program

Clearly, the activities of the three laboratories must be closely coordinated, and must focus on the needs of commercial geothermal operators and the DGE mission-oriented regional development plans for accelerating the commercial development of various types of geothermal reservoirs to meet the objectives for electric power, process heat and space heating applications.

IV. TECHNICAL PLAN

A. Approach

The Geothermal Logging Instrumentation Development Program is divided into three major tasks: 1) high temperature components development, 2) prototype system development, and 3) borehole test and evaluation.

The components development task is directed toward alleviating existing technical deficiencies, such as temperature limited electronics, cables, and elastomeric seals which rapidly degrade in high temperature geothermal fluid. Those components which require basic design development will be identified. Work will proceed from materials and design studies through fabrication, test, and evaluation to technology transfer and commercialization. This task will be coordinated with industry's own efforts and with other DGE materials and component development activities. These components will serve as a basis for prototype system design and testing throughout this program. Special efforts will be made for rapid transfer of new technology developments to the logging industry to stimulate their own inventions[2] and contributions in geothermal logging.

Prototype logging systems will be designed using the technological repertoire developed in Task 1. Developments will be contracted to industry with complementary development at Sandia and other DOE laboratories to provide special devices and components for incorporation into complete prototypes ready for borehole testing.

Both laboratory and borehole testing will be performed to evaluate the performance of advanced components in complete prototype systems operating in the geothermal environment.

B. Program Tasks

Task 1. High Temperature Components

The objective of this task is to identify and, if necessary, develop components and fabrication techniques for making high temperature cables, electronic circuits, and environmental seals which will operate downhole in a stable fashion. These components must also survive the rigors of field handling and use. A further task objective is to make all significant details of the fabrication and performance of these components available to commercial suppliers and users in order to facilitate technology transfer to private industry. To this end, every effort will be made to use commercially available components and fabrication practices. To stimulate commercialization, Sandia will seek out individual concerns to fabricate the high temperature electronics developed by this program. See Figures II-2 through II-5 for descriptions of the schedule and funding of this commercialization activity.

a. Passive Electronic Components and Interconnections

A limited range of passive electronic components for 275°C operation has been identified and reported.[3] These components are all commercially available and applicable to thick film hybrid microcircuits.

Thick Film Hybrids -- Thick film hybrid microcircuit techniques are a logical and natural approach for downhole well logging purposes. They are made by depositing special resistor and dielectric inks in a circuit pattern onto an insulating substrate. The assembly is then baked at very high temperature (typically

1000°C) to fuse the inks in place. After the substrates cool, discrete devices, such as transistor chips, are bonded and wired to the assembly to complete the hybrid microcircuit. With this approach, an appropriate level of miniaturization can be achieved which will fit the available volume of the required geothermal sondes. Furthermore, these circuits can be modified for use up to 350°C when used with appropriate active discrete components. An additional consideration is that commercial manufacturers now produce about 80% of their hybrids by thick film techniques so that technology transfer should be relatively straight-forward as discussed in Section V, Technology Transfer. To assure this tranfer, selected hybrid circuits will be fabricated by industry under contract to Sandia Laboratories.

Printed Circuit Boards -- These boards are required in circuit development and laboratory testing. Currently available boards fail after temperature cycling, because their metal-foil-to-polyimide lamination degrades. Therefore, continuing development is needed to obtain suitable lamination bonding for 275°C applications.

Resistors -- Further development is required of thick film resistors for 275°C and higher temperature use. Resistors of 100 ohm to 1 Megohm, which have temperature coefficients of resistance (TCR) of 50 ppm/°C or less and which are stable at 275°C to within 1% for 1000 hours are needed. Smaller TCR and similar stability requirements will be needed for applications up to 350°C. 275°C resistor studies will continue through FY79. Development of 350°C resistors will be conducted concurrently with active device development through FY82.

Capacitors -- For 275°C use, thick film capacitors fulfill some needs. However, further study of these, as well as thin film and multilayer ceramic brick discrete capacitors, is necessary to achieve the required miniaturization. These studies will extend through FY79, with emphasis on 275°C applications, and extend through FY82 for 350°C applications.

Thermistors -- Thermistor selection and development is required to implement high temperature circuits. Thermistors are used to compensate for changes with temperature of the internal resistances of semiconducting active devices. Thick film thermistor fabrication methods will be investigated because of compatibility with the preferred circuit fabrication method, the commercial availability of appropriate thermistor materials, the long-term stability of these materials, and the fact that they can be trimmed to size by conventional techniques.

Magnetics -- The development of high temperature transformers is required for two purposes. First, they are needed for the traditional uses of voltage alteration, impedance matching and DC voltage isolation. Second, they offer an alternative to certain active devices through magnetic amplifiers. Also high temperature magnetic materials are needed for magnetic memories.

Electric Motors -- High temperature electric motors are needed in some of the borehole instruments, such as the caliper, borehole televiewer, and sidewall coring tool. Motors are available for operation up to 230°C. Key problem areas are the magnet wire insulation, bearing design and lubrication. Development efforts will focus on these problem areas, with most of the work done under contract with some materials science and engineering support from Sandia Laboratories.

Bonding -- Bonding studies will be required to support activities in discrete component selection and development and circuit development. Because of the high temperature application of the electronics, traditional bonds may not be appropriate due to unfavorable chemical reactions in the bond zone.

b. Active Electronic Devices

A series of commercial silicon junction field effect transistors (Si-JFETs) has been found which are suitable for 275°C operation.[4] In order to attain greater versatility in 275°C circuit design and to develop the required array of higher temperature active devices, the following will be pursued:

Si-JFET Devices -- Studies of Si-JFETs will be extended to improve their 275°C performance. For the near-term, these are the most promising devices. Studies will proceed through FY79.

Other Silicon Devices -- Investigation of other silicon devices, such as metal oxide semiconductor field effect transistors, will be undertaken because availability of these devices will provide the needed flexibility for circuit design and they offer improved reliability and temperature performance. Integrated circuit technology will also be investigated because it offers greater circuit density and design sophistication than the discrete transistor approach. This investigation will begin in FY78 and continue through FY81.

Gallium Arsenide Devices (GaAs) -- For 350°C applications, silicon devices cannot be expected to suffice because the electron band gap for silicon (1.11 electron volts at 27°C) is sufficiently narrow that at 300°C silicon devices become intrinsic conductors and thereby lose their semiconductor properties. GaAs, on the other hand, has a wider band gap (1.40 electron volts at 27°C) which theoretically permits operation to 425°C. GaAs is also a promising substitute material for silicon since it is commercially produced now for very high frequency applications. Preliminary studies conducted under this program show that the existing commercial GaAs transistors are not suitable due to high temperature degradation, but these difficulties are not fundamental to GaAs; they appear to be related to device designs and processing methods. Beginning in FY78, the GaAs investigation will aim at understanding the high temperature failure mechanisms and then, in FY79 through FY82, developing suitable designs and processes that are compatible with commercial fabrication capabilities.

Ceramic Vacuum Tube Devices -- A line of miniature ceramic envelope vacuum tubes is commercially available and has been shown to perform in laboratory tests up to 500°C in a study by Mechanics Research Institute.[5] These offer possible solutions to some circuit applications which may arise in the FY79 to FY86 time frame.

Integrated Thermionic Devices -- Integrated thermionic devices, which are planar vacuum tubes integrated onto a single substrate, are under development at LASL for DGE.[6] These devices have been operated at temperatures up to 900°C. Although they are not now commercially available, they will be developed because they have the potential to provide very compact vacuum tube circuits operating at extremely high temperatures. Their application could develop in the FY81 to FY82 time frame. Key problem areas under investigation are materials and package design.

c. Insulation Materials

Insulators, such as elastomers, plastics and ceramics, capable of withstanding temperatures of at least 275°C and 7,000 psi in the presence of geothermal brine for up to 100 hours, are required for geothermal well logging applications in seals, gaskets, connectors, cable sheathing and wire insulation. An important function of insulators in these applications is the protection of sensitive electronic components from the corrosive fluids in a geothermal reservoir. The elastomers are also needed in blowout preventers and borehole packers for geothermal well testing and completion. Unfortunately, performance data on commercially available materials is lacking for these applications.

The approach taken to fulfill these technical deficiencies includes the following:

1) Coordination of insulation needs and developments with DGE's geochemical engineering program and industry activities;
2) Test and evaluation of available high temperature, steam resistant elastomers as moisture barrier seals;
3) Investigation of special coating to enhance the chemical and steam resistance of elastomers made from available polymers.

Evaluation of 275°C elastomer test data to support prototype tool design, is presently underway and is expected to be completed by the end of FY78. Specific components such as cables, seals, and wire insulation will be tested to more severe conditions in FY78 and FY79. Elastomer coating investigations will continue in support of specific geothermal logging development needs.

Electric Cables -- One of the most critical elastomeric needs is for geothermal qualified electric cables.[7] Activities in this area begin with the overall elastomer evaluation already underway complemented with limited laboratory testing of specific cable designs in FY78. Industry owned and operated test facilities have been located which can statically test short cable samples in simulated geothermal environments. These tests, together with data obtained in earlier DGE cable test projects, will yield a first order assessment of cable material's performance. By mid FY79, this information will be available as an input to formulating the scope of additional cable development activity. This information, together with field test experience and industry inputs, will also be used to assess the need for more extensive test facilities. Anticipated additional cable development and test activities include: 1) establishment of cable performance requirements, 2) investigation of alternate insulation and structural support materials; 3) recommendation of one or more geothermal cable configurations; 4) competitive procurement of the design and fabrication of one or more of the recommended cables; 5) competitive procurement of a geothermal cable test facility, should one be needed, along with appropriate testing services; and 6) based on the above, the establishment of a recommended industry standard geothermal cable configuration.

Task 2. Prototype System Development

To satisfy the near-term needs of geothermal reservoir engineering, to assist in directing components developments activities and to test and verify components' performance in complete systems, prototypes of the most critically needed tools for geothermal applications will be developed. A list of these sondes in the order of their priority is given in Table IV-I. This list was compiled with the assistance of the Geothermal Reservoir Engineering Management Program. This priority listing will be appropriately updated with additional inputs from the Steering Committee, the Geothermal Log Interpretation Program, and the geothermal industry at large. Schedules for development and field testing of these sondes are given in Section II-D. As shown in the schedules and in Table IV-I, the temperature, pressure, flow, caliper sondes, and fracture mapping techniques have the highest priority and are being addressed first. The following is a status report and plan for each of these high priority developments.

Temperature -- During FY77 both printed circuit board and hybrid microcircuits for a temperature tool were completed, and the tool's housing and necessary interconnections were prepared. In FY78, laboratory environmental testing and field testing will be emphasized and necessary circuit revisions will be made. In FY79 through FY82, modifications will be made to improve accuracy, simplify commercial manufacture, and shift the development to 350°C. As is the case with all these instruments, the accuracy, resolution, repeatibility, and reliability of the temperature tool will be assessed in laboratory testing using high temperature-high pressure

Table IV-1. Prototype Geothermal Logging Tools

(up to 275°C operation)

Tool	Performance Goal
Temperature	1.0°C accuracy, 0.5°C resolution
Pressure	0-7000 psi, 0.1 psi accuracy, 0.01 psi resolution - desired 0.1 psi resolution - goal
Flow	0-2000 gpm in diphasic flow
Caliper	6 arm borehole geometry, 0.1 in. accuracy with fracture indication
Casing Collar Locator	Detect standard collars
Fracture Mapping	To be determined
Formation Resistivity	To be determined
Casing and Cementing Inspection	To be determined
Directional Survey	To be determined
Sonde Refrigerator	50 watts cooling to 125°C for at least 100 hours
Additional Tools	To be determined

chambers and microprocessor based controls and instrumentation.

Pressure -- The major thrust of this activity is directed toward the development of a 275°C quartz crystal based pressure instrument which strives for 0.01 psi resolution in a 7000 psi borehole environment. Both the quartz crystal and its associated hybrid electronics will be developed in the FY78 through FY80 time frame. Field testing will begin in FY79 with technology transfer and refinement of the instrument's measurement resolution requiring additional time in FY80. To complement this high resolution sonde, a low resolution Bourdon tube pressure sensor will be coupled to a 275°C electronics package, a modification of the temperature tool's electronics, to produce a field version high temperature sonde in FY78. Field testing of this 2% resolution pressure instrument is scheduled during the last quarter of FY78.

Combined Tool -- During FY79, the development of a combination 275°C temperature/pressure tool and its associated electronics is planned. This tool will enable operation on a monoconductor cable through the use of a Si-JFET multiplexer currently under development. In geothermal applications, monoconductor cable, because of its simpler design and construction, has been found to be more reliable, more rugged and less expensive than an equivalently rated multiconductor cable.

Flow -- During FY77, a high temperature impeller type transducer and a signal feedthrough mechanism were constructed. In FY78, the associated hybrid electronics for 275°C operation will be developed and laboratory and field tests will occur. In the period FY79 through FY82, development activities will be directed toward exploring alternate transducers and attendant 275°C electronics to measure downhole two-phase flow (thus providing flow volume rate and associated mass flow rate information) and to improve measurement sensitivity.

Caliper -- A caliper tool is a necessary adjunct to the impeller type flow tool in order to compute flow rate. The caliper is also necessary to identify the open borehole geometry and thereby establish a basis for log interpretation and well completion strategy. In addition, a caliper is also useful in gross fracture mapping where the fractures are at least 0.1 inches wide. The major deficiencies in existing calipers are the corrosive susceptibility of the metals and seals and the temperature limitations of the seals and displacement transducers. In FY78, commercial calipers are being upgraded by replacement of deficient metals, seals and transducers with components appropriate for the geothermal environment. Because of its simplicity, a four arm caliper will be upgraded first and field tested in FY79. Following this, a six arm caliper will be upgraded and will incorporate some special features for geothermal applications, such as fracture finding fingers. Development and field testing of these calipers will be completed by the end of FY80.

Fracture Mapping -- Most liquid dominated hydrothermal reservoirs appear to be fracture dominated permeable zones rather than the integranular dominated permeable zones common in petroleum reservoirs. The development of fracture mapping techniques for geothermal reservoir assessment is, therefore, of very high priority, as shown in Figures II-2 through 5.

DOE/DGE is currently sponsoring Westinghouse Research Laboratory to improve and temperature harden transducers for the Borehole Televiewer (BHTV). The BHTV incorporates a high frequency (1.5 MHz) acoustic tranducer system which provides an acoustic image of the borehole wall to indicate cracks and associated fracture zones.

Activites in acoustic fracture mapping will initially focus on development of the BHTV because such development will complement industry's own efforts. Also, pioneering work by the USGS* indicates that the BHTV has a high potential for satisfying geothermal needs. Throughout the development of the BHTV, there will be close cooperation with the USGS in the areas of establishing performance requirements, identifying specific problems, recommending candidate solutions and field testing and evaluating upgraded hardware. There will also be close cooperation with the BHTV's patent holder, Mobil Research & Development Corporation and their licensees engaged in the development, fabrication, or commercial application of the BHTV.

The majority of the BHTV's development will be contracted to industry, with Sandia Laboratories responsible for system integration, coordination, technology transfer and commercialization.

The BHTV's development activities are divided into four major areas: 1) the transducer system, 2) downhole electronics, 3) surface controls, and 4) display and recording. As mentioned above, the transducer sytem is presently being upgraded. Additional

*US Department of Interior, Geological Survey, Water Resources Division, Denver, Colorado.

work will be required through FY80 to produce upgraded hardware for field testing. Upgrading the BHTV's downhole electronics and surface controls will be started in the last half of FY78 and will continue through FY82. An improved display and recording system is presently being developed by industry. If necessary, additional development of the display system will be undertaken in FY81 to complement industry's efforts. During the period from FY81 to 83, the BHTV will be refined for greater resolution and for use as an acoustic caliper. Field testing of upgraded BHTV's will begin in FY79 and continue through FY83.

There are also many other techniques which may be applicable to geothermal fracture mapping and/or permeability measurement. Although the BHTV will be the prime focus for development, these other techniques will be reviewed to assess their geothermal applicability, the state of their development, and the opportunities to stimulate further development and commercialization. The exploration into other fracture mapping techniques will be started at a low level in FY79 and is expected to continue to the end of this activity in FY85.

Other tools -- Development of other tools will be undertaken only after preliminary investigation has established their needs and requirements, identified no industry development duplication and finally determined an appropriate course of action. In all cases, the actions taken will begin with application of the technological repertoire from Task 1 to assist industry in upgrading their existing designs. New work at the material, device and component level will be started as necessary to supply any technology which is both deficient and unavailable through other development programs. This new technology will then be used in the design and fabrication of advanced prototype tools. These tools will be tested and evaluated to confirm their design and the adequate performance of their component parts.

Thermal Protection -- An alternate approach to high temperature sondes is the provision of either passive or active thermal protection. Available passive thermal protection devices such as eutectic heat sink equipped dewar flasks are presently the industry staple to package and protect state-of-the-art electronics for logging geothermal wells. However, the best available dewars are limited to no more than 12 hours of operation in boreholes up to 275°C. A reliable instrumentation refrigerator, capable of providing active thermal protection for 100 hours or more, will enable operation of existing downhole electronic packages and thereby open up the geothermal logging market to conventional logging service. This approach is technically challenging and outside the normal endeavors of the logging industry; but due to the high potential payoffs of a sonde refrigerator, this activity is currently being contracted to industry, with appropriate technical support from Sandia.

Task 3. Borehole Test and Evaluation

a. Needs and Facilities

Commercially available hardware, components developed in Task 1, and the prototype tools developed under Task 2 will be tested and evaluated in appropriate laboratory and field environments. The determination of suitable, representative test conditions and boreholes will be closely coordinated with the responsible DGE participants in reservoir engineering and log interpretation. Test needs will be identified and suitable industry facilities will be utilized if they are available. University, non-profit laboratory and Government test facilities may also be used to supplement industry tests. Special test needs for components, sondes or cables which cannot be satisfied by this approach will be documented and action will be taken to obtain the necessary funding and establish such facilities with private industry through competitive bidding. If program objectives will be best served by a Government owned test installation, special test facilities may be established at this or other DOE laboratories. For example, the DGE field test support capability which has been procured and is operated by Sandia Laboratories will provide an interim capability to test this program's prototyped logging tools and supply a data base for measurements needed in log interpretation and geothermal well testing.

In addition to the above, DGE Experimental facilities at other labs and geothermal sites will be employed to expedite sonde evaluation and provide support for their respective borehole measurement needs. For example, reservoir engineers at LBL and log interpreters at LASL have access to certain geothermal wells from which they need reliable borehole data such as temperature and pressure. Although each has a competent test staff and sufficient resources to contract for logging services, they lack some of the special high temperature tools under development and commercialization in this program. Therefore, after successful completion of their initial tests and evaluation, a limited number of these prototype sondes, cable heads, and supporting electronics will be supplied to these experimental test needs on an interim basis.

To begin fulfilling these needs routinely, two types of logging service activities will be contracted with logging service companies. The first type will provide for fabrication of tools developed in this program and fielding them, together with suitable support equipment, to provide a geothermal logging service. The second type will cover contracts for field testing of technology transferred to industry and industry developed geothermal logging equipment. Details concerning the budget and scope of these contracts are given in Section II-D and VI.

In addition to the need to test new tools, a requirement exists to calibrate and normalize geothermal borehole instrumentation. Many petroleum logging companies operate calibration pits and wells and also test their new tools in representative boreholes at the invitation of petroleum producers. It is not envisioned that similar geothermal facilities will be procured or directly operated under this plan because suitable calibration wells and supplementary test pits may become a part of another DGE program. However, the Logging Instrumentation Development Program will coordinate with DGE and the DOE labs to establish selection criteria, test facility designs and access for the required calibration wells and pits.

In addition, Sandia Laboratories has received a number of formal and informal invitations from geothermal producers to test experimental systems in their wells. In each instance the operators have expressed a need for the tools under development in this program. These invitations present an opportunity to conduct tests in actual geothermal wells under field conditions. Such tests will have high visibility and credibility in the geothermal industry, and it is Sandia's intent to take advantage of these invitations at the proper stage of prototype development and commercialization.

b. Planning and Operation

To support the component and tool developments scheduled in Section II-D, a series of laboratory and field tests will be conducted each year. These tests will be documented in the annual operating plan as described in Section VII-E. To support the many anticipated long duration geothermal reservoir tests, prototype hardware will be procured for use by the appropriate DOE laboratory's test staff or their contractors. Consistent with this plan, Sandia will support these tests with additional equipment and personnel as required.

The DGE logging field test unit will be operated by Sandia Laboratories' engineers and technicians with appropriate industry observers or resident engineers in attendance. Each field test will be planned by the Sandia Borehole Test Leader and reviewed by the Sandia Project Manager.

Using a microprocessor based system, test logs will be compiled for a data bank and made available to all interested parties. The above approach partially addresses the need for an automated, multiple well data gathering computer system identified by LBL at their Review Task Force Meeting August 4 - 5, 1977.

V. TECHNOLOGY TRANSFER AND RESEARCH UTILIZATION

To be effective in achieving the geothermal program's goals, improved technology must be applied in the field by the logging service industry in a timely manner and in sufficiently large quantities to serve the needs of geothermal development. Therefore, the results of the research conducted under this program must be effectively communicated to industry. The effect of rapid transfer of this information will be two-fold: 1) tools and measuring techniques developed under this program can be used in design prototypes by industry in developing their own production tools; and 2) the high temperature components development which will be conducted will serve as direct input to the ongoing industry research effort. Timely and effective information transfer will lead to the most rapid development of commercially available production logging tools.

Sandia will conduct vigorous technology transfer activities. Since much of the research will be conducted by industry contractors, close informal contacts with industry representations will be maintained. Also, a great deal of information will be exchanged in informal technology interchanges with the logging service industry, geothermal producers and DGE program participants. Larger audiences will be addressed in formal workshops for interested industries during which the results of sponsored research will be presented; periodic reports to the Geothermal Logging Instrumentation Steering Committee, most of whose members are industry representatives will further accelerate the transfer of information. Whenever appropriate, industry representatives will be invited to observe and evaluate laboratory and/or field tests of hardware developed under the program. In addition, industry personnel may be asked to participate in Sandia in-house research under the Sandia Resident Engineer Program. Both of the above procedures will directly involve industry in ongoing research activities sponsored by this program.

Where appropriate, patents and formal licensing of the technology will be pursued through DOE. All results obtained under this program will be published in reports and submitted to appropriate technical and trade journals. Presentations will be made at meetings of professional societies, and the reports will be disseminated to a broad range of the logging and associated industries. Thus, the results of this program will become part of the open literature on geothermal well logging.

VI. COMMERCIALIZATION

Commercialization is vital to achieve this program's goals. Planning for the commercialization of new products and services, such as geothermal logging instrumentation, must begin with an adequate perception of the marketplace and the forces which may be brought to bear to produce desired changes.

Petroleum producers contract with service companies to log new wells. They seek information which will aid in deciding whether or not to complete and produce the well. A substantial capital investment hinges on this decision; and the operating company desires accurate, reliable information. The logging industry is highly competitive, and it is to the advantage of the service company to provide reliable, high quality information at low costs.

Logging service companies and their suppliers conduct aggressive in-house research and development programs to continually improve their services and products through proprietary hardware developments. These companies have fielded a vast array of technically impressive hardware, which is operated on a global scale by equally impressive field organizations. They effectively provide the information needed for decision making in the world's largest business--providing fossil fuels.

Although 500 Mw_e is being generated now by private geothermal producers at The Geysers in California, entrepreneurs engaged in geothermal exploration and production represent a relatively small market for logging services. Nevertheless, logging instrument manufacturers and service companies are diligently attempting to fulfill their geothermal customer needs. In this endeaver, they are impeded by deficiencies in technologies outside of their established capabilities, as discussed in Section II, and for which there are insufficient incentives for them to develop. However, these technologies are precisely those under development in this program; namely high temperature electronics, together with prototype design applications for metals, ceramics, and polymers suitable for operation in hot, corrosive brines. Industry is also beginning to see potential applications for these developments in the increasing number of very deep (~20,000 feet) oil and gas wells. Temperatures in these wells approach the lower geothermal range (~200°C).

Service companies and logging instrumentation manufactures have indicated that they are eager to use new technology to answer their rapidly developing needs for severe environmental capability. Geothermal producers have indicated strong interest in enhanced geothermal logging capability; so it seems certain that markets will exist for high temperature/corrosion resistant logging equipment and services when this technology becomes available. Commercialization of the technology developed in this program will be undertaken in two ways: joint industry/DGE development and geothermal logging market stimuli.

A. Joint Industry/DGE Developments

Consistent with this program plan, mutually beneficial joint projects will be pursued on a fair and equitable basis, with commercial logging instrumentation developers, logging service companies and their suppliers. The objective of each of these development projects is to achieve a marketable geothermal logging instrument product or service which is offered by an appropriate commercial enterprise. For example, the expertise of a logging service company, Gearhart Owen Industries, is being combined with the device, component and system integration capabilities of Sandia Laboratories and its contractors to develop and demonstrate a prototype set of the most critically needed tools for geothermal logging.

The initial objective in building these prototypes is to confirm the performance of the new technology under actual field conditions. Also, the information obtained from testing these systems will assist in forming a base of logging data which will be useful for log interpretation and reservoir engineering. The service company will incorporate the special devices and components supplied by Sandia and other program participants into the design and fabrication of each prototype. After successful completion of developmental tests, these prototypes will be demonstrated by Sandia and the service company in logging appropriate geothermal wells. All of the design information developed under these Government contracts will be made available to the entire industry.

B. Market Stimuli

In order to accelerate industry participation where companies have their own in-house developments, contracts which cover the cost of testing new industry developed components and tools will be placed. Geothermal logging services, in which Sandia acts as a producer requesting logging service, will also be contracted. The wells logged will be special DGE test and calibration boreholes, on which extensive data will be collected and made available to industry through the Reservoir Engineering and Log Interpretation Programs. The measurement data obtained will help the industry in calibrating their tools and will assist in efforts to develop and refine their interpretation in geothermal wells. Additionally, cost sharing alternatives will be explored in which this program may pay some of the costs of component testing, sonde testing and geothermal logging services. As part of the cost sharing, industry will develop, pay for, and retain the rights to their new inventions.

VII. MANAGEMENT PLAN

A. Approach

DOE/DGE retains the overall programmatic responsibility for direction of this project. DGE, with assistance from Sandia, will set the project goals, establish budgets and major milestones, and provide general guidance toward meeting them. Sandia will implement the programmatic direction provided by DOE/DGE consistent with the resources provided.

Sandia Laboratories will provide overall as well as day-to-day management of the Geothermal Logging Instrumentation Development Program and will plan, initiate, and coordinate technical work within the overall scope and objectives of the project. Close technical and administrative coordination will be established as detailed in Section VII-I between the Sandia project management, DGE management, Lawrence Berkeley Laboratory's Reservoir Engineering management and Los Alamos Scientific Laboratory's Log Interpretation Program management. Special attention will be directed toward transferring technology developed under the program to the logging service industry and to the evolving geothermal production industry. Field testing and demonstration will be coordinated with geothermal regional development plans.

Sandia will, prior to the beginning of each fiscal year and as described in Section VII-E, provide DGE with a program approval document detailing the specifics of the program for each new fiscal year.

B. Sandia Project Management Structure

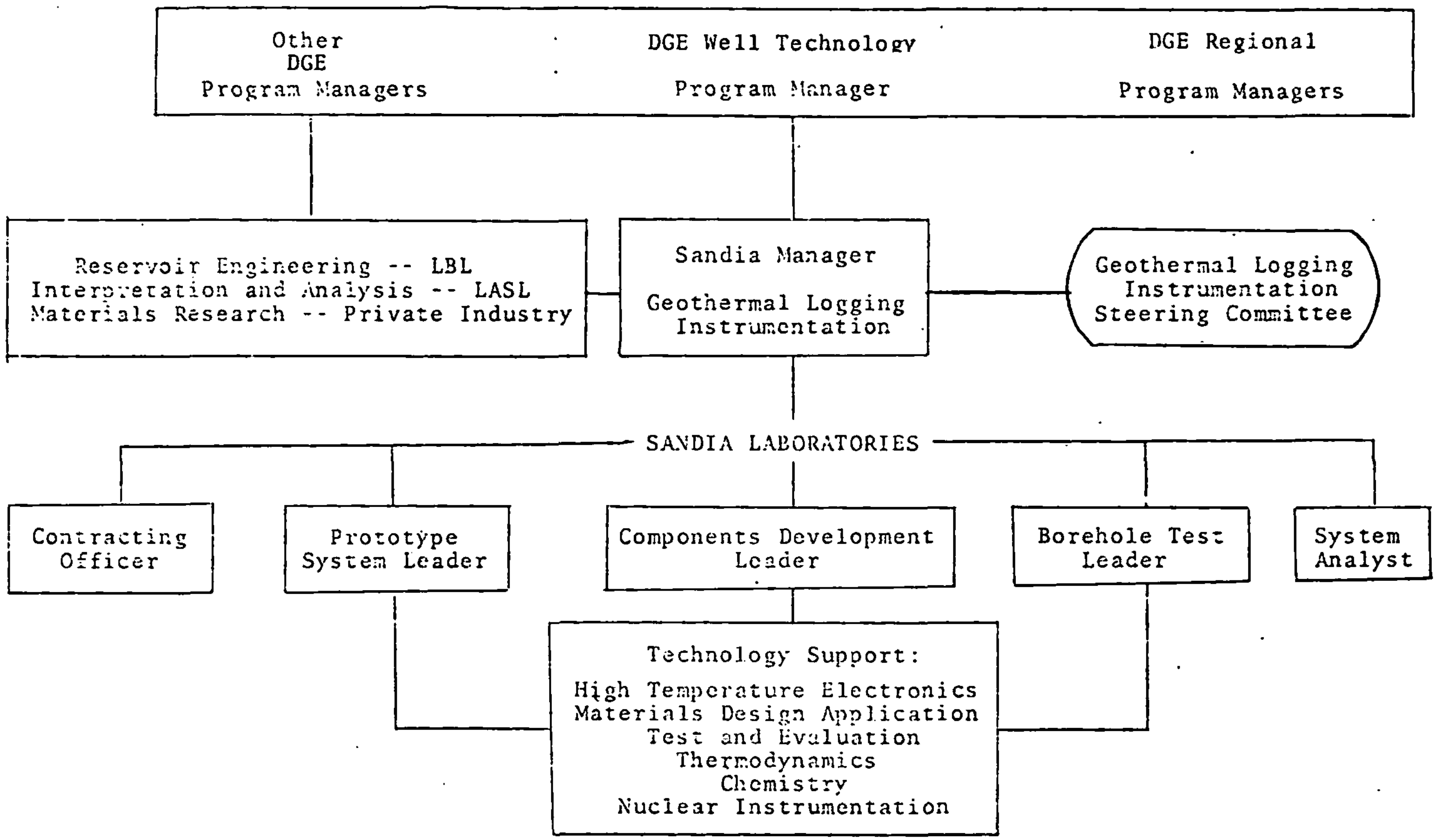
The Logging Development Program's management structure is shown in Figure VII-1. The Sandia Project Manager has overall responsibility for accomplishing the technical objectives of the project within the specified budgets and schedules. Working under Sandia policies, he will obtain appropriate Sandia management concurrence in the expenditure of project funds. He will be versed in all technical aspects of the project and will maintain familiarity with all relevant R&D activities outside the project. He will be responsible for preparing and updating program planning documents, as well as directing contracting and procurement activities consistent with the Laboratories' policies. In addition, he will coordinate the various program tasks and interfaces with other elements of the National Geothermal Program. He will also be responsible for maintaining close coordination and direct communication with the DGE Geothermal Well Technology Program Manager.

A panel comprising representatives from the production and logging service industry and appropriate DGE programs will serve as a steering committee for the program. This panel will meet on a periodic basis, typically semiannually, review the program's progress and provide advice concerning the program's direction, objectives, and priorities. The Sandia Program Manager will work closely with this panel in directing and reviewing specific program details.

The Sandia program is divided into three main technical tasks and an administrative support task as shown in Figure VII-1. The technical tasks are:

1. High Temperature Components Development
2. Prototype System Development
3. Borehole Test and Evaluation

FIGURE VII-1. GEOTHERMAL LOGGING DEVELOPMENT PROGRAM MANAGEMENT STRUCTURE



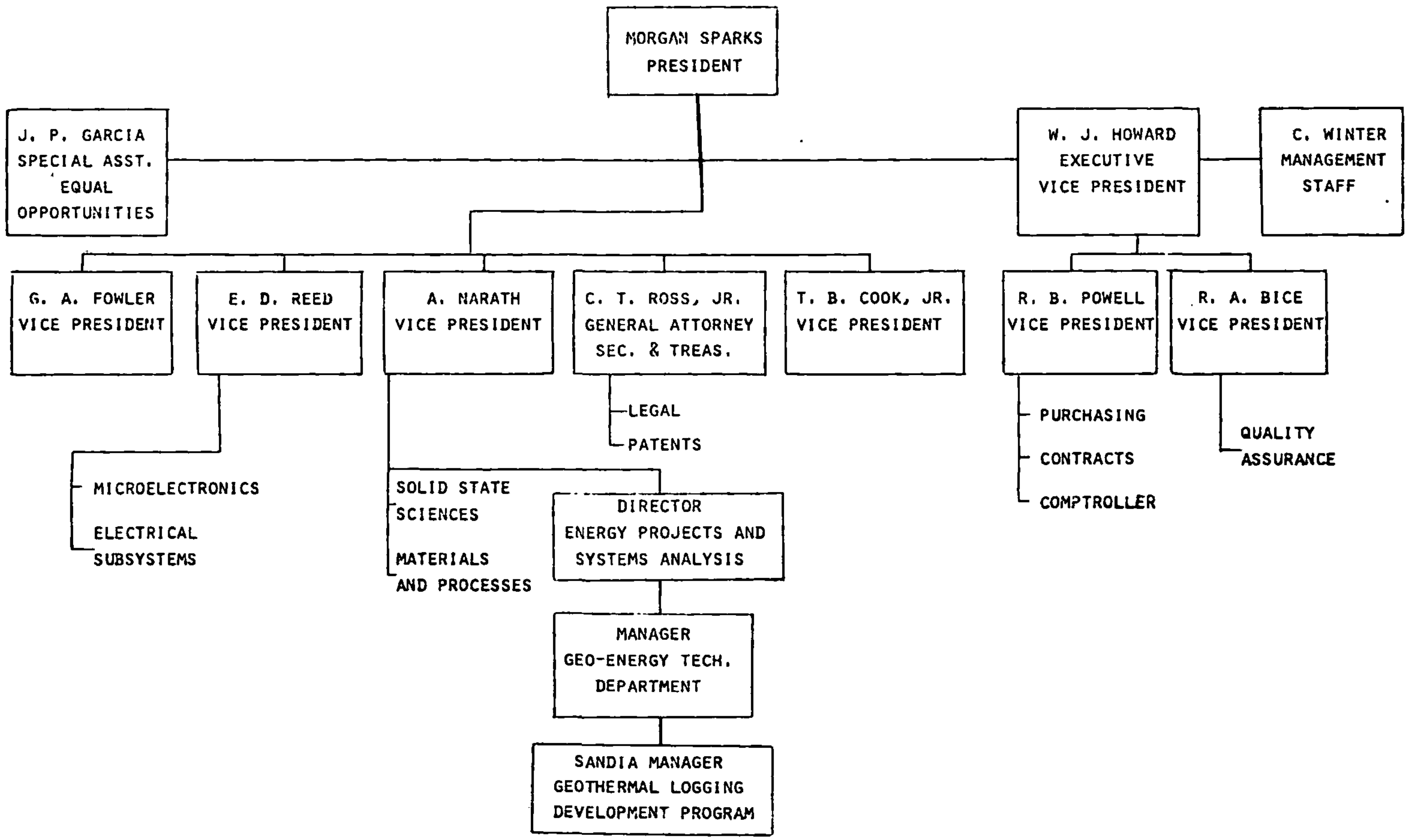
Each task will be headed by a Sandia task leader, who will be responsible for the management of the technical aspects and the monitoring of the contract activities in his area. In addition, technical specialists with appropriate backgrounds and areas of expertise will be assigned as technical reviewers for specific contracts. For example, a Sandia specialist in thermodynamics will be assigned responsibility to monitor the proposals, specifications, and progress on a downhole refrigerator. Similarly, Sandia engineers involved in an ongoing project in uranium logging will be assigned to advise the Sandia logging program manager on a project in nuclear techniques for measuring true formation temperature. Administrative support will be provided by the Sandia Auditing, Purchasing, and Legal organizations as required.

The relationship of DOE/DGE's Geothermal Logging Instrumentation Development Program to the Sandia Laboratories corporate structure is shown in Figure VII-2. The program will be administered by the Geo-Energy Technology Department of the Energy Projects and Systems Analysis Directorate. The management structure shown in Figure VII-2 provides the Sandia program manager with the mechanism for monitoring the technical and fiscal activities of the program. An important measure of the program performance will be in the form of periodic reviews to be given to DGE and cognizant Sandia upper management by the Sandia Program Manager and his task leaders.

C. Procurement and Contract Management

Sandia Procurement activites will be conducted in general accordance with established DOE procurement policy. Within the framework of the procurement system there is strong empahsis on competitive

FIGURE VII-2. SANDIA LABORATORIES MANAGEMENT STRUCTURE



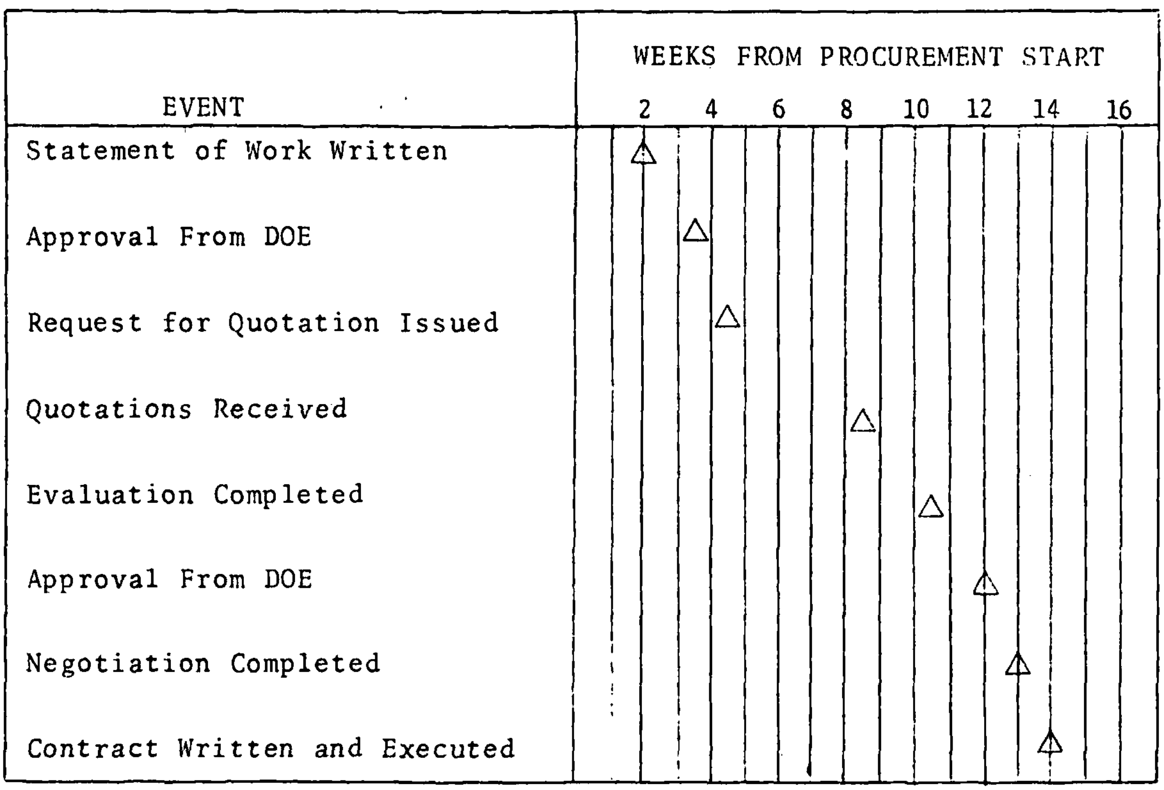
solicitation, with guidelines for request for quotations (RFQs), the method of proposal evaluation, and appropriate source selection techniques. Where facts and circumstances indicate the possible impracticability of placing a specific requirement on a competitive basis, the system provides for the possibility of non-competitive procurement on a sole source basis.

The Sandia Program Manager, in coordination with the responsible DGE program manager, will establish the requirements of major project tasks to be contracted. Procurement and competitive solicitation will be handled by a combination of Sandia technical and administrative personnel. Figure VII-3 illustrates a typical competitive procurement planning schedule. Contractor, technical, and fiscal activities and performance will be monitored through plant visits, review of contractor reports and component or subsystem performance at Sandia facilities or other outside facilities, as appropriate. The monitoring efforts will be conducted by the technical/procurment staff responsible for the respective contracts.

D. Project Administrative Approval Structure

In addition to the normal Sandia administrative approval procedure as set forth in the Sandia Laboratories Instructions (SLIs) for major contractual tasks, DGE retains approval right on the Statement of Work contained in RFQs that Sandia will issue to perform the work on the Project, and will have the opportunity to make additions to source lists. Sandia will send DGE documentation containing the key factors pertinent to the proposed RFQ including a proposed source list, at least ten days prior to initiating procurement action. Procurement will proceed after the ten-day period if no suggested

Figure VII-3. Typical Competitive Procurement Planning Schedule



changes are received by the Sandia Program Manager. Similarly, Sandia will send DGE the results of the source selection process at least ten days before notification of winners and will proceed with contract negotiation at the end of the ten-day period in the absence of objection by DGE.

DGE reserves the right to require publication of advance notice of intent to contract in the Commerce Business Daily.

E. Annual Operation Plan

Prior to the beginning of each fiscal year, at a time determined by DGE, the Sandia Program Manager will submit a Laboratory Program Approval Document (LPAD) which sets forth the specific objectives activites, schedule, funding requirements, in-house level of effort, project management personnel, and any special review or reporting procedures planned for the upcoming year. Upon approval of the LPAD, DGE will issue a Program Authorization Letter to implement the program.

F. In-house Research and Development

In-house technical work is necessary to complement the planned industry activities and also to maintain a viable technical expertise in the Laboratories' staff. In addition, Sandia Laboratories possesses many unique technological resources which can benefit the National Geothermal Program. The scope of the in-house work, as approved by DGE, may include the following:

1. High Temperature Components Development Task

Devices, materials and components suitable for use in geothermal logging systems will be identified, tested and evaluated. Efforts in this task will concentrate on Sandia's established expertise in high temperature electronics, metallurgy, ceramics, and polymers for severe environments. Special efforts will be made for rapid transfer of these technologies to the logging industry to stimulate their own inventions and contributions to geothermal logging development.

2. Prototye System Development Task

Sandia's engineering expertise in system integration will be used to complement the logging service industry in the development of prototype systems for near-term geothermal logging. Typically, Sandia will work with the logging industry by supplying the appropriate devices, components and circuits developed in Task 1 and contracting to industry for their incorporation into complete prototypes ready for test and evaluation in geothermal boreholes.

3. Borehole Test and Evaluation Task

The initial objective of this task is to test and evaluate prototype geothermal borehole instruments in appropriate laboratory and field environments. As this hardware development test phase reaches maturity, the activity will be directed toward development of tool calibration and normalization techniques in calibration holes or test pits. This will, of course, require close coordination with the respective managements of the Reservoir Engineering and Log Interpretation Programs.

4. Technical Contractor Support

The in-house work will include, as approved by DGE, technical specialist support of program element contractors. Support will generally take the form of technical reviews to anticipate needs and identify potential problems and, if necessary, trouble shooting and technical assistance if a contractor is in need of special technical help to successfully complete his project.

G. Sandia Support and Relevant Experience

Sandia is an equal opportunity DOE systems and component engineering and development laboratory employing about 7,300 people. Of these, about 6,300 people are at the Albuquerque Laboratories, where responsibility for this program will reside. The Laboratories have a wealth of experience in planning and managing important national energy program, both large and small.

As manager of the Geothermal Logging Instrumentation Development Program, Sandia's role and responsibility will be to plan, initiate, direct, integrate, and evaluate the activities needed to meet the specific objectives and schedules of the program. This will be done in close coordination with DGE management. Sandia possesses the expertise, resources and enthusiasm to accomplish this role in keeping with the overall spirit and objectives of the National Geothermal Programs.

For the necessary technical and administrative support of the program, the Sandia Program manager will draw upon the resources of the various Sandia organizations indicated in Figure VII-2. All of the organizations listed, except the legal organization, are directorates typically having 100-150 people each. These organizations are engaged in a broad range of research and technology development and comprise a pool of technological expertise relative to the program. The Program Manager will ask these functional organizations for appropriate project support. Especially related to the project are Sandia's technical capabilities in the areas of:

- Materials and device physics

- Materials and process development
- Component and subsystem evaluation and environmental testing
- Subsystem and system compatability testing
- System integration
- Systems analysis and research
- Rock mechanics research
- Computer code modeling and parametric studies of energy systems

Sandia is strongly committed to the development of geo-energy sources as demonstrated by current programs in the following areas:

- Geothermal drilling and completions
- Oil and gas drilling technology development
- In-situ coal gasification
- Enhanced gas recovery--massive hydraulic fracturing
- Enhanced oil recovery
- Supporting research studies in coal liquefaction
- Magma energy research
- Offshore technology

The experience gained and facilities acquired in the planning, operation, and management of these activities are of value to this instrumentation development program.

The FY77 effort in the above geo-energy areas was approximately 100 direct man-years. While substantial, this level of effort and its projected growth represent a very small fraction of the Laboratories' resources. It is expected that the present and future manpower and technical needs of the Logging Program can be met without difficulty and without disrupting other activities of the Laboratories.

H. Cost Control and Reporting

The Sandia Laboratories Case Cost System will be used for the control and allocation of funds. For this program, a budget case will be originated and will contain subordinate subcases. Monthly computer printouts will show in detail the status of each subcase. This information will be reviewed, aggregated by major task levels, and then summarized in the monthly program report to DGE as discussed below.

I. Project Reporting and Review

1. Project Reviews

In addition to periodic internal Sandia program reviews, formal progress reviews will be conducted semiannually for DGE management, Sandia management, and other designated program reviewers. The reviews will be in the form of detailed presentations on the status of the various program tasks to be given by the involved Sandia personnel or by the contractors. Project accomplishments, as well as problem areas affecting objectives, schedules, and costs, will be emphasized. Evaluations from these reviews will be utilized to update program plans and schedules. Special reviews and interface meetings may also be necessary at other times, such as prior to major program decision points.

2. Management Reports

a. Monthly Status Reports

A letter program report will be provided to DGE on a monthly basis, except when the month coincides with the due date for the semiannual report. The monthly reports will include the following:

1) Schedule status

2) Planned and acutual costs an obligations

3) Planned and actual in-house manpower

4) Significant accomplishments, any problems and problem resolution

5) Summary of interactions between Sandia and other participants in the National Program

6) Listing of contractor reports and in-house technical reports on the program

b. <u>Annual Reports</u>

Annual reports will be issued at the end of each fiscal year and will cover all aspects of the program. These reports will cover the achievements of the year and their implications relative to overall program objectives and milestones and will provide a measure of performance with respect to goals set forth at the beginning of the year.

c. <u>Contractor Reports</u>

Contractors will submit periodic progress reports to Sandia detailing the activities and accomplishments of their work. Emphasis will be on technical results, commercialization and transfer to the log industry, schedules, costs, and problem areas. Interim and final contract reports for public dissemination will be issued.

d. <u>Special Reports and Project Information</u>

From time to time it will be necessary to prepare special summary reports. This may be dictated by completion of a major program activity, a steering committee meeting, a workshop or by unusual or unexpected development affecting the overall program. Program information in the form of visual aids, desk-top models, and prototype hardware will be furnished to DGE to aid the staff in presenting program overviews as needed.

3. Dissemination of Technical Information

Sandia is a no-fee, no-profit DOE laboratory and energy R&D information is made available to all interested parties. All patents developed by Sandia's staff are assigned to the U.S. Government and are handled in accordance with DOE policies to protect the public interest.

In order to promote technology transfer to industry, commercialization, and to provide timely technical information to interested scientific and industrial communities at large, Sandia personnel actively involved in the technical work will participate in the presentation of technical papers at scientific meetings and workshops; contractor representatives will also be encouraged to do so. Significant technical accomplishments will be described in the form of special reports and will be submitted to appropriate scientific and technical journals. Appropriate Sandia publications, such as semiannual reports and technical reports, will be made available to the public through the National Technical Information Service. Publication of research results by contractors, in accordance with the terms of the contract and conditions regarding release of information, will be encouraged. Sandia public releases will be coordinated with the DGE program manager before publication. Seminars and workshops will be organized as deemed useful.

J. DOE/Laboratory Management Coordination

The need for close coordination of the Geothermal Logging Program with the activities of reservoir engineering, log interpertation and materials research has been discussed in Section II. Sandia will accomplish this integration by maintaining close contacts with the appropriate organizations responsible for managing related programs and with DGE regional program manager. To assist in coordination, Sandia has included participants for LASL, LBL, and DGE Headquarters on the Steering Committee. In addition, Sandia will participate in the planning and review activities in the Reservoir Engineering Management and Geothermal Log Interpretation Programs. This participation will include soliciting program plans, periodic reports to their management, staff and review panels, and appropriate participation in their respective program planning and task force reviews. Internal to Sandia, the Geothermal Logging Instrumentation Development Program will insure that Sandia is aware of activities of the Geothermal Drilling and Completions Technology Program, so that related needs and activities such as materials application, design and testing are fully coordinated and unnecessary duplication is avoided.

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