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# GEOTHERMAL ENERGY PROGRAM

ASSISTANT SECRETARY FOR
CONSERVATION AND RENEWABLE ENERGY

U.S. DEPARTMENT OF ENERGY

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# I. GEOTHERMAL ENERGY

## 1.0 INTRODUCTION

Geothermal energy sources are concentrations of the earth's internal heat stored in subsurface rocks and fluids at accessible depths. Geothermal energy can be used for electric power production, residential and commercial space heating and cooling, industrial process heat, and agricultural applications. Hydrothermal, geopressured, and hot dry rock are the three principal types of geothermal resources.

Hydrothermal resources include hot water and steam trapped in fractured or porous rock relatively near the surface. Worldwide installed geothermal electric capacity is 2,475 megawatts electric (MWe), with expansion planned through 1985 for an additional 2,450 MWe electric among 14 countries. Nine countries are making significant use of hydrothermal resources for nonelectric applications amounting to some 8,300 megawatts thermal (MWt). In the United States, electricity is generated at The Geysers steam field in California. The economic production of power from hot water reservoirs is expected in several western states in the near future. Hydrothermal resources already being used for direct heat applications in a number of western states could now be used at many more sites, including some eastern states.

Geopressured resources are hot water aquifers containing dissolved methane trapped under high pressure in deep sedimentary formations. Commercial production of energy (primarily methane) from these large resources may begin in the late 1980s along the U.S. Gulf of Mexico coast.

Hot dry rock (HDR) resources are geologic formations at accessible depths that have abnormally high heat content but contain little or no water. Usable energy is extracted by circulating a heat transfer fluid, such as water, through deep wells that are connected by manmade fractures in the rocks. Commercial production of energy from these resources is expected to occur in the early 1990s.

Estimates of the amount of U.S. thermal energy that could be recovered from these three resource types are presented in Table III-I-1. These estimates depend on a number of factors, including the available supply of geothermal energy, the economics of energy conversion, and estimates of future demand for electricity and heat. Estimates include energy potential at known sites as well as of inferred resources yet to be located.

Figure III-I-1 shows those areas of the United States already identified as having known or potential hydrothermal resources: 37 states are included. The West has the greatest potential for hydrothermal development, particularly for electric power generation and direct heat applications requiring relatively high temperatures. The Atlantic coastal area and southeastern states

Table III-I-1

## Estimates of Geothermal Energy Supply[1]

| Resource Type | Recoverable Resource Base[2] (Quads) | Energy for Utilization[3] (Quads) |
|---|---|---|
| Hydrothermal | | |
| 150°C | 920 - 1,430 | 90 - 140 |
| 90 - 150°C | 1,475 - 945 | 185 - 350 |
| Geopressured | | |
| Thermal | 270 - 2,800 | 30 - 320 |
| Methane | 158 - 1,640 | 80 - 820 |
| Hot Dry Rock | 1,400,000 | 230 - 1,780 |

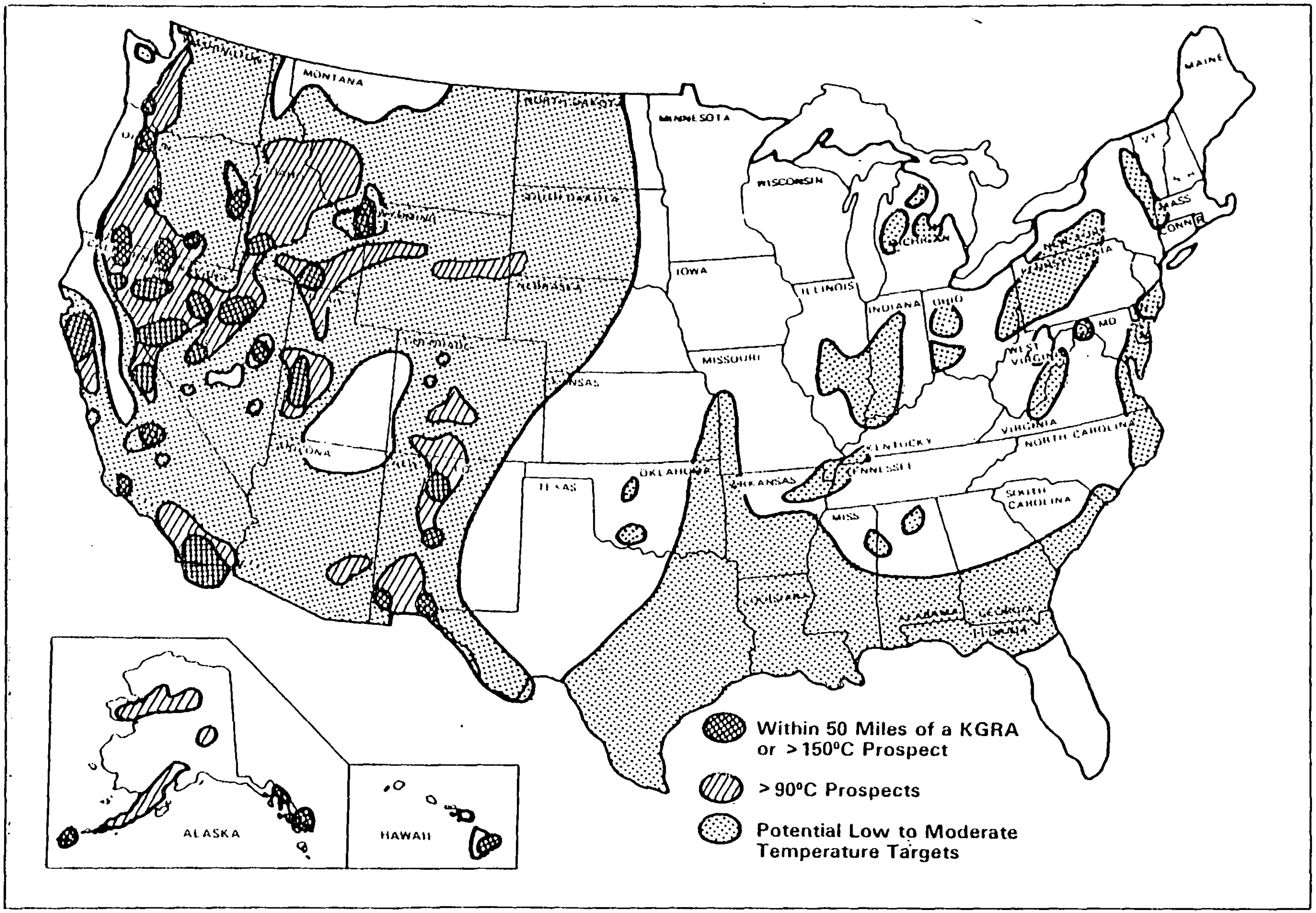
1 Based on data contained in USGS Circular 790 (1978)

2 Recoverable Resource Base (thermal energy); identified plus undiscovered
- (a) Hydrothermal = 0 - 3 km depth
- (b) Geopressured = 0 - 7 km depth; Northern Gulf of Mexico basin, both onshore and offshore
- (c) Hot Dry Rock = 3 - 7 km depth, assuming a recovery factor of 10%

3 Estimates of the amount of thermal energy that might be technically and economically feasible to extract from the earth at some future time.

Figure III-I-1

## Known and Potential Hydrothermal Resources



contain a number of prospective targets for development as low-to-moderate temperature heat sources. Geopressured resources are located primarily along the Texas and Louisiana Gulf Coast, but they appear in sedimentary formations elsewhere in the United States. Hot dry rock resources at usable depth are generally widespread in the West and may also exist in the East.

## 1.1 PROGRAM DIRECTION: PAST AND PRESENT

DOE vests its interests in geothermal energy in the Division of Geothermal Energy (DGE) under the direction of the Assistant Secretary for Conservation and Renewable Energy. Exceptions are some basic research conducted by DOE's Office of Energy Research. The DGE headquarters staff is organized into five branches: Program Coordination; Advanced Energy Systems; Geothermal Industrialization; Geosciences; and Hydrothermal Technology.

DOE's current program is focused primarily on research and development activities particularly in those areas which are high-risk and have potentially high payoff. Some of the more important R&D efforts include: drilling and completion technology; extraction, conversion and stimulation technology, geochemical engineering and materials research; environmental control; geosciences; and technology development associated with geopressured and hot dry rock resources.

## 1.2 PROGRAM ACCOMPLISHMENTS

The success of the geothermal program has accelerated the use of geothermal resource development by the private sector, both for generating electricity and for direct heat applications. Some of the specific accomplishments of the program in FY 1980/1981 are listed below:

- A market penetration analysis for hydrothermal resources has indicated the extent to which the private sector will develop these resources.
- State development planning efforts in 15 western states will be completed, having successfully identified and stimulated private sector interest in over 100 projects.
- The Geothermal Progress Monitoring system was established and provides early indications of success or shortfalls in geothermal development.
- The first high-flow rate geopressured reservoir assessment well has been completed and tested.
- Five loans for geothermal projects have been issued where $136 million have been guaranteed.

- The first well has been completed and the second well is near completion for the 20-50-MWt hot dry rock experiment at Fenton Hill, New Mexico.

- Leadership of the Interagency Geothermal Coordinating Council resulted in Congressional initiatives that provide enhanced tax incentives and regulatory exemptions for geothermal projects.

- The National Conference of State Legislatures participated in 41 state legislative workshops which led to the introduction of 58 geothermal bills by 12 state legislatures.

- Nineteen technical and economic feasibility studies of direct heat applications have identified prospective nonelectric users at low-to moderate-temperature hydrothermal reservoir locations.

- Six direct heat demonstration projects are operational and six others are expected to become operational in the next year.

- The Raft River, Idaho, 5-MWe pilot plant will be completed and turned over to a utility group.

- Successfully developed microcircuits for instrumentation that operate in high temperature geothermal environments. This is being commercialized by the private sector.

- Completed an agreement with the Federal Republic of Germany and Japan to share the cost of experimental work in Fenton Hill, New Mexico.

## 1.3 PROGRAM BENEFITS

The economic competitiveness of some high temperature hydrothermal resources, such as those already in production, has been clearly established. The Divisions's R&D effort will increase the economic competitiveness of liquid-dominated hydrothermal resources. This will be accomplished by developing improved technology designed to make electric power production more reliable and cost competitive using moderate temperature resources. In the United States the contribution from hydrothermal resources will range from 5,800 to 17,000 MW of electric power production and from 0.18 to 0.75 quads per year of thermal energy for direct heat applications by the year 2000. Beside the potential for reducing oil imports, geothermal heat is an environmentally benign energy source. It is a dispersed small-scale source that can have a significant economic benefit for rural areas.

The Division R&D effort to define and characterize geopressured resources has begun to confirm the great potential of the resource. Because the potential of geopressured resources is so large (428 to 4,440 quads) and because methane is such a desirable fuel, early evaluation of this resource is imperative.

The benefits of the hot dry rock R&D effort are also hard to quantify. Again, the tremendous magnitude of the resource (230-1,400,000 quads) justifies technology development to determine the technical and economic feasibility of using the resource. The fact that the Federal Republic of Germany and Japan are sharing the costs of research with DOE implies that hot dry rock has significant long-term potential.

## 2.0 RATIONALE FOR GOVERNMENT ACTION

In addition to displacing oil and benefiting rural areas, geothermal energy offers public utilities and private industry a noninterruptible energy supply that will not rapidly escalate in cost. Because of institutional, technical, and economic uncertainties currently associated with geothermal energy, the private sector views geothermal development as a high-risk venture. As a result most industrial investment to date has been limited to steam or high temperature/high flow rate hydrothermal reservoirs. However, the latest assessment of the amount of thermal energy that might be extracted from the nation's geothermal resources ranges from 780 to 3,245 quads. In view of the potential value of developing these very large resources, it is important that the government participate in the long-term/high-risk research and development required to reduce barriers to the small domestic geothermal industry.

The DOE geothermal program is part of the Federal Geothermal Energy Program, which was authorized through several statutes involving multiple agency responsibility and dispersed authority. The basic authorizing statutes affecting the DOE geothermal program are as follows:

- P.L. 93-410, the Geothermal Research, Development and Demonstration Act of 1974 -- established the national Geothermal Energy Coordination and Management Project (now the Interagency Geothermal Coordinating Council) and authorized a Geothermal Loan Guaranty Program.

- P.L. 93-438, the Energy Reorganization Act of 1974 -- created the Energy Research and Development Administration vesting in the Administrator the geothermal energy functions formerly performed by the National Science Foundation and the Atomic Energy Commission.

- P.L. 93-577, the Federal Non-Nuclear Energy Research and Development, and Demonstration Act of 1974 -- authorized ERDA to establish and conduct a comprehensive national program of basic and applied R&D, including commercial demonstrations of geothermal energy technologies and environmental control systems.

- P.L. 95-91, the Department of Energy Organization Act -- abolished ERDA, FEA, and the Federal Power Commission and transferred their respective functions along with other agencies in the Department of Interior to the Department of Energy. This act placed major emphasis on the development and commercial use of geothermal energy.

- P.L. 95-238, the Department of Energy Act of 1978 -- Title V amended the Geothermal RD&D Act of 1974; re-established the Interagency Geothermal Coordinating Council (IGCC) and enlarged its jurisdiction; increased the Geothermal Loan Guaranty provisions for maximum project loan guaranty and specifically included direct thermal applications as eligible projects.

- P.L. 96-294, the Energy Security Act, Title VI, the Geothermal Energy Act of 1979 -- contains provisions for reservoir confirmation loans, direct heat feasibility study and construction loans, reservoir insurance and a reinsurance feasibility study, modifications to the Geothermal Loan Guaranty Program, Federal buildings program, and exclusion of geothermal facilities of 80 MWe or less in the small power-producer category under the Public Utility Regulatory Policy Act. No funds have been appropriated for these programs.

These acts not only authorize research, development, and demonstration on technological and socioeconomic problems in the development of geothermal energy, but also assign DOE the lead responsibility for the Federal Geothermal Program, including the coordination of related policies and programs of other Federal agencies. The latter function is carried out for geothermal energy through the Interagency Geothermal Coordinating Council chaired by an Assistant Secretary in DOE.

## 3.0 PROGRAM STRUCTURE AND BUDGET

The basic program structure has not been changed even though the program has shifted from emphasizing both commercialization and R&D to primarily R&D. The private sector should now pursue the shorter term industrialization aspects of geothermal resource development. Major research and development elements that will be supported under DOE's redirected program include hot dry rock technology development, geopressured resource definition, and advanced technology development.

The geothermal energy program consists of five activities:

- Hydrothermal Industrialization
- Geothermal Resource Development Fund
- Geopressured Resources
- Geothermal Technology Development
- Program Direction.

Table III-I-2 presents the actual program activity funding levels for FY 1980 and the estimated funding levels for FY 1981 and FY 1982. The following sections describe these activities in more detail.

## 3.1 HYDROTHERMAL INDUSTRIALIZATION

This activity has included research, development, and demonstration projects designed to stimulate hydrothermal resource development, including:

- Resource definition in cooperation with the U.S. Geological Survey, state agencies, and industry.
- Nonelectric demonstrations to determine the engineering and economic aspects of using hydrothermal resources for direct heat. The participants have been selected through competitive solicitation.
- Planning and analysis activities and interagency coordination programs and state commercialization teams.
- Private sector development activities involving technical assistance centers, transfer of technology developed under the Federal geothermal energy program to the private sector, and legal and regulatory streamlining and reform.

Table III-I-2

## Funding Levels for Geothermal Energy Activities FY 1980 through FY 1982

| Activity | Budget Authority (Dollars in Thousands) Actual FY 1980 | Estimate FY 1981 | FY 1981 Rescission | Revised Estimates FY 1981 | Estimate FY 1982 | Increase (Decrease) |
|---|---|---|---|---|---|---|
| **Hydrothermal Industrialization** | **70,412** | **67,935** | **(12,374)** | **55,561** | **6,000** | **( 61,935)** |
| Resource Definition | 12,634 | 21,224 | ( 8,100) | 13,124 | 0 | ( 21,224) |
| Non-electric Demonstration | 9,778 | 11,500 | 0 | 11,500 | 0 | ( 11,500) |
| Planning and Analysis | 6,011 | 6,081 | 0 | 6,081 | 0 | ( 6,081) |
| Private-Sector Development | 3,409 | 2,378 | ( 274) | 2,104 | 0 | ( 2,378) |
| Geothermal Facilities | 35,363 | 24,152 | ( 4,000) | 20,152 | 6,000 | ( 18,152) |
| Environmental Control | 2,184 | 2,600 | 0 | 2,600 | 0[a] | ( 2,600) |
| Capital Equipment | 1,033 | 0 | 0 | 0 | 0 | ( 163) |
| **Geothermal Resource Development Fund** | **181** | **43,266** | **(22,066)** | **21,200** | **200** | **( 43,066)** |
| Program Direction | 181 | 193 | 0 | 193 | 200 | 7 |
| Guaranty Reserve Fund | 0 | 41,982* | (22,066) | 19,916 | 0 | ( 41,982) |
| Loan Evaluation Fund | 0 | 1,091 | 0 | 1,091 | 0 | ( 1,091) |
| Energy Security Act | 0 | 0 | 0 | 0 | 0 | 0 |
| **Geopressured Resources** | **34,692** | **35,800** | **( 3,865)** | **31,935** | **20,336** | **( 15,464)** |
| Resource Definition | 33,032 | 32,126 | ( 3,865) | 28,261 | 18,900 | ( 13,226) |
| Supporting Reserach and Development | 1,360 | 3,474 | 0 | 3,474 | 1,436 | ( 2,038) |
| Capital Equipment | 300 | 200 | 0 | 200 | 0 | ( 200) |
| **Geothermal Technology Development** | **41,178** | **49,910** | **( 2,261)** | **47,649** | **20,439** | **( 21,810)** |
| Component Development | 25,058 | 35,300 | ( 2,261) | 33,039 | 10,439 | ( 24,861) |
| Hot Dry Rock | 14,000 | 13,500 | 0 | 13,500 | 10,000 | ( 3,500) |
| Capital Equipment | 2,120 | 1,110 | 0 | 1,110 | 0 | ( 1,110) |
| **Program Direction** | **1,802** | **2,376** | **0** | **2,376** | **1,600** | **( 776)** |
| **Total Geothermal Energy** | **148,265** | **199,287** | **(40,566)** | **158,721** | **48,575** | **(150,712)** |

* Represents reappropriation of unobligated balances in FY 1981.

a Transferred to Geothermal Technology Development.

- Geothermal facilities constructed and operated to perfect new geothermal equipment and process techniques, particularly for electric power production. These facilities include a 50-MWe demonstration flash-steam power plant to produce electric power from a high temperature hydrothermal reservoir.

- Environmental control research and development seeking technological solution to environmental problems that might deter geothermal development.

## 3.2 GEOTHERMAL RESOURCE DEVELOPMENT FUND

The Geothermal Energy Resource Development and Demonstration Act of 1974 provided for the establishment of the Geothermal Loan Guaranty Program and the Geothermal Resource Development Fund to support the federal geothermal energy program. Five loans have been guaranteed. The loan guaranty program is now being phased out as responsibility is being shifted to the private sector. The Energy Security Act (1980) authorizes expenditures from the fund for reservoir confirmation loans and feasibility study loans. The Energy Security Act also provides for a study of the need for a reservoir insurance program. If such a program is enacted, appropriations will be required prior to the start-up of this program. To date, no appropriation bill has been enacted for any of the Energy Security Act programs.

## 3.3 GEOPRESSURED RESOURCES

The objective of this activity is to assess the onshore geopressured geothermal resource by delineating, through data gathering and surface work, optimum Gulf Coast reservoir areas, and by performing confirmation drilling and testing to obtain reservoir and brine characteristics needed to establish the commercial viability of the resource to provide heat, hydraulic pressure energy, and entrained or dissolved methane.

Wells that have been drilled into or through geopressurized reservoirs by the private-sector petroleum industry in the search for oil and gas have been made available for testing and provide information on important properties of the reservoir fluids (e.g., salinity, water chemistry, gas chemistry, and gas-to-water ratios) and on the reservoir characteristics around the wellbore.

These activities include supporting research and development addressing the longer term technology development required for ultimate commercial use of geopressured resources by the private sector.

## 3.4 GEOTHERMAL TECHNOLOGY DEVELOPMENT

The Geothermal Technology Development activity seeks technical solutions to the problems of operating in geothermal environments. The component technology efforts focus on: developing techniques, materials, and equipment specifically tailored to geothermal conditions; and reducing technology costs.

Research into high-temperature drilling technology, reservoir stimulation, wellbore pumping, and binary power plants will have a great impact on geothermal energy costs. Research in exploration technology and reservoir engineering will accelerate discovery of new resources and provide a methodology for evaluating the financial risk of reservoir-related development. In most instances, major technological advances will result in more economic recovery of energy from geothermal resources.

The activity also assesses the potential of hot dry rock resources and supports development of new energy extraction techniques. Although research began in 1972, the present hot dry rock program was started in FY 1979 after successful operation of a 5-MWt thermal loop at the Fenton Hill site in New Mexico in 1978. The general objectives of this effort are: (1) to confirm the potential of HDR resources; (2) to develop a technology base for HDR energy extraction; (3) to verify the acceptability of environmental and social consequences of HDR energy development.

3.5 PROGRAM DIRECTION

Several hundred DOE geothermal projects are active throughout the United States and abroad. In addition, DOE has significant federal interagency coordination responsibilities with respect to geothermal development.

Management of such a complex program requires a geographically dispered organization that employs a wide range of professional skills. DOE's management approach is to concentrate policy, planning, overall budget definition, and program defense activities at its Washington, D.C. headquarters. DOE field organizations (i.e., operations offices, national laboratories, and regional representatives) are responsible for project definition, day-to-day project management in the field, and coordination with state and local authorities.

DOE, designated as the lead agency for Federal geothermal development, works through the Interagency Geothermal Coordinating Council (IGCC) to guide the Federal Geothermal Program. The Council, chaired by DOE, is made up of representatives at the Assistant Secretary level from 8 federal agencies involved in geothermal activities; about 25 agencies are represented in working groups, panels, and committees. The major research and development is carried out by DOE and by agencies of Department of Interior (DOI), especially the U.S. Geological Survey (USGS), the Bureau of Mines, and the Bureau of Reclamation. Environmental research, monitoring, and policy development is the primary responsibility of the Environmental Protection Agency, as well as USGS and U.S. Fish and Wildlife Service, and DOE. Federal geothermal land leasing is accomplished by DOI's Bureau of Land Management with the assistance of USGS, and the U.S. Forest Service on Federal lands administered by the U.S. Department of Agriculture.

The IGCC fulfills its oversight and coordination functions through a staff committee, budget planning and working group, and through panels. The body serves as a vehicle to develop a comprehensive Federal Geothermal Program Plan; prepare a combined federal geothermal budget request to the President's Office of Management and Budget; prepare an annual report to Congress on program strategy, plans and achievements; and recommend appropriate changes in national policy and legislation.

The major management centers for DOE geothermal programs are listed below:

- DOE Nevada Operations Office
- DOE Idaho Operations Office
- DOE San Francisco Operations Office
- Los Alamos National Laboratory
- Lawrence Berkeley Laboratory
- Idaho National Engineering Laboratory
- Sandia National Laboratories.

## 4.0 GOALS, STRATEGIES, AND PRIORITIES

### 4.1 PROGRAM GOALS

DGE's goals are different for each resource reflecting the different stages of development of their respective technologies.

#### 4.1.1 Hydrothermal Resources

The potentially useful geothermal resources in the United States span a broad spectrum of reservoir temperatures and fluid chemistry. The higher temperature (T>400°F) liquid-dominated hydrothermal resources are presently marginally cost competitive with alternative energy sources and are the major target of the private sector's development activities. However, the temperature distribution of the resource is such that most of the potential occurs at temperatures below 400°F where technological innovation is required to make development economically feasible. The objective of the geothermal R&D program is to develop new or improved technology that will expand the economically exploitable resource base (by a factor of four or more) while complementing current private sector activities.

The goal is to reduce geothermal field development costs by 25 percent, to reduce capital costs for electric generating facilities by 20 percent, to improve resource utilization effiiency, and to reduce the risks in all aspects of geothermal fluid handling (production, utilization, treatment, and disposal), which by the year 1987 will have the overall effect of reducing the electric busbar costs by 10 to 15 percent for high-temperature geothermal resources and as much as 30 percent for moderate-temperature resources.

#### 4.1.2 Geopressured Resources

Several recent investigations have indicated that the geopressured-geothermal aquifers of the Texas and Louisiana Gulf Coast contain vast quantities of dissolved natural gas and represent a significant source of hydraulic and thermal energy (for electric power production and direct heat uses). The reservoir characteristics of the geopressured aquifers have not been adequately examined even though thousands of oil and gas wells have penetrated the geopressured formations.

The goal is to conduct R&D activities directed primarily at resource definition (including the confirmation of optimum reservoirs), and to identify and resolve key engineering, environmental and institutional problems. These R&D activities will provide a basis for industry to begin developing geopressured resources by 1986.

#### 4.1.3 Hot Dry Rock Resources

Extracting heat energy from hot dry rock has proved to be technically feasible on a small scale at Fenton Hill in New Mexico.

However, the economics of full-scale energy production for electric power and direct use applications have not been fully assessed.In addition, the magnitude and geographical distribution of the resource are not fully known.

The goal, therefore, is to conduct R&D activities aimed toward resource definition and improved energy extraction technology that will provide the necessary data to support evaluating the technical and economic viability of HDR resources for commercial deployment by 1990.

#### 4.1.4 Geothermal Loan Guaranty Program

Five loans have been guarantied. The goal is to manage these guaranties until the projects are brought to a successful conclusion.

#### 4.1.5 50-MWe Flash Electric Power Demonstration

The 50-MWe flash steam electric power demonstration project is in the final stages. The goal is to complete construction in 1983 and then to turn the project over to the private sector.

### 4.2 PROGRAM STRATEGY

The aim of the geothermal program is to transform the many types of geothermal resources into an array of technically, economically, and environmentally sound sources of energy. The strategies reflect the different conditions of technical and economic readiness of the three resource types (hydrothermal, geopressured, and hot dry rock).

For hydrothermal energy, the strategy is to continue to work with industry to identify technical problems that significantly affect the technical and economic feasibility of hydrothermal applications, to assess the need for Federal involvement in seeking solutions, and, where applicable, to perform the high risk/high payoff research and development needed. This applies to component technology, geosciences, and environmental control technology.

In addition to methane, the geopressured resource contains thermal and hydraulic energy; however, the methane has the highest economic value making it the economic determinant. Therefore, the strategy will focus on methane recovery. Since little is known about recoverability of energy from geopressured resources, the first element of the strategy is to collect reservoir performance data through a series of high-rate, long-term flow tests of geopressured wells during the next 3-4 years. The second element of the strategy is to collect fluid characteristics data from a series of tests of nonproducing oil and gas wells that have penetrated a geopressured reservoir.

Hot dry rock resources could be a significant energy source in the long term, but HDR technology is at the earliest stages of development. The strategy is to concentrate on energy extraction experiments to refine the technology and to decrease costs. Development of drilling and fracturing technology for high temperature environments will be emphasized in the 20-50-MWe thermal loop experiment.

### 4.3 PRIORITY

The highest priority of the program is to conduct research and development on the high-risk/high-payoff technologies. The geopressured program focus is on determining the technical and economic feasibility of obtaining methane from the geopressured resources. The hot dry rock program focus is on determining the technical and economic feasibility of obtaining energy from this vast resource. To benefit the development of all geothermal resources, component technology R&D development focuses on long-term, high-risk/high-payoff activities.

## 5.0 ISSUES

This section describes the key impediments to the development of geothermal resources and DGE's response.

<u>The energy potential and longevity of hydrothermal systems is unknown.</u> DGE collaborates with USGS to conduct regional and national assessments of hydrothermal resources. Reservoir engineering, and reservoir modeling and assessment techniques are being developed. Producing reservoirs are being monitored to obtain data and to test the models. Private industry will be reluctant to develop economically viable projects without sufficient information about the extent of the resources.

<u>Current costs of utilization technologies make some resources unattractive.</u> To reduce the cost of exploiting hydrothermal resources, DGE conducts research and development to create more reliable, efficient, and less costly technologies. Development of the marginal geothermal resources will be limited if the technology is not improved.

<u>The discovery and utilization of geothermal resources is impeded by a lack of materials and equipment appropriate to geothermal conditions.</u> Technology improvements would reduce the cost of the wells that must be drilled to bring geothermal power on line. DGE works with research laboratories and private industry to develop and field-test new methods, equipment and materials capable of withstanding the effects of heat, brine, and other characteristics of geothermal fluids. This activity produces advancements in drill bit and pump technology, geochemical engineering and materials, energy conversion and environmental control technology.

Because of the expense involved in developing this new and specialized technology for a currently small market, it is unlikely that private industry would find it cost-effective to develop these technologies. Without the technical progress provided by these activities a large portion of the resource will not be made available for development.

<u>The size and producibility of geopressured resources is unknown.</u> DGE conducts activities to determine the magnitude, availability, and producibility of geopressured resources. Because the characteristics of geopressured aquifers vary widely, a substantial number of tests will be required to predict the potential of this resource. DGE focuses on well tests to identify reservoir characteristics and basic drive mechanisms that enable the production of geopressured brine.

Because of the complexity and variability of the geopressured resource base, research is still in the initial stage. Without this research, private industry will not undertake development of a resource of such uncertain and long-range potential.

The technical feasibility of fracturing hot dry rock to economically recover heat energy is unknown. Development of this resource depends on significant improvements and cost reduction in current drilling and fracturing technology. DGE has successfully operated a 5-MWt loop facility at Fenton Hill, New Mexico. A 20-50 MWt loop is also being developed at Fenton Hill for research and demonstration of thermal energy extraction.

Without technical field experiments and pilot projects, the economic viability of hot dry rock technology cannot be assessed. A potentially significant source of energy would remain undeveloped.

The private sector has limited knowledge about the long-term potential of geothermal resources and technologies. Private development of geothermal resources has been impeded because information on which to base the necessary long-range planning decisions has been unavailable or very costly. The exploratory and technical development activities of DGE are designed to expand this information base. In addition to publications, surveys and forums for technology transfer to private industry, DGE also provides potential users with information on the availability and competitive cost of geothermal energy.

Knowledge about the geothermal resource base and the technology to exploit it is growing steadily. Without programs to facilitate transfer of technology, private industry will not be able to pursue economically competitive projects in a timely and least-cost way.

The environmental effects of extensive production of geothermal energy are not known. The cost of complying with environmental regulations can be a barrier to private developers. Without assurance of the existence of environmental compliance technology, private industry is discouraged from investing in geothermal resources.

## 6.0 PROGRAM ELEMENT DESCRIPTIONS

### 6.1 HYDROTHERMAL INDUSTRIALIZATION

Hydrothermal resources consist of hot water and steam trapped in the earth. Different energy conversion systems are used to recover the energy found in hot water or steam hydrothermal resources. Electricity is generated from dry-steam deposits by passing the steam directly through turbines. Liquid-dominated deposits are exploited for electric power either by flashing the hot liquid into usable steam at the surface (flash-steam system) or by transferring its heat to a secondary working fluid which in turn is vaporized to drive a turbine-generator (binary-cycle system).

Energy derived from hydrothermal resources can also be used for direct thermal applications. These non-electric applications, primarily space conditioning and industrial process heat, are feasible using fluids from reservoirs at temperatures suitable for electric power generation as well as at lower temperatures. Hot water is piped directly from the geothermal reservoir over relatively short distances to the point of use.

Thirty-seven states contain hydrothermal resources; most western states contain known geothermal resource areas. Substantial electric power and direct use capacity is expected to be realized by 1984. Projections of approximately 2,600 MWe of electric power generating capacity and nearly 300 MWt of thermal power reflect the near-term potential for this resource.

The major objective of the Hydrothermal Industrialization activity was to encourage private-sector development and commercial use of hydrothermal resources for electric power production and direct heat applications. The activity consists of RD&D projects designed to stimulate geothermal development by the private sector.

The Hydrothermal Industrialization activity is divided into five major subactivities:

- Resource Definition
- Non-Electric Demonstration
- Planning and Analysis
- Private-Sector Development
- Geothermal Facilities.

These subactivities and the tasks comprising them are described in the following sections.

### 6.1.1 Resource Definition

DOE and USGS are collaborating on a federal program to establish the extent of geothermal resources and their locations throughout the United States. The objectives of the assessment program are: (1) to characterize the geological nature of each type of geothermal resource; (2) to estimate the location, distribution, and energy content of geothermal resources in the United States; and (3) to evaluate geothermal energy potential in the United States through inventory of the identified portion and prediction of the undiscovered portion of the nation's resources.

In pursuit of these objectives, DGE has worked with the USGS to conduct regional and national assessments of hydrothermal resources. Additionally, DGE supports drilling to confirm high-temperature reservoirs with near-term commercial potential under projects cost-shared with private resource developers. Areas of high promise for low- to moderate-temperature reservoirs are the targets of geological and geophysical analyses in projects supported by joint federal and state funding. Further, an exploratory drilling task has focused on several regions with potential for direct heat applications, but without confirmed hydrothermal reservoirs. DOE support for this task will end in FY 1981 with responsibility being shifted to the private sector.

### 6.1.2 Nonelectric Demonstration

Use of geothermal energy for nonelectric purposes by the private sector within the United States has been limited. There is, however, a large potential market for thermal energy in the 50° to 150°C temperature range used in industrial processing (paper mills, sugar refineries, and other chemical and food processing plants); agribusiness (space-, soil-, and water-heating in applications such as greenhouses, fish farming, and animal husbandry); and space/water-heating of commercial downtown business districts (shopping centers, schools, hospitals); and in residential buildings.

### 6.1.3 Planning and Analysis

This activity formulates geothermal development plans, maintains a national progress monitoring system, assesses the market penetration potential for hydrothermal resources, and identifies direct heat markets suitable for early market penetration. Other activities encompass continuing interagency coordination and policy development.

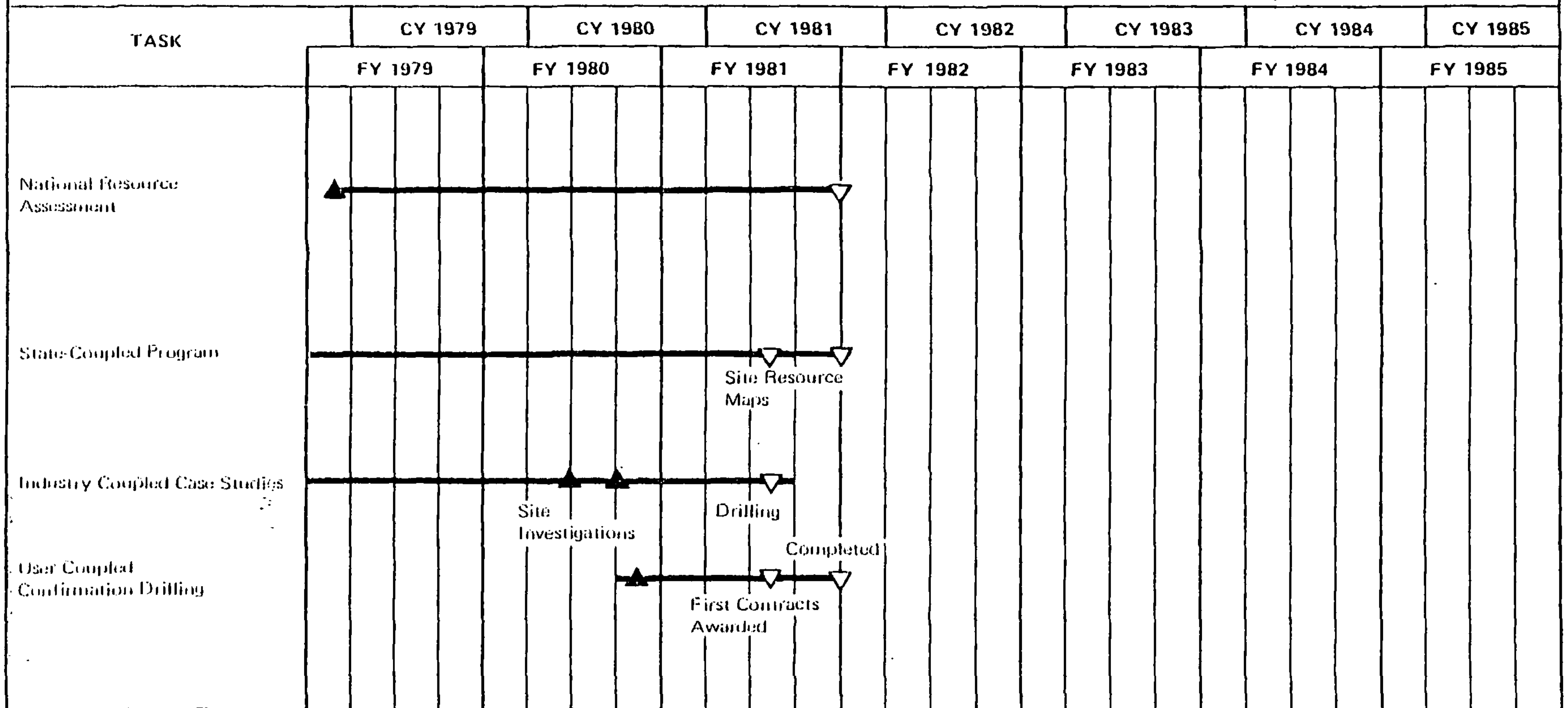
### 6.1.4 Private-Sector Development

This subactivity includes projects designed to acquaint potential users with: the availability and competitive cost of hydrothermal energy; the availability of financial assistance through various federal programs; the availability of technical assistance to start projects; and the availability of legal assistance to help states prepare appropriate legislation.

Exhibit III-4-1

ACTIVITY · HYDROTHERMAL INDUSTRIALIZATION
SUBACTIVITY RESOURCE DEFINITION

LEGEND
△ BEGIN MILESTONE
▽ END MILESTONE
◁ DECISION MILESTONE
▲ COMPLETED TASK
◆ ORIGINAL MILESTONE




| Total Budget Authority (Dollars in Thousands) | FY 1979 | FY 1980 | FY 1981 | FY 1982 | FY 1983 | FY 1984 | FY 1985 |
|---|---|---|---|---|---|---|---|
| | 26,163 | 12,818 | 21,224 | 0 | | | |

Exhibit III-I-2

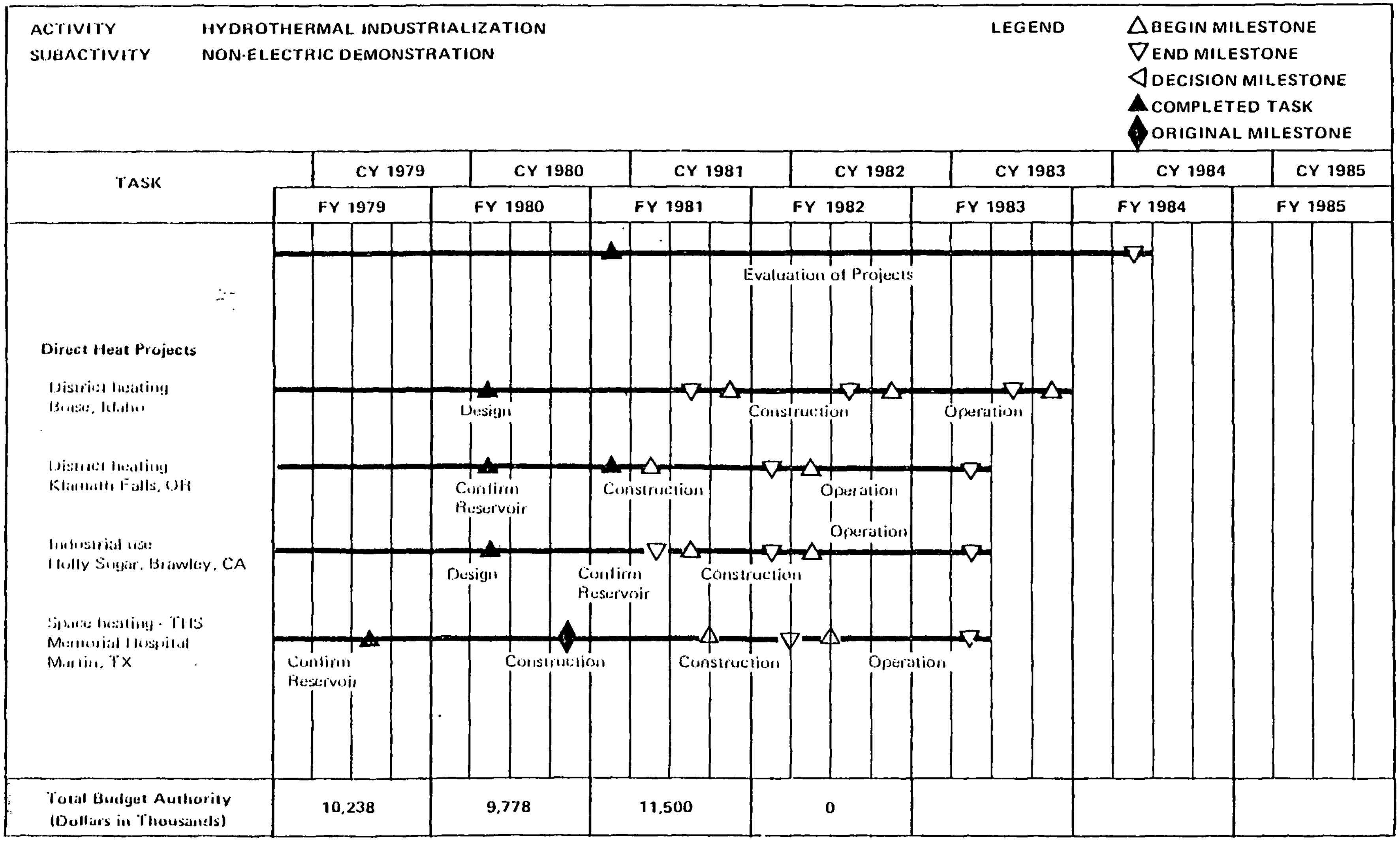


Exhibit III-1-3

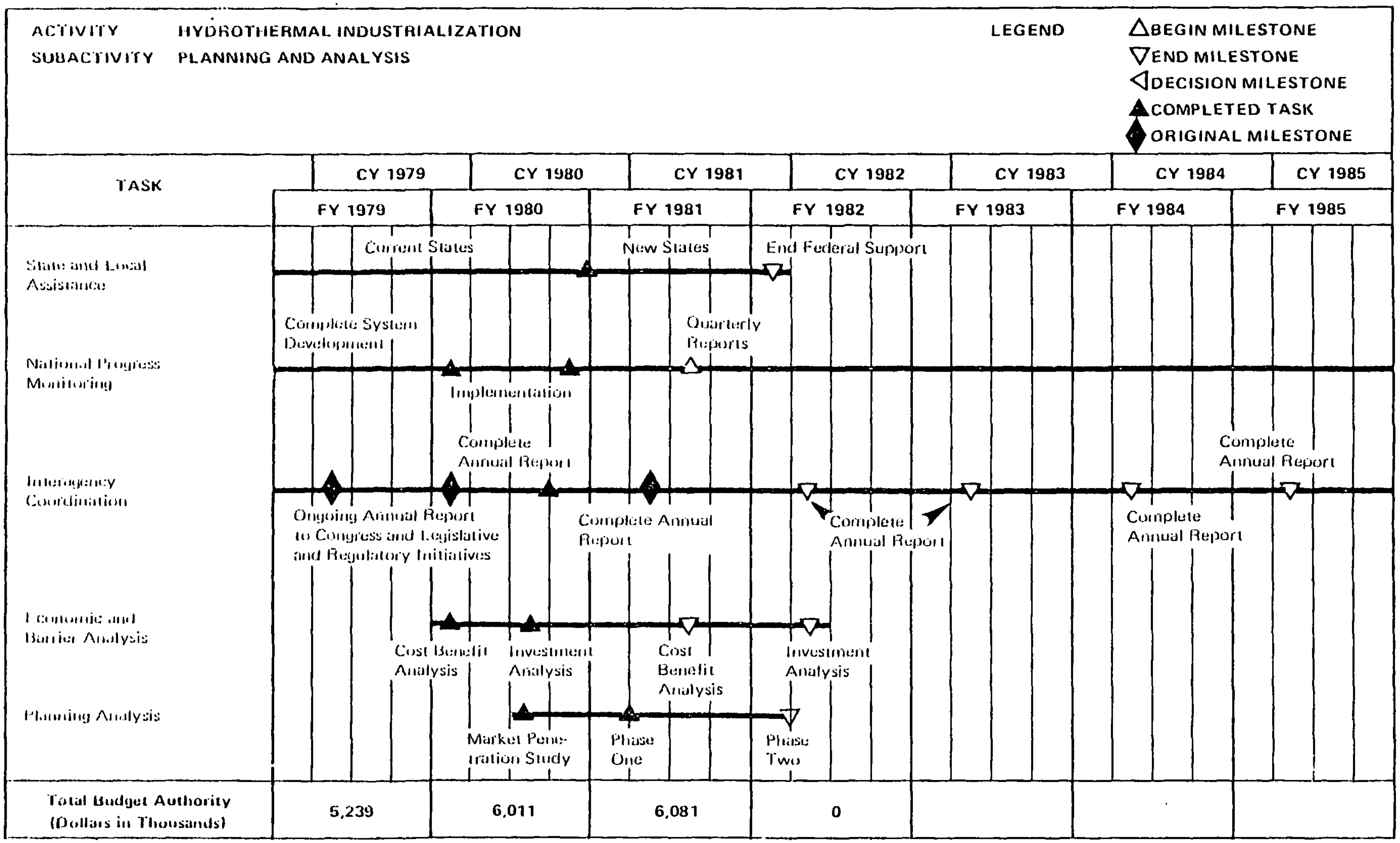
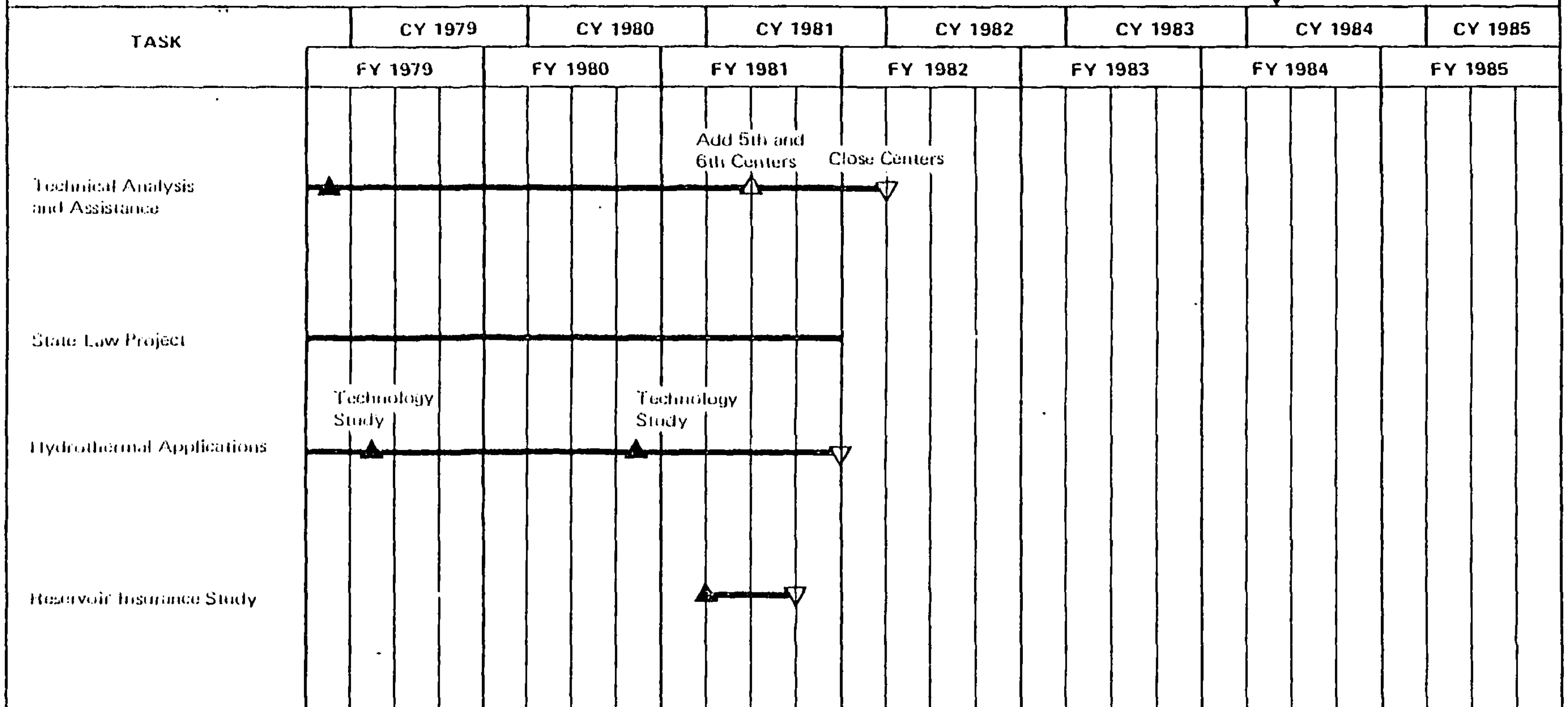


Exhibit III-4-4

ACTIVITY HYDROTHERMAL INDUSTRIALIZATION

SUBACTIVITY PRIVATE-SECTOR ANALYSIS

LEGEND
- △ BEGIN MILESTONE
- ▽ END MILESTONE
- ◁ DECISION MILESTONE
- ▲ COMPLETED TASK
- ◆ ORIGINAL MILESTONE




| Total Budget Authority (Dollars in Thousands) | FY 1979 | FY 1980 | FY 1981 | FY 1982 | FY 1983 | FY 1984 | FY 1985 |
|---|---|---|---|---|---|---|---|
| | 4,410 | 3,409 | 2,378 | 0 | | | |

Exhibit III-1-5

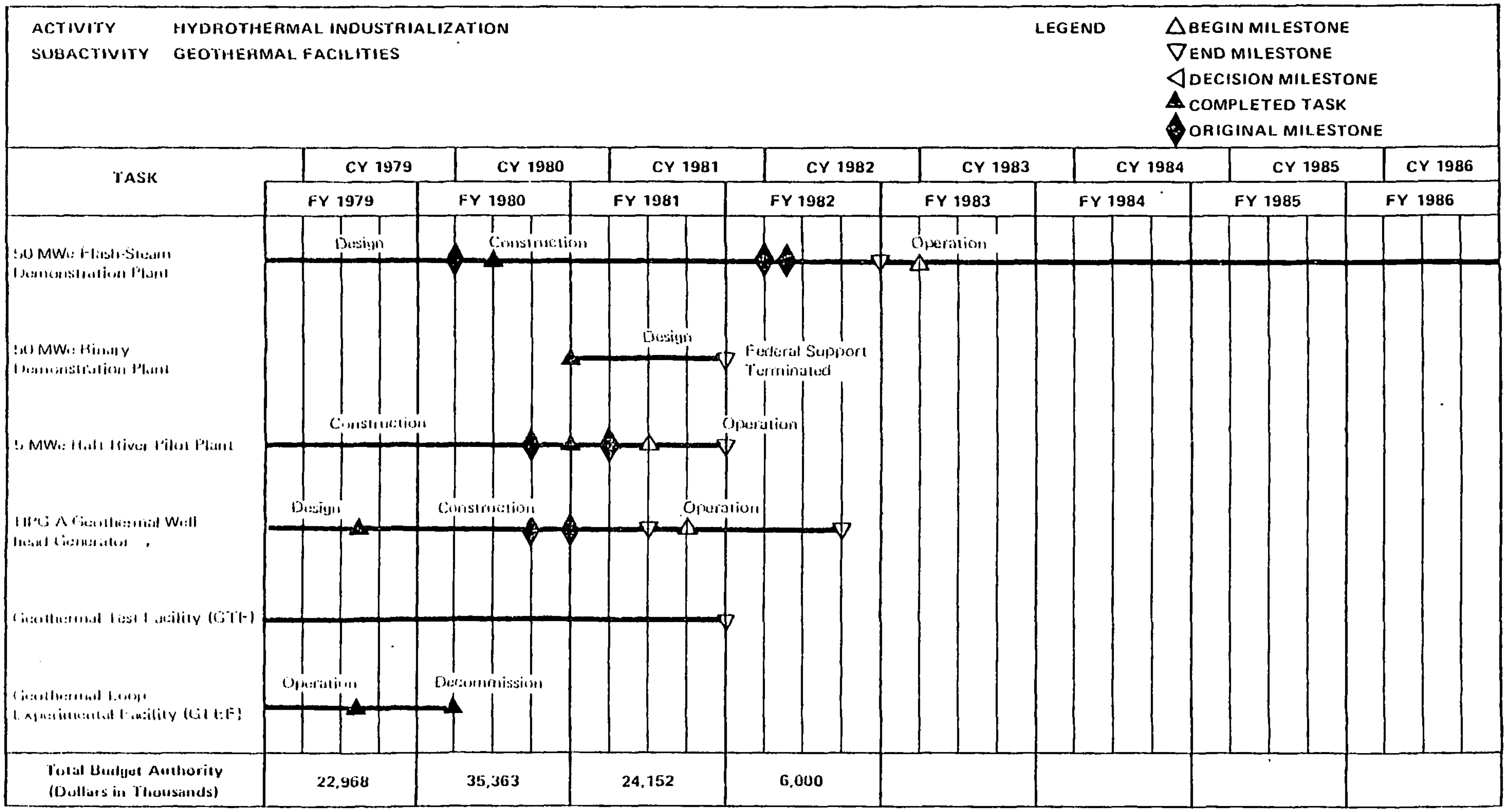


Table III-I-3

## Funding Levels for Hydrothermal Industrialization Subactivities FY 1980 through FY 1982

| Subactivities | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Resource Definition | 12,634 | 21,224 | 0 | (21,224) |
| Non-Electric Demonstration | 9,778 | 11,500 | 0 | (11,500) |
| Planning and Analysis | 6,011 | 6,081 | 0 | ( 6,081) |
| Private-Sector Development | 3,409 | 2,378 | 0 | ( 2,378) |
| Geothermal Facilities | 35,363 | 24,152 | 6,000 | (18,152) |
| Environmental Control[a] | 2,184 | 2,600 | 0[a] | ( 2,600) |
| Capital Equipment | 1,033 | 0 | 0 | ( 0) |
| **Total** | **70,412** | **67,935** | **6,000** | **(61,935)** |

a Transferred to Geothermal Technology Development.

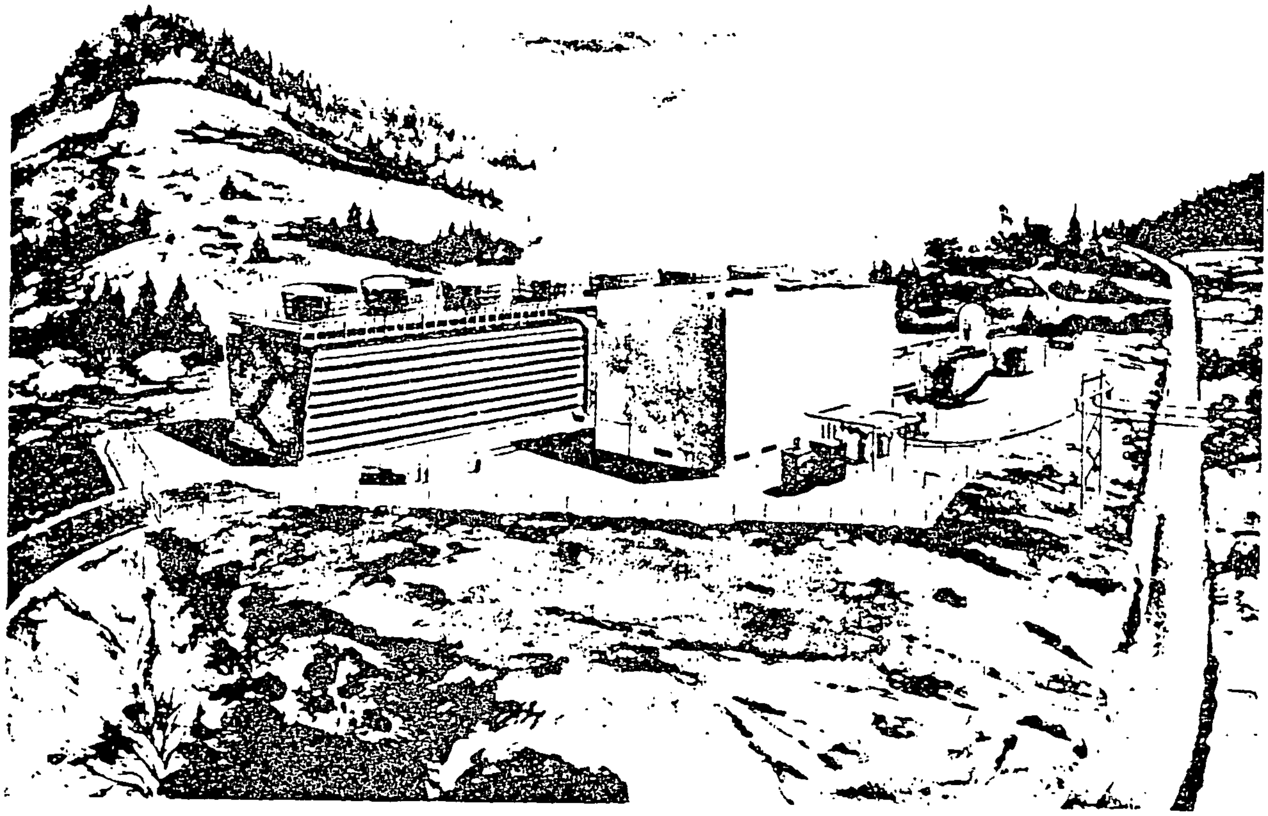


Figure III-1-2

50-$MW_e$ Hydrothermal Demonstration Plant

### 6.1.5 Geothermal Facilities (Electric)

DGE has supported the design, construction, and operation of pilot and commercial-scale electric power plants. These facilities generate technical and economic operating data and provide information on the environmental impact of geothermal electric power generation.

The purpose of these pilot plants and test facilities is to stimulate non-federal development of liquid-dominated hydrothermal resources for generating elecric power by (1) demonstrating technical and economic feasibilty and environmental acceptability of geothermal systems, (2) providing "hands-on" operating experience for industry, and (3) fostering growth of an industrial infrastructure necessary for wide-scale use of geothermal systems.

## 6.2 GEOTHERMAL RESOURCE DEVELOPMENT FUND

The Geothermal Energy Research Development and Demonstration Act of 1974 provided for the establishment of the Geothermal Loan Guaranty Program (GLGP) and the Geothermal Resource Development Fund to support the program. The Energy Security Act (1980) authorized appropriations to the fund for reservoir confirmation loans and feasibility study loans. The Energy Security Act also provides for a study of the need for a reservoir insurance program.

The Geothermal Resource Development Fund activity has been divided into four subactivities. These are:

- Program Direction
- Guaranty Reserve Fund
- Loan Evaluation Fund
- Energy Security Act.

## 6.3 GEOPRESSURED RESOURCES

The objective of the Geopressured Resources activity is to determine the magnitude and economic potential of this resource. To accomplish this objective, efforts are underway to define the extent of the resource (principally natural gas potential), demonstrate recovery potential, and identify possible environmental effects of development.

Geopressured aquifers are underground reservoirs of hot, overpressured brine that contains methane in solution. Such geopressure-geothermal aquifers are known to occur in the United States along the Gulf of Mexico Coast, the Pacific Coast, and in Appalachia, as well as in deep sedimentary basins elsewhere in the nation. Extraction of methane, thermal energy, and mechanical energy from these aquifers could make a substantial contribution to U.S. energy supply.

Table III-I-4

## Funding Levels for Geothermal Resource Development Fund Subactivities FY 1980 through FY 1982

| Subactivity | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Program Direction | 181 | 193 | 200 | 7 |
| Guaranty Reserve Fund | 0 | 41,982* | 0 | (41,982) |
| Loan Evaluation Fund | 0 | 1,091 | 0 | ( 1,091) |
| Energy Security Act | 0 | 0 | 0 | 0 |
| **Total** | **181** | **43,266** | **200** | **(43,066)** |

* Represents reappropriation of unobligated balances in FY 1981.

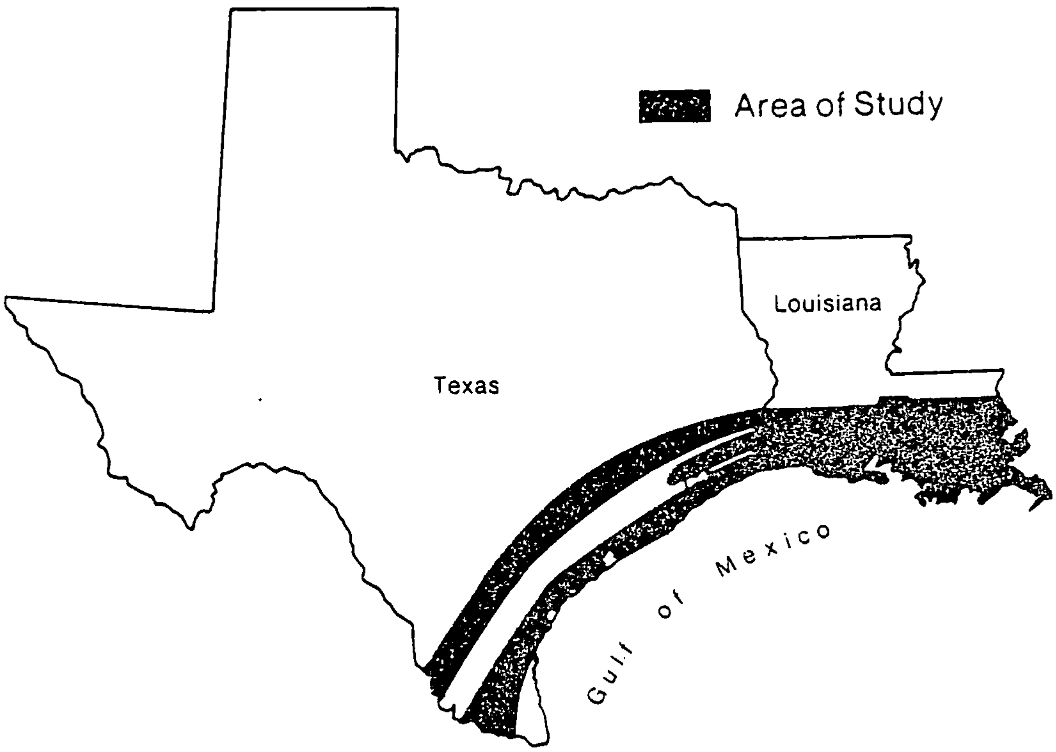



Figure III-I-3
Gulf Coast Geopressured Zones

The geopressure-geothermal resource base (energy in the ground) is believed to be substantial. Estimates of the amount of in-place methane range between 1,000 and 50,000 trillion cubic feet (Tcf). This large variation reflects uncertainties about the geographic area, the size of the reservoirs, and the volume of methane dissolved in the geopressured brines. USGS estimates that 5,700 Tcf of natural gas is contained in the waters of sandstone formations in onshore and offshore areas along the Gulf of Mexico. Recoverability has been estimated at 50-5,000 Tcf. (This is significant in that the United States uses about 20 Tcf of natural gas per year.)

The initial target for DOE's geopressured resources activity is the methane in solution in aquifers found in the onshore coastal areas of Texas and Louisiana. The importance attached to the recovery of methane stems from the larger size of the resource and its high recovery potential relative to that of thermal and mechanical energy.

The Gulf Coast oil and gas producing industry can be expected to undertake rapid commercial development of geopressured resources. The Geopressured Resources activity is designed to show that the resource base is sufficiently large and that it can be tapped economically without unacceptable environmental effects. DGE supports activities in resource definition and environmental

The Geopressured Resources activity is divided into two major subactivities:

- Resource Definition
- Supporting Research and Development.

These subactivities are discussed below.

### 6.3.1 Resource Definition

The purpose of the resource definition effort is to establish the location and size of the aquifers by conducting geologic studies and well tests. This will build a base of engineering and geologic data by the end of FY 1986, and is expected to reduce the uncertainty associated with the size and nature of the recoverable resource, and will establish the location of aquifers suitable for commercial development.

Aquifer data will be gathered as an output of the wells of opportunity and design wells programs. The Gas Research Institute is cooperating with DOE in these efforts.

#### 6.3.1.1 Wells of Opportunity

These are wells that the petroleum industry has drilled into or through geopressured reservoirs in the search for oil and gas, and that are made available for testing. The advantage of using these wells for short-term tests of geopressured zones is that they allow DOE to obtain valuable information at costs considerably below those of design wells. The disadvantage is that these wells are often drilled on-structure or near structural closure for entrapment of hydrocarbons; accordingly, they may not be in the most favorable locations for testing high-volume delivery of aquifers. The testing provides information on important properties of the reservoir fluids (e.g., salinity, water chemistry, gas chemistry, and gas-to-water ratios) and on the reservoir characteristics around the wellbore.

Plans include tests of two to three wells of opportunity per year for each of the next 4 years. Efforts will be made to select wells from the prime prospect areas of Texas and Louisiana, which include the Wilcox and Frio formations in Texas, and the Tuscaloosa and Tertiary formations in Louisiana.

The first successful test of a geopressured aquifer, conducted in Vermilion Parish, Louisiana, in 1977, produced methane-saturated brine. Additional tests in a well located in St. Mary's Parish were conducted in FY 1979. Through the end of FY 1980, a total of five wells had been sucessfully tested. Two recent tests in low-salinity aquifers proved the existence of high methane content in a variety of formations.

6.3.1.2 Design Wells

These are wells completed in potentially favorable geopressure-geothermal locations as defined by the best available geological and geophysical data. Large-volume reservoirs are required to enable the high cost design wells to determine crucial issues, such as whether geopressured aquifers can be produced at high-volume flow rates for the period of time required for acceptable economic returns.

One design well is being tested in Brazoria County, Texas. Two more are being drilled in Louisiana, one in Vermilion Parish and one in Cameron Parish. DOE has contracts for four more design wells through FY 1984.

6.3.2 Supporting Research and Development

This subactivity involves such tasks as program coordination, geopressure-environmental control, and engineering applications. The purpose of the program coordination task is to identify the economic, environmental, institutional, and technological considerations that must be met in order to develop geopressured resources. The activity also provides overall program planning. Policy options and technical programs are being assessed in coordination with federal, state, and local government agencies, industries, utilities, field operators, and public interest groups. Coordination of regional planning activities is organized through the Louisiana State University and the University of Texas.

Exhibit III-1-6

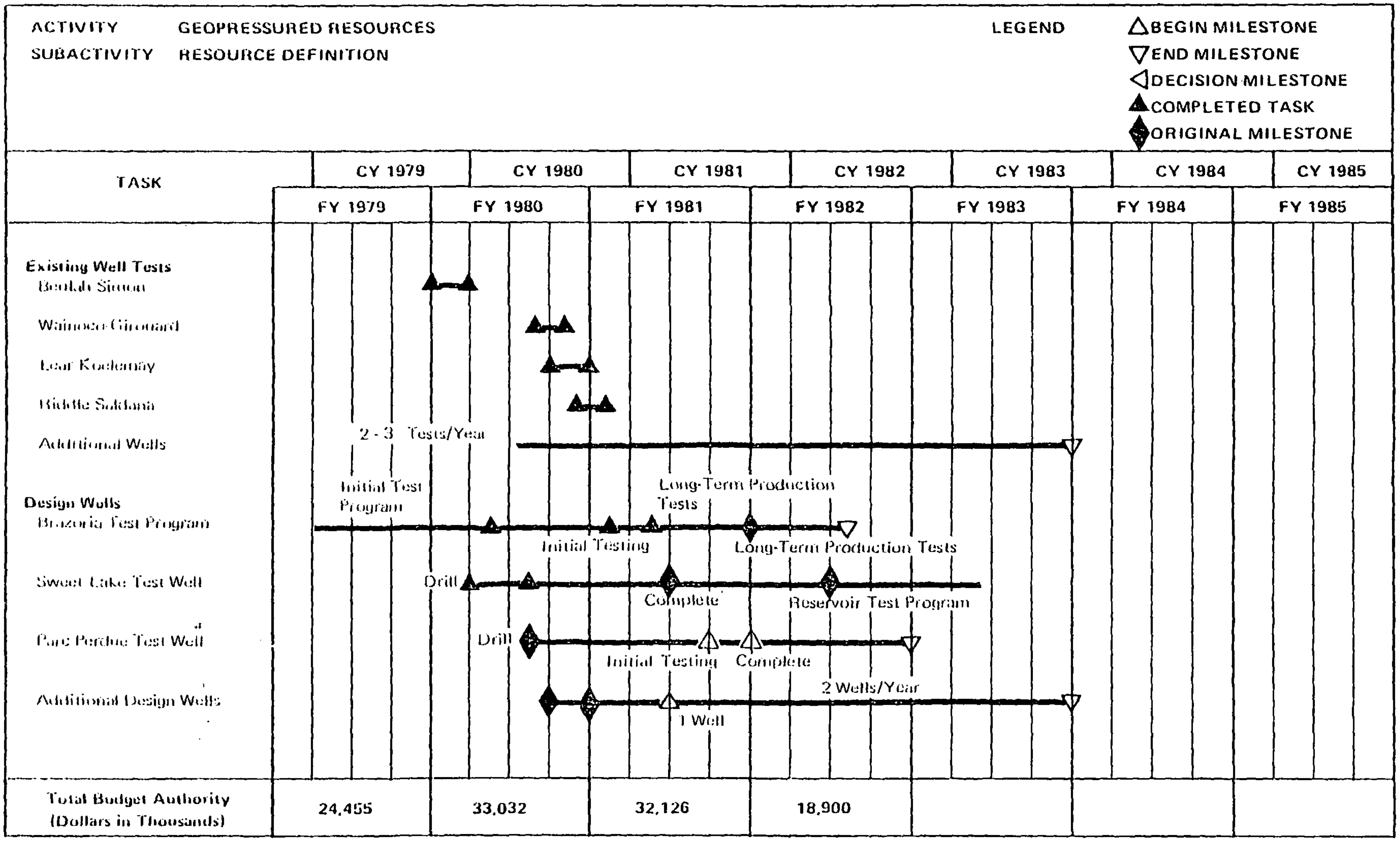


Exhibit III-4-7

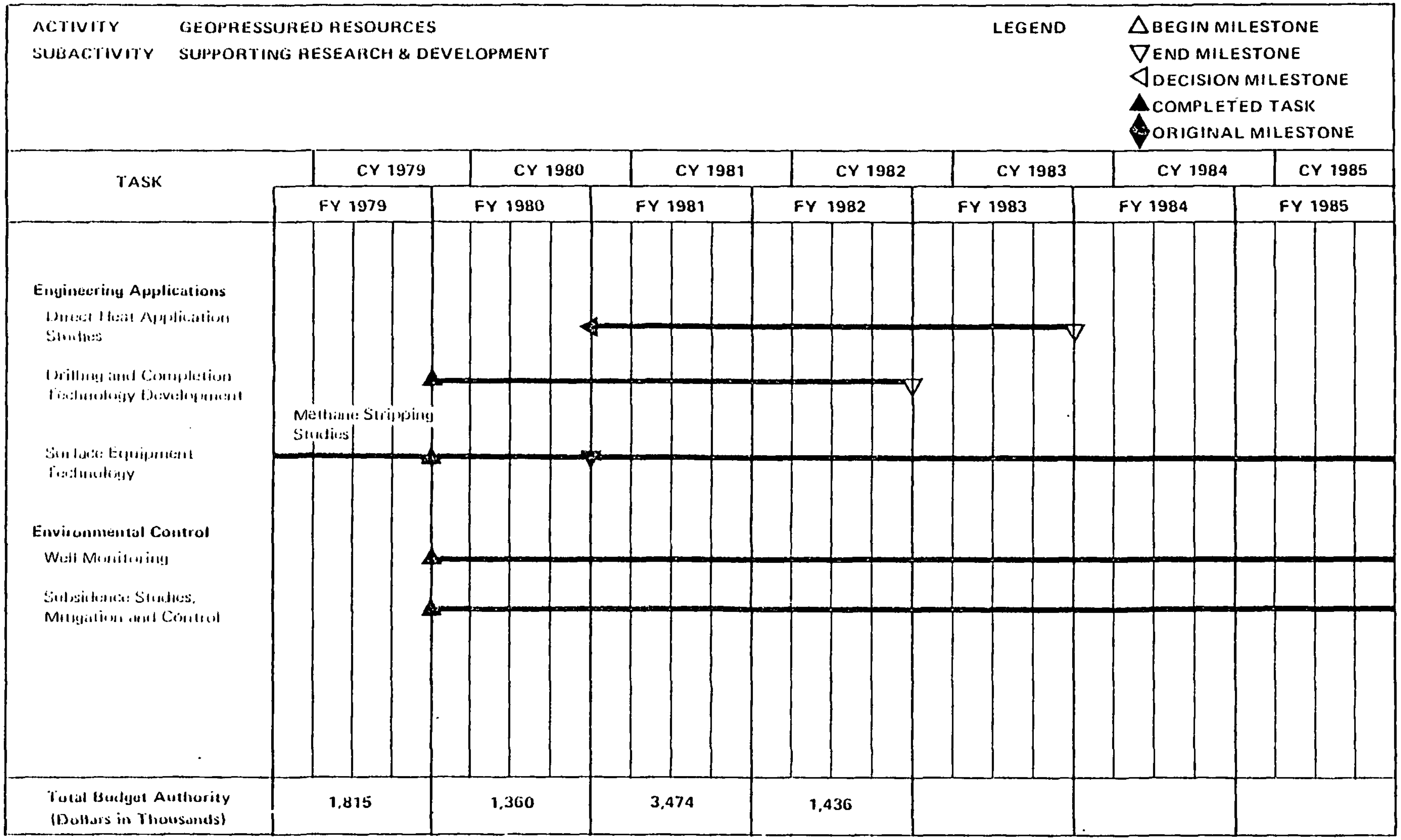


Table III-I-5

Funding Levels for
Geopressured Resources Subactivities
FY 1980 through FY 1982

| Subactivity | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Resource Definition | 33,032 | 32,126 | 18,900 | (13,226) |
| Supporting Research and Technology Development | 1,360 | 3,474 | 1,436 | ( 2,038) |
| Capital Equipment | 300 | 200 | 0 | ( 200) |
| **Total** | **34,692** | **35,800** | **20,336** | **(15,464)** |

The geopressure-environmental control task supports continued research on potentially adverse environmental effects of sustained high-volume production of geopressured brines. The high pressure of the fluids produced and the large volume of fluid withdrawal present potentially far more serious environmental problems than does production of conventional resources.

The two main environmental concerns are subsidence and fluid disposal. Subsidence is a particular concern on the Gulf Coast. In many localities, elevations are low and large-scale subsidence could have a serious impact. Current waste treatment technology is probably adequate to prevent contamination of drinking water, but new technology may be needed to remove hazardous substances from geothermal fluids.

The Pleasant Bayou Test Well in Brazoria County, Texas, has been instrumented to measure environmental parameters, including subsidence, micro-seismicity, and air and water quality. Data obtained for the monitoring of the well tests will be used to gauge the potential environmental impact of geopressured aquifer development.

Environmental assessment and monitoring of well sites in Texas and Louisiana will be accelerated to keep pace with drilling. Environmental documentation will be prepared as necessary in connection with well-testing activities conducted under the resource definition subactivity.

The engineering applications task seeks to establish the technical and economic feasibility of recovering energy from geopressured resources. This is essential for industry interest and development. It requires establishing the technical feasibility of high-volume brine production and disposal and the economic recovery of the produced energy, gaining an improved technical and mathematical understanding of the resources, and resolving any legal and institutional constraints that may impede timely development. The program is carried out under two basic categories, (1) surface technology and resource utilization, and (2) well drilling and completion.

Activities in surface technology and resource utilization have been conducted for methane fuel production, direct heat utilization, and power generation. This work includes conceptual design of facilities for electric power generation and for direct heat applications from geopressured resources. Appropriate experiments will be undertaken in FY 1982 and FY 1983. Studies on methane stripping will take place in FY 1981.

The development of well drilling and completion technology will focus on problems related to the high temperature, pressure, and salinity associated with geothermal wells.

## 6.4 GEOTHERMAL TECHNOLOGY DEVELOPMENT

Geothermal resources can be exploited with technology similar to that used for oil and gas exploration and production. Oil field equipment and water well equipment can be used safely and economically for some low-temperature geothermal applications. However, the special conditions associated with moderate- and high-temperature geothermal resources often exceed the design capabilities of existing techniques, materials, and equipment.

DGE's geothermal technology development program seeks technical solutions to the problems of operating in geothermal environments. Efforts focus on developing techniques, materials, and equipment specifically tailored to geothermal conditions, reducing technology costs, and encouraging establishment of industry-wide standards for geothermal materials and equipment. DGE is also developing techniques to extract energy from hot dry rock (HDR).

The activity is divided into two major subactivities:

- Component Development
- Hot Dry Rock.

These subactivities are discussed in detail in the following sections.

### 6.4.1 Component Development

This subactivity is organized into several tasks aimed at improving the overall discovery and exploitation of a geothermal resource.

The drilling and well completion tasks could reduce the cost of geothermal wells 25 percent by 1983 and 50 percent by 1987. These technology improvements would affect the cost of the wells that must be drilled in order to bring geothermal power on line.

The conversion tasks are developing pumps, heat exchangers, and systems for use with moderate-temperature geothermal fluids for economic production of electricity.

The reservoir stimulation task seeks ways to increase production from individual wells, thereby reducing the number of wells required to exploit a reservoir.

The geochemical engineering and materials task addresses the special character of geothermal fluids and their interaction with other materials. Program efforts focus on developing materials and methods to combat problems of scaling, corrosion, injection well plugging, and materials failure.

The geoscience task concentrates on improving the technologies for exploration, reservoir engineering, logging instrumentation, and log interpretation.

#### 6.4.1.1 Drilling and Completion Technology

Private industry has identified improvements in drilling and well completion technology as a major requirement for reducing costs of geothermal field development. The drilling and completion effort is developing conventional rotary drilling equipment, such as drill bits and down-hole motors, and completion equipment for use in geothermal environments.

Bit Development. Field evaluations are planned for 10 advanced drill bits that were supplied by 4 manufacturers, 3 of whom used cutter placements designed by Sandia Laboratories. Testing will begin at the Geysers fields, California, and at the Baca fields, New Mexico, after evaluation testing at the Drilling Research Lab, Salt Lake City, to establish performance characteristics.

The third generation polycrystalline diamond cutter (PDC) drag bits manufactured by General Electric Co. are ready for field tests. General Electric's participation in this project is now complete and Sandia Laboratories will carry out further development.

Advanced Drilling Systems. With support from Sandia Laboratories and DGE, high-speed downhole motors and bits are being developed to facilitate exploitation of high-temperature, hard rock geothermal reservoirs. The motors are made with special bearings and seals that should permit their operation for up to 200 hours under high-temperature conditions. New materials are also being used in the development of percussion drill bits. The new materials replace plastic parts, which deform and fail at the high temperatures encountered in many geothermal reservoirs. DOE support of this effort will not continue after FY 1981 as responsibility is shifted to the private sector.

Completion Technology. Geothermal well costs are strongly dependent on completion techniques. Improperly completed wells can substantially reduce energy production and require additional well drilling or frequent workover. The approach to improved completions is to develop design criteria, completion techniques, and/or hardware that will extend well life and improve production. Projects are presently under way to design a downhole perforator, for monitoring tools to detect critical failure modes of a geothermal well completion, to design and demonstrate a system using a controlled cavitation technique for downhole geothermal well cleaning and scale removal, and to investigate drilling fluid/formation interactions.

### 6.4.1.2 Energy Conversion Technology

The objective of the energy conversion technology task is to reduce geothermal electric generating costs by increasing well productivity (pumping), increasing plant efficiency at moderate temperatures, and improving overall system reliability. The task emphasizes technology for moderate-temperature geothermal reservoirs, which constitute a much larger resource base than do high-temperature resources. Downhole pumps, heat exchangers, and conversion systems for electricity production are being developed under this task. Specific activities are discussed below.

Downhole Pump Development. Wells attaining commercial flow rates (adequate for producing 3 MWe or more per well) become progressively less common as reservoir temperatures decline below 400°C due to the rapid reduction of water vapor pressure resulting from reduction in temperature. Mechanical pumps can sustain high flow rates while they simultaneously suppress scale and precipitate. Unfortunately, the hostile temperature and chemical environment in a geothermal reservoir causes conventional oil-field pump technology to be highly unreliable for geothermal applications (service life seldom exceeds a few weeks). The pump development subtask involves a number of activities ranging from pump modification (redesign and/or new materials) to extensive laboratory component testing and long-duration field testing. The program's objective is to produce pumps with service lives of 12 to 18 months.

Gravity Head Binary. The gravity head binary subtask focuses on an advanced binary process (i.e., two-fluids, geothermal and fluorocarbon) capable of producing 30 percent more power per unit of brine at essentially the same capital cost as conventional binary designs. The system, now in the final design phase, features a downhole heat exchanger and a thermal siphon effect for fluorocarbon circulation. A large (30-inch diameter) well has been successfully drilled and flow-tested at the East Mesa, California, geothermal test facility. Downhole component testing will begin during the second quarter of FY 1981. Work on this technology will be phased out in FY 1981.

Direct Contact Binary. The direct contact binary design is intended to reduce capital and operating costs while maintaining efficiency comparable to conventional binary designs. This contrasts with the gravity head binary process, which benefits from increased efficiency. The term "direct contact" refers to the heat exchange process in which geothermal brine and isobutane are mixed during counter-current flow in a simple open column. The isobutane is vaporized and exits at the top of the column, where it powers a turbine. The direct contact heat exchanger is approximately 80 percent less expensive than a conventional shell and tube heat exchanger, and it is not subject to fouling or leakage. The concept has been demonstrated in a highly successful 500-kWe pilot plant being tested at the East Mesa geothermal test facility.

Waste Heat Rejection. Geothermal power plants, require removal of approximately four times more heat per kWh to condense the working fluid than do either fossil fuel or nuclear plants. As cooling is normally accomplished through water evaporation in a cooling tower, excessive water consumption will result unless advanced technology is employed for geothermal applications. The waste heat rejection subtask, in cooperation with DOE's nuclear program, is investigating technology capable of using low quality water sources, such as brine, for cooling tower systems or for partial dry-cooling systems.

Alternate Systems. Numerous other activities are being carried out under the energy conversion technology task. These

Exhibit III-4-8

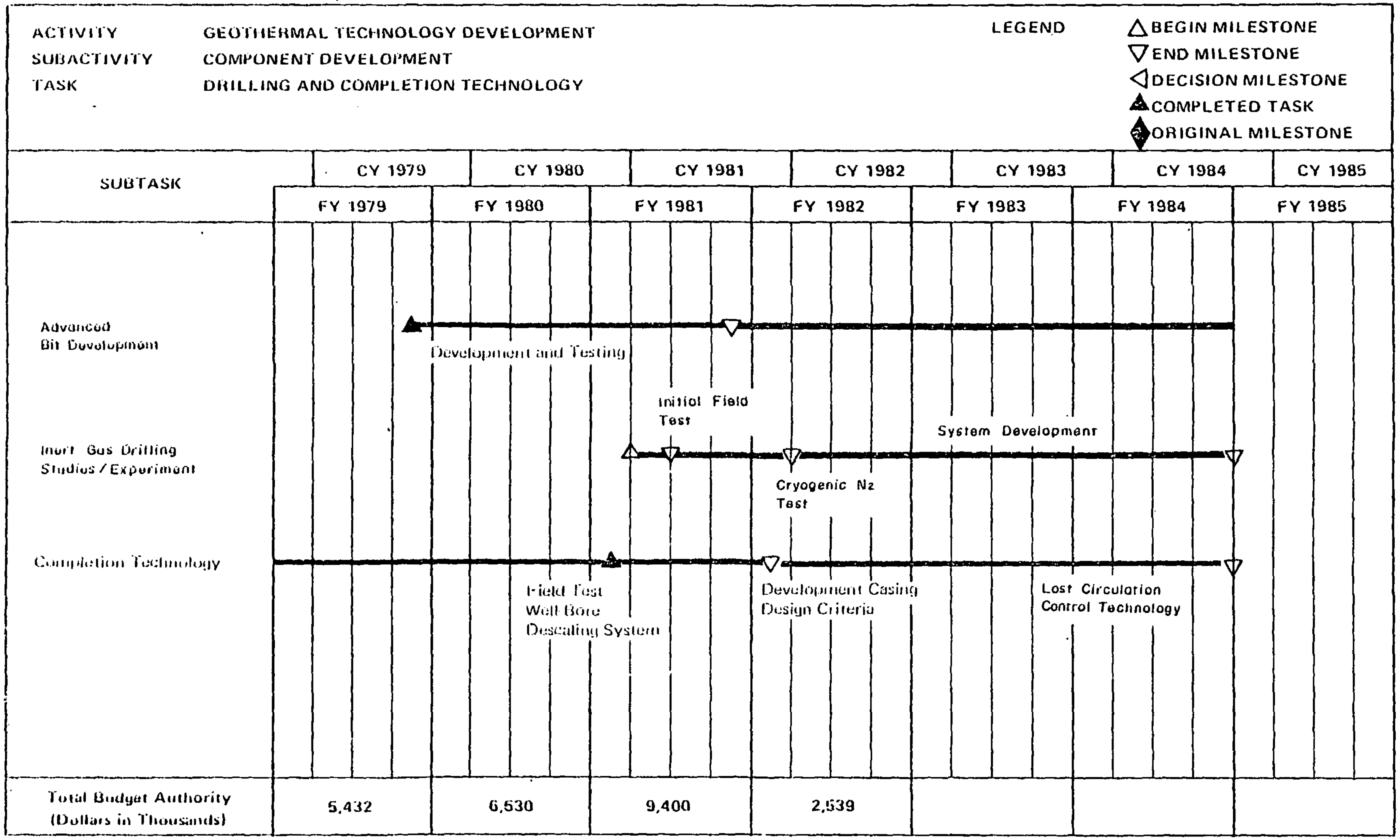


Exhibit III-1-9

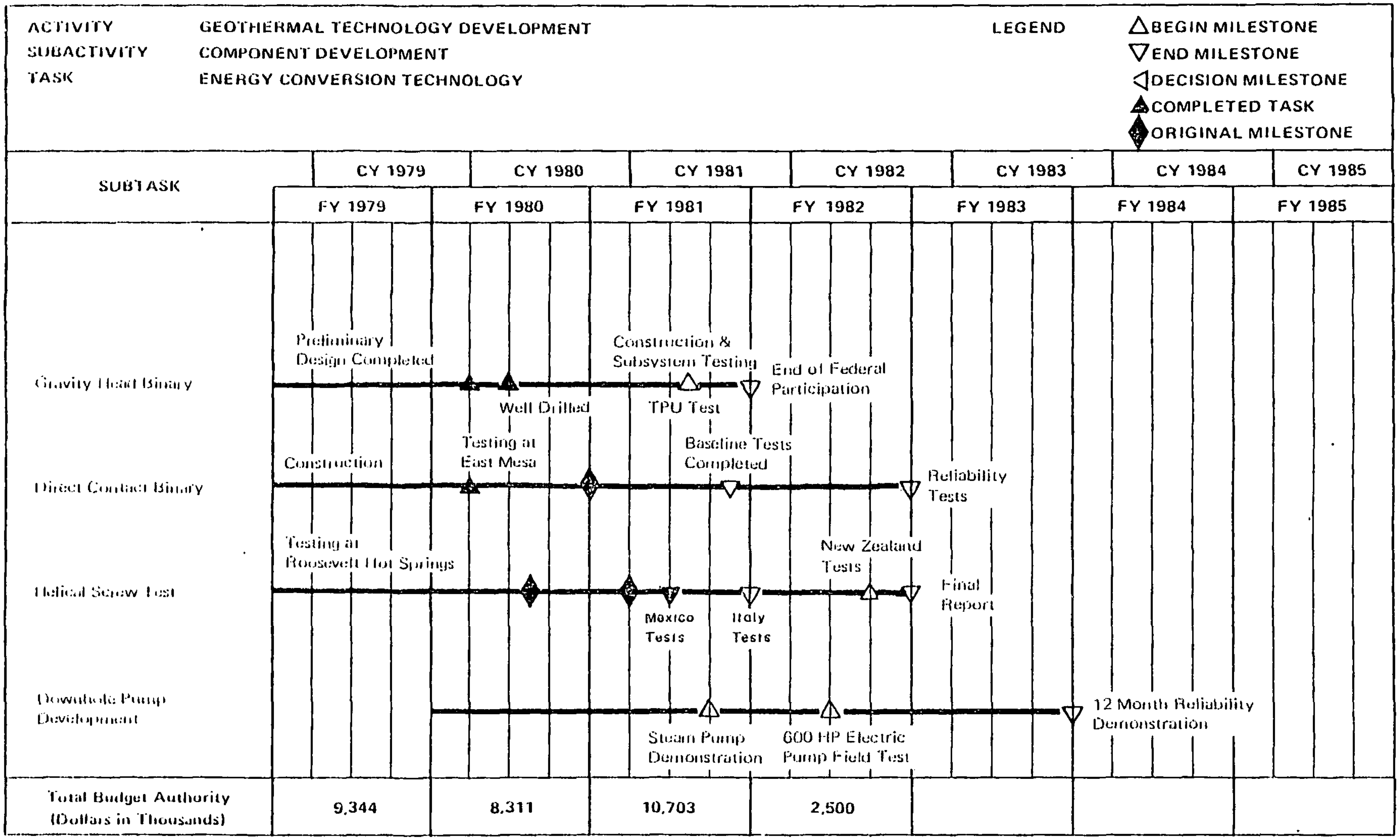


Table III-I-6
## Funding Levels for Drilling and Completion Technology Subtasks FY 1980 through FY 1982

| Subtask | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Bit Development | 3,918 | 5,640 | 1,523 | (4,117) |
| Advanced Drilling Systems | 653 | 940 | 0 | ( 940) |
| Completion Technology | 1,959 | 2,820 | 1,016 | (1,804) |
| Capital Equipment | 100 | 350 | 0 | ( 350) |
| **Total** | **6,630** | **9,750** | **2,539** | **(7,211)** |

Table III-I-7

Funding Levels for
Geothermal Technology Development Subactivities
FY 1980 through FY 1982

| Subactivity | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Component Development | 25,058 | 35,300 | 10,439 | (24,861) |
| Hot Dry Rock | 14,000 | 13,500 | 10,000 | ( 3,500) |
| Capital Equipment | 2,120 | 1,110 | 0 | ( 1,110) |
| **Total** | **41,178** | **49,910** | **20,439** | **(29,471)** |

Table III-I-8

## Funding Levels for Component Development Tasks FY 1980 through FY 1982

| Task | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Drilling and Completion Technology | 6,530 | 9,400 | 2,539 | ( 6,861) |
| Energy Conversion Technology | 8,311 | 10,703 | 2,500 | ( 8,203) |
| Reservoir Stimulation | 1,656 | 3,200 | 1,900 | ( 1,300) |
| Geochemical Engineering and Materials | 3,931 | 4,700 | 700 | ( 4,000) |
| Geoscience Technology | 4,630 | 7,297 | 2,300 | ( 5,627) |
| Environmental Control Technology | 0 | 0 | 500 | 500 |
| **Total** | **25,058** | **35,300** | **10,439** | **(24,861)** |

Table III-I-9

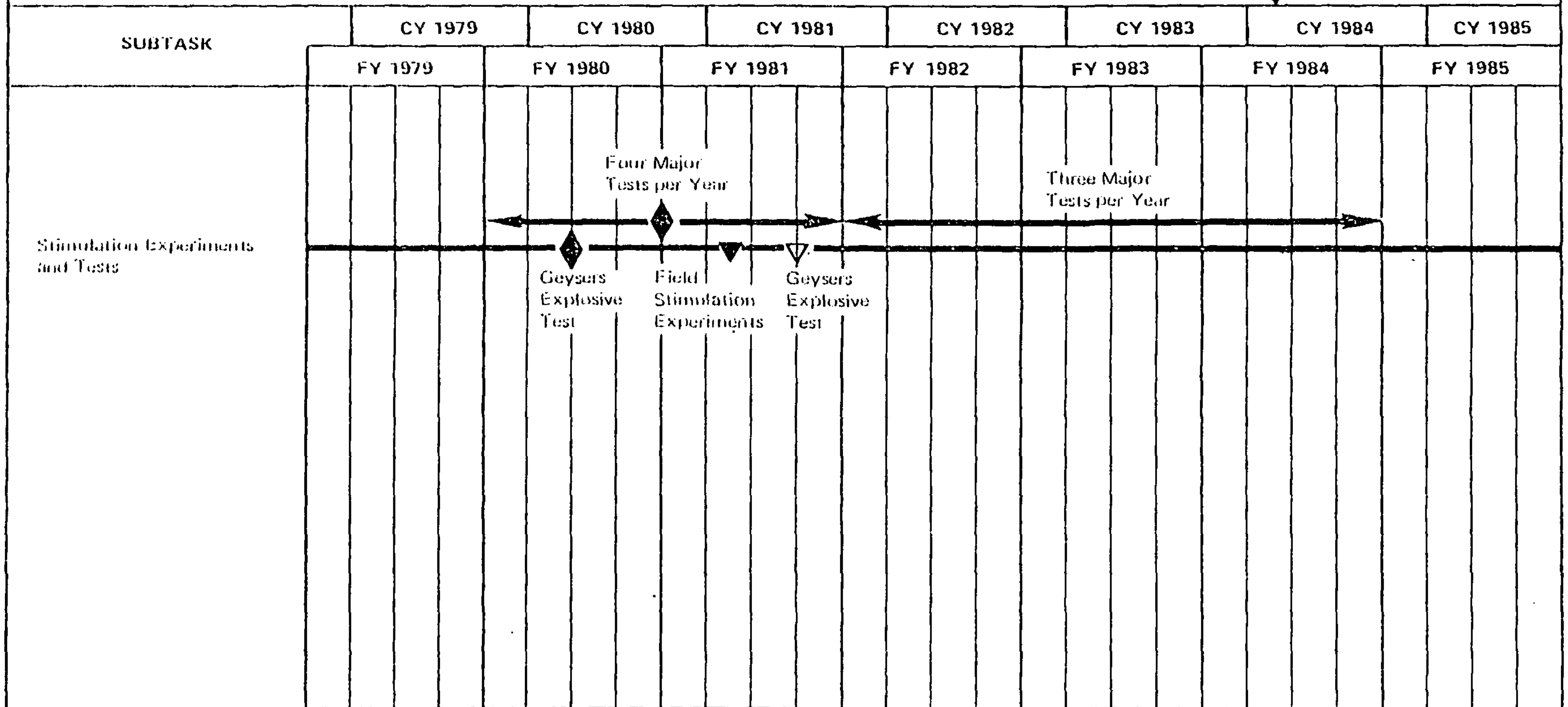
## Funding Levels for Energy Conversion Technology Subtasks FY 1980 through FY 1982

| Subtask | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Downhole Pump Development | 1,000 | 1,000 | 600 | ( 400) |
| Gravity Head Binary | 3,911 | 6,000 | 0 | (6,000) |
| Direct Contact Binary | 2,000 | 2,000 | 685 | (1,315) |
| Waste Heat Rejection | 1,000 | 1,000 | 230 | ( 770) |
| Alternate Systems | 400 | 703 | 725 | 22 |
| Capital Equipment | 470 | 115 | 260 | 145 |
| **Total** | **8,781** | **10,818** | **2,500** | **(8,318)** |

Exhibit III-1-10

ACTIVITY GEOTHERMAL TECHNOLOGY DEVELOPMENT
SUBACTIVITY COMPONENT DEVELOPMENT
TASK RESERVOIR STIMULATION

LEGEND
△ BEGIN MILESTONE
▽ END MILESTONE
◁ DECISION MILESTONE
▲ COMPLETED TASK
◆ ORIGINAL MILESTONE




| | FY 1979 | FY 1980 | FY 1981 | FY 1982 | FY 1983 | FY 1984 | FY 1985 |
|---|---|---|---|---|---|---|---|
| Total Budget Authority (Dollars in Thousands) | 4,442 | 1,656 | 3,200 | 1,900 | | | |

Table III-I-10

## Funding Levels for Geochemical Engineering and Materials Subtasks FY 1980 through FY 1982

| Subtask | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Geochemical Engineering | 1,943 | 2,548 | 250 | (2,298) |
| Materials Development | 779 | 1,177 | 350 | ( 827) |
| Alternate Materials Development | 1,209 | 975 | 100 | ( 875) |
| Capital Equipment | 265 | 95 | 0 | ( 95) |
| **Total** | **4,196** | **4,795** | **700** | **(4,095)** |

East Mesa. In return, DOE will gain information on fluid characteristics. Among the new instruments being developed as part of this project are high-temperature meters, specific ion electrodes, conductivity meters, and corrosion-monitoring equipment.

Materials Development. In order to achieve overall economy in construction, operation, and maintenance of geothermal systems, durable materials resistant to corrosion and catastrophic failure are required. To help develop such materials, DGE has been involved in forming a special committee of the American Society for Testing and Materials on geothermal resources and energy to evaluate standards for geothermal materials and procedures.

In 1978, DGE published an analysis handbook of materials available for electric applications of geothermal energy. A completely revised edition of the handbook will be published in March 1981. This expanded edition will include information on non-electric applications and extensive international information. In addition, DGE issues a monthly newsletter, "Geothermal Materials Review."

A series of high-temperature well cements have been developed and tested at the National Bureau of Standards as part of an American Petroleum Institute task group effort to develop geothermal well cement standards. With laboratory development complete, field testing of high-temperature well cements will begin under an arrangement with the Mexican government.

Alternate Materials Development. Polymer concrete, high-temperature elastomers, and casing materials have been developed with 15 to 20 percent improvements in durability and corrosion resistance for geothermal environments. Polymer concrete-lined pipes and flash tanks were tested at Niland, California, and at East Mesa. Carbonate scale did not adhere to the concrete surface, thereby offering a potential remedy to the scaling problem in geothermal fields with high carbonate content.

The manufacture of commercial, prototype polymer concrete pipes and of a high-temperature logging cable and the technology transfer of new high-temperature elastomers were initiated during 1978 and 1979. A non-destructive evaluation technique to predict drill pipe failure will be field tested in FY 1981.

Work on geothermal materials in FY 1981 will emphasize development and testing of elastomers, metals, and cements that are durable at high temperatures and resistant to localized corrosion, wear, fracture, and fatigue failures. Improvements in these materials are essential for the success of downhole pumps, cables, and motors, and for greater longevity of surface, well, and drilling equipment.

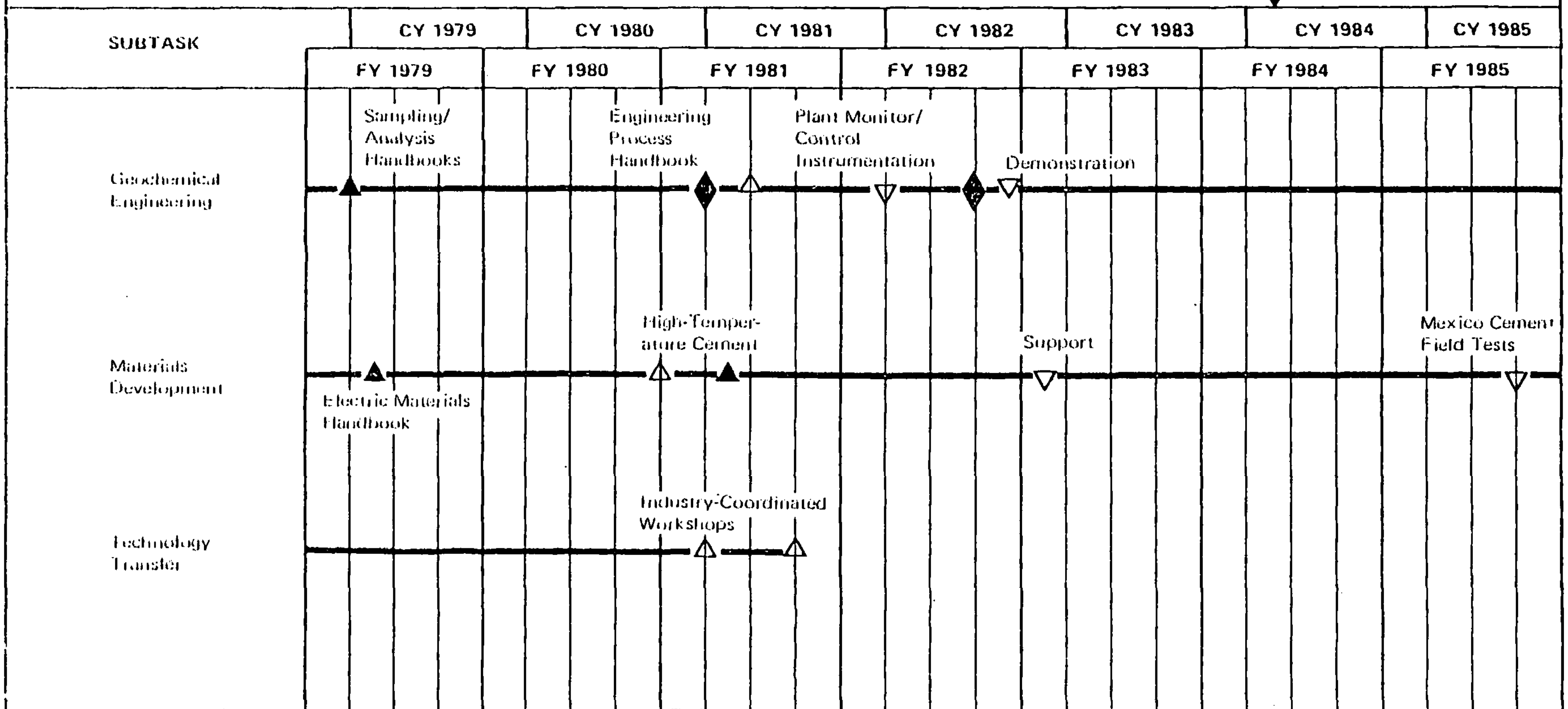
6.4.1.5 Geoscience Technology

Improvements in technology related to exploration for geothermal resources and assessment of reservoirs are essential to

Exhibit III-4-11

ACTIVITY GEOTHERMAL TECHNOLOGY DEVELOPMENT
SUBACTIVITY COMPONENT DEVELOPMENT
TASK GEOCHEMICAL ENGINEERING AND MATERIALS

LEGEND
△ BEGIN MILESTONE
▽ END MILESTONE
◁ DECISION MILESTONE
▲ COMPLETED TASK
◆ ORIGINAL MILESTONE




| Total Budget Authority (Dollars in Thousands) | FY 1979 | FY 1980 | FY 1981 | FY 1982 | FY 1983 | FY 1984 | FY 1985 |
|---|---|---|---|---|---|---|---|
| | 7,071 | 3,931 | 4,700 | 700 | | | |

Table III-I-11

## Funding Levels for Geoscience Technology Subtasks FY 1980 through FY 1982

| Subtask | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Exploration Technology | 1,138 | 2,938 | 900 | (2,038) |
| Reservoir Engineering | 2,110 | 2,320 | 1,400 | ( 920) |
| Logging Instrumentation | 956 | 1,699 | 0 | (1,699) |
| Log Interpretation | 426 | 340 | 0 | ( 340) |
| Capital Equipment | 285 | 50 | 0 | ( 50) |
| **Total** | **4,915** | **7,347** | **2,300** | **(5,047)** |

maintain the current rate of discovery and development. The geoscience technology task consists of four subtasks:

- Exploration technology
- Reservoir engineering
- Logging instrumentation
- Log interpretation.

Exploration Technology. The objective of this subtask is to develop an effective strategy, based on demonstrated methods, that will accurately locate hydrothermal resources in a number of varying geological settings. In order to do this, a series of exploration case studies have been accumulated, particularly under the industry-coupled task. These case studies are used to evaluate the effectiveness of different geological, geochemical, and geophysical techniques in providing pertinent information on the location and extent of the resource. Where case histories were incomplete under the industry-coupled task, additional surveys were funded under exploration technology so that a complete set of survey techniques could be evaluated for their effectiveness in delineating reservoirs confirmed by drilling.

For the first time, two- and three-dimensional models have been developed for use in interpreting data from magnetotelluric and resistivity surveys. Factors such as topographic variations, layering, and other structural features can be introduced into the models, thereby affording a more meaningful interpretation of results.

Reservoir Engineering. The major emphasis to date in reservoir engineering has been on the analysis and simulation modeling of high-temperature reservoirs.

Cooperative agreements with countries having geothermal reservoirs with long production histories have permitted development of valid reservoir simulation models. These models are continually refined as additional data become available and as understanding of reservoir behavior improves.

Logging Instrumentation. The well-logging services presently available are often unsuitable for the hostile environments of geothermal wells, and essential data for reservoir engineering are difficult to acquire. Logging instrumentation activities are therefore aimed at upgrading tool capabilities from the present rating of 180°C to typical geothermal temperatures of up to 275°C.

Development of high-temperature (275°C) components for logging tools will not receive DOE support after FY 1981. Prototype tools that use high-temperature circuits have been made commercially available. Sandia Laboratories and Union Oil Co. have successfully tested hand-wired prototype temperature, pressure, and flow tools. Other prototype tools that use commercially made circuits are being evaluated.

Log Interpretation. To improve techniques of log interpretation, DOE is participating in the construction of a calibration/test facility at the Denver Federal Center. Two large, heated tanks containing samples of rock representative of those found in geothermal reservoirs have been completed, with one more in progress. Saw cuts in the rock simulate fractures that control production of geothermal reservoirs. When completed, the facility will be available for use by geothermal developers, logging companies, and others as a standard for calibrating tools. In addition, two wells, one at East Mesa, and the other at Roosevelt Hot Springs, Utah, are available to the public at no charge. The East Mesa well was used six times and the Roosevelt well, four times. DOE support of these facilities will not continue after FY 1981 as responsibility is shifted to the private sector.

6.4.1.6 Environmental Control Technology

Environmental control technology (ECT) issues and priorities were established in the "Status of Environmental Controls for Geothermal Energy Development - April 1980" prepared by the Environmental Control Panel of the Interagency Geothermal Coordinating Council. Research is needed to improve the state-of-the-art of geothermal ECT to comply with federal, state, and local environmental regulations. To accomplish this, DOE and the U.S. Environmental Protection Agency (EPA) are pursuing a research program to control hydrogen sulfide and other air emissions, injection of geothermal fluids as they may affect underground sources of drinking water, solid waste resulting from geothermal operations, induced subsidence, and induced seismicity.

$H_2S$ Technology. Hydrogen sulfide ($H_2S$), ammonia, boron, carbon dioxide, methane, arsenic, radon and mercury vapor have been found associated with geothermal fluids. $H_2S$, which is found in high concentrations in certain geothermal fluids, has required particular control. Stringent state air quality standards have been established to reduce $H_2S$ odor and protect public health.

DOE and EPA have jointly initiated a project to develop a process that removes $H_2S$ and at the same time produces a usable by-product (sulfur) rather than solid waste. This process will be field tested during FY 1981-1982. Laboratory and field testing of other $H_2S$ removal systems is planned for 1981-1982.

A demonstration of an EIC Corporation prototype process to scrub 100,000 pounds of raw steam per hour, was tested at the Geysers field in California. Supported by DOE, EPA, and Pacific Gas & Electric Co. (PG&E), this process removes $H_2S$ during stream stacking (when the plant is shut down). Following the pilot-scale field test of the process, PG&E contracted with EIC Corporation for a full-scale plant. Installation should be complete by 1984.

DOE is continuing work on theoretical $H_2S$ research and on improving the economics and applicability of existing systems.

Exhibit III-I-12

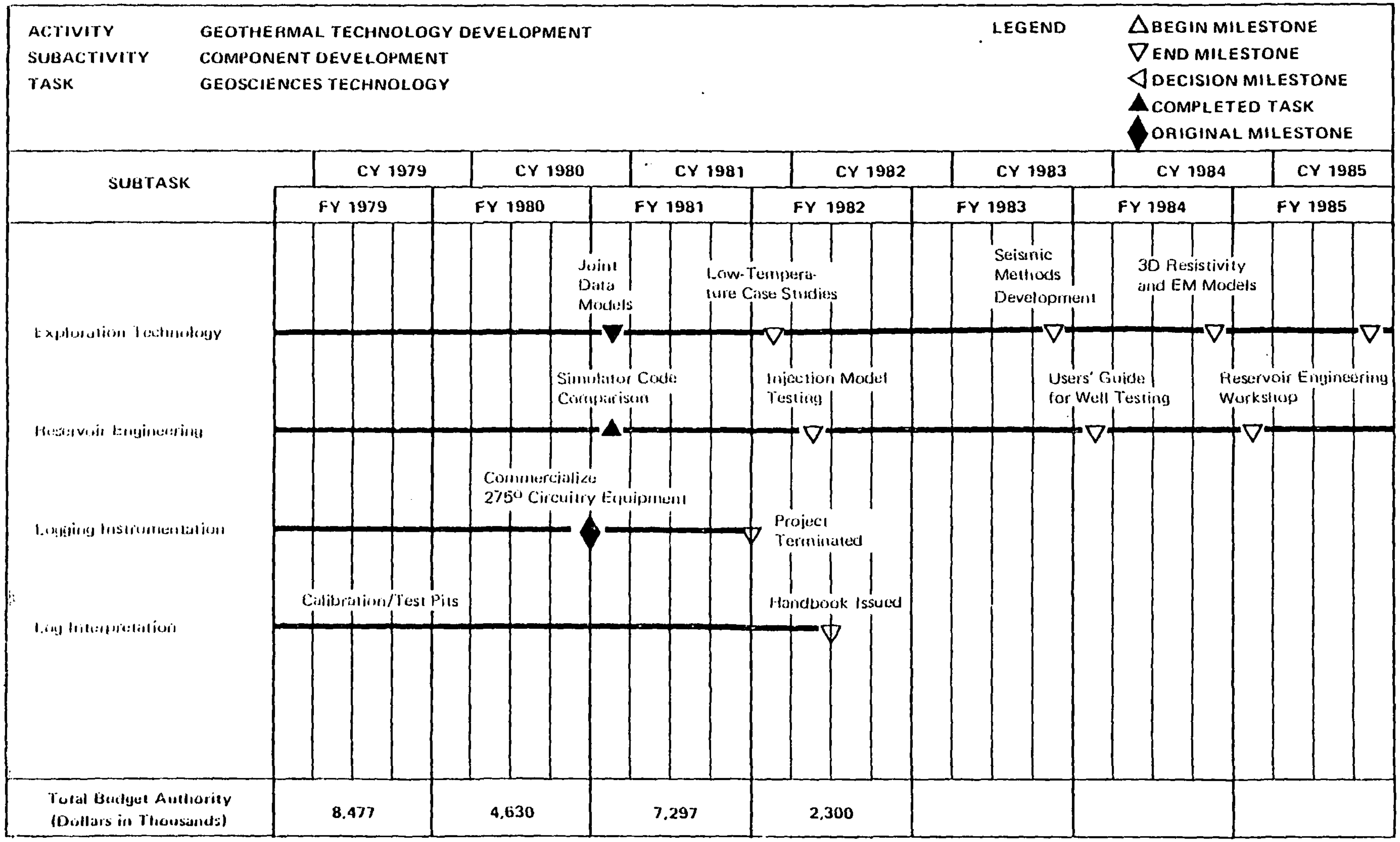


Table III-I-12

## Funding Levels for Environmental Control Technology Subtasks FY 1980 through FY 1982

| Subtask | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| $H_2S$ Technology | 247 | 1,500 | 200 | (1,300) |
| Capital Equipment | 13 | 0 | 0 | 0 |
| Fluid Waste | 0 | 300 | 200 | ( 100) |
| Solid Waste | 37 | 200 | 0 | ( 200) |
| Subsidence | 1,840 | 300 | 0 | ( 300) |
| Induced Seismicity | 60 | 300 | 100 | ( 200) |
| **Total** | **2,197** | **2,600** | **500** | **(2,100)** |

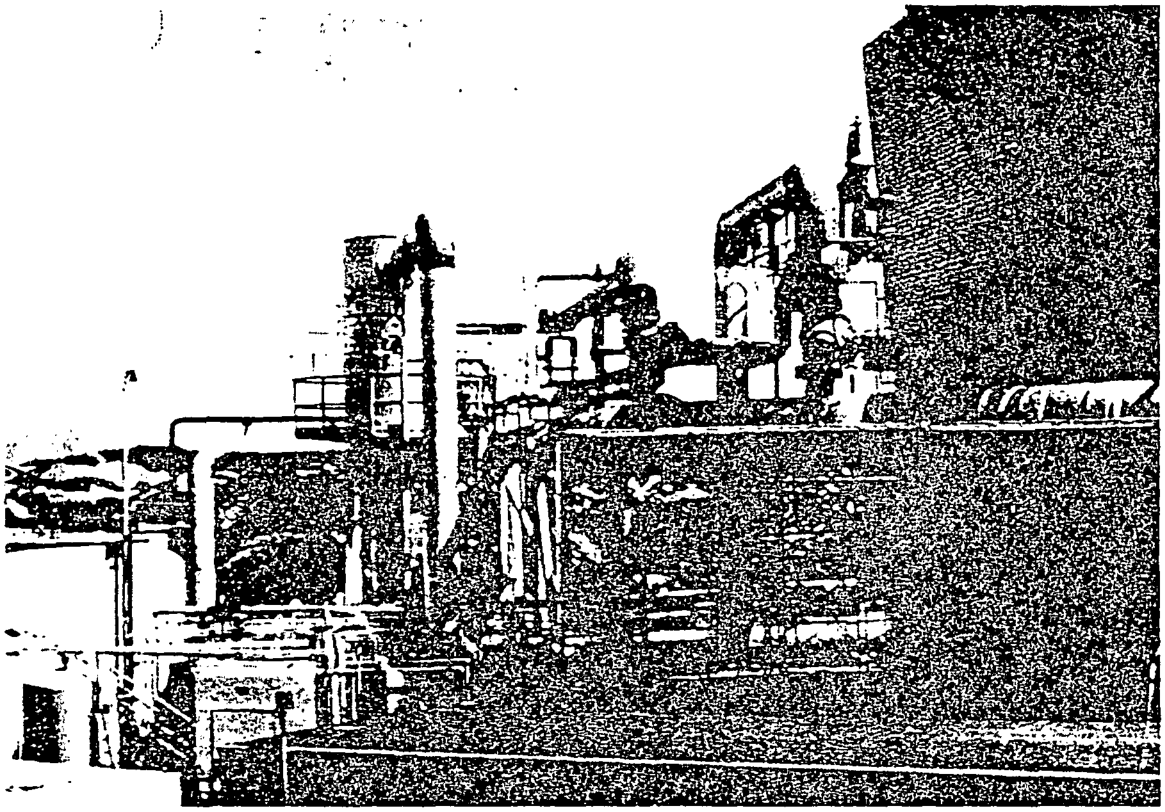


Figure III-I-4

Hydrogen Sulfide Removal System at The
Geysers Geothermal Field

Also planned for 1981-1983 is a cooperative agreement with industry on $H_2S$ removal systems.

To date, other air emissions have not been identified as causing significant environmental impacts. EPA, however, plans a characterization study to better understand air emission rates from geothermal operations.

Fluid Waste. Both surface and subsurface injection of geothermal fluids, which may contain hazardous substances, could adversely affect the use of surface water and of underground sources of drinking water. Current waste treatment technology is probably adequate to prevent contamination of drinking water, but new technology may be needed to remove hazardous substances from geothermal fluids.

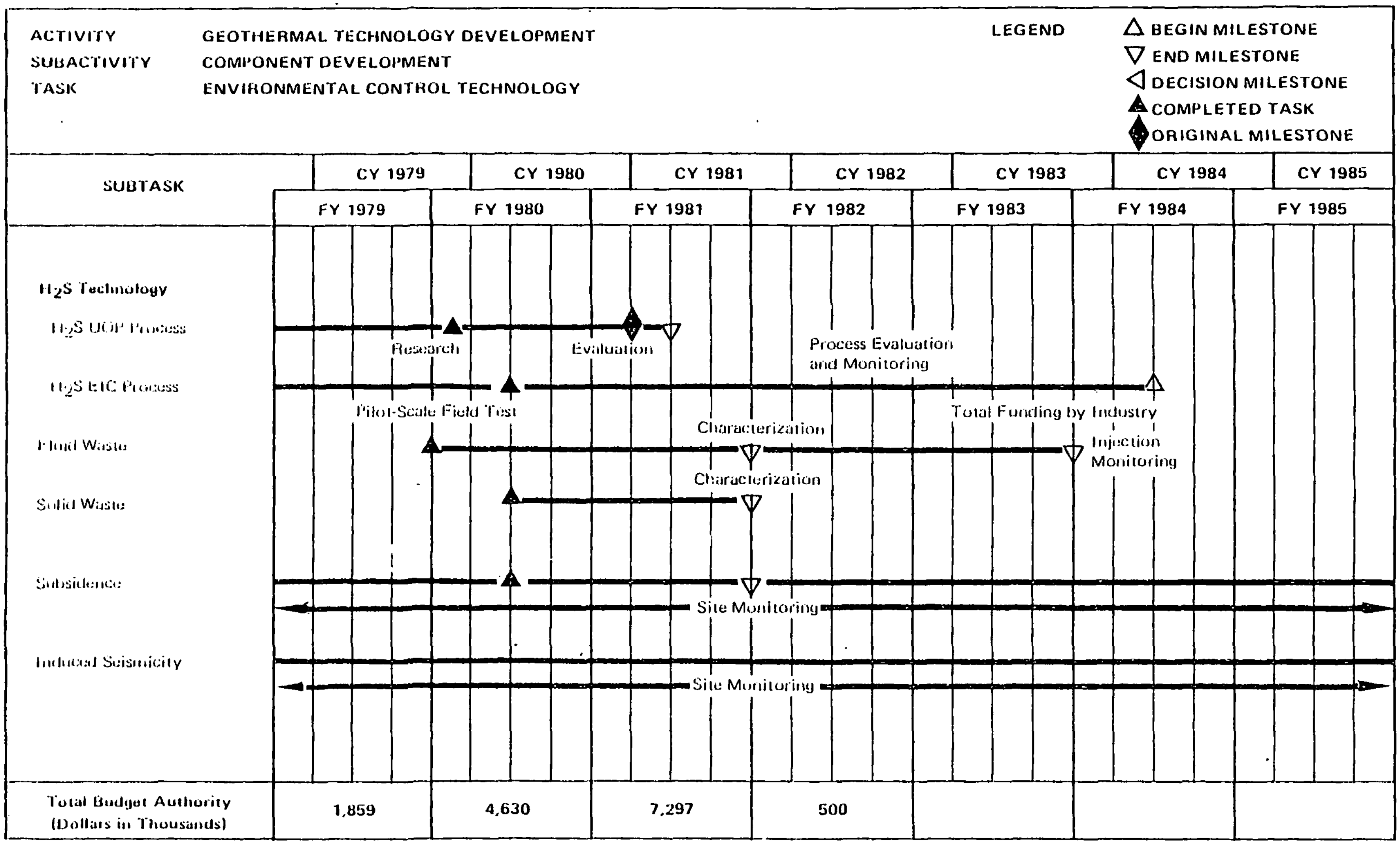
Of particular concern is the lack of a reliable technique to monitor the migration of injected fluids in hydrologic regimes containing ground water fit for drinking. DOE plans a project in conjunction with Lawrence Livermore Laboratory to develop remote sensing instrumentation to track fluid migration from injection wells. The project is scheduled to begin in FY 1981 and run through FY 1983.

Solid Waste. Quantities of solid waste are generated by geothermal operations. Water treatment and air abatement as well as drilling operations contribute to the load. When hazardous materials are found, waste storage, transport and disposal controls are required.

Subsidence. DOE continued its subsidence research, establishing the geothermal subsidence research effort to characterize, measure, predict, and mitigate subsidence. This year DOE completed an assessment of the environmental and economic effects of subsidence and prepared a manual of guidelines for monitoring surface displacements. Projects continued to assess mathematical subsidence models, study the compressibility of reservoir cores, and study the compaction properties of reservoir materials. Case histories of subsidence were prepared for Long Beach, California, and Wairakei, New Zealand. Analytical models were developed for comparison with observed data. Near-future projects will include a detailed case history for Chocolate Bayou, Texas, a subsurface risk assessment, and an assessment of potential indirect measurement techniques.

Induced Seismicity. A major effort to understand, predict, and mitigate induced seismic activity from geothermal development is in progress by USGS and DOE. A study to evaluate the effectiveness of current seismic control techniques was begun and was scheduled for completion in FY 1980. Monitoring nets were emplaced in northern Nevada, at Roosevelt Hot Springs, Utah, and at the Geysers field in California to detect and measure induced seismicity.

Exhibit III-I-13



### 6.4.2 Hot Dry Rock

The HDR geothermal resource is defined as the heat stored in rocks that contain little or no water. Energy is extracted from HDR by drilling two wells, fracturing the rock between the wells to provide a large heat exchange surface, then establishing a circulating fluid loop. Commercialization will depend on significant technical improvements and cost reduction in drilling and fracturing technology.

The HDR development subactivity assesses the potential of the resource and supports development of new technical approaches for extracting energy from HDR. Although HDR research began in 1972, the present HDR program was formally instituted at the beginning of FY 1979 after successful operation of a 5-MWt thermal loop at the Fenton Hill site in New Mexico in 1978. General program objectives are (1) to confirm the potential of the HDR resource, (2) to develop a technology base for HDR energy extraction, and (3) to verify that the environmental and social consequences of HDR development are acceptable.

#### 6.4.2.1 Technology Development

This task centers on a demonstration site at Fenton Hill, New Mexico, where a 5-MWt loop has been operated successfully, with the first electricity from HDR generated on May 13, 1980. Emphasis at Fenton Hill will now shift from research to engineering development. A second loop (20-50 MWt) is under construction at the site. The design of the engineering system for the second loop at Fenton Hill will allow for a possible follow-on commercial electric pilot plant. The project is intended to show that the HDR concept demonstrated at Fenton Hill can be successfully and economically applied to other sites. The project will simulate, as closely as possible, a commercial venture, and research work at the site will be kept to a minimum. The building of a pilot plant is outside the scope of DGE's program, but an electric cooperative has expressed interest in acquiring the site once tests of the engineering system are completed.

Environmental studies will be directed at obtaining more definitive information about the effects of commercial-scale HDR development. Much experience from hydrothermal projects is directly applicable to these studies because the effects are similar to those expected from HDR; other environmental aspects of HDR are unique to its application. The investigations will not try to resolve outstanding issues. Rather, environmental monitoring will be done in conjunction with the demonstration projects. This operation experience will clarify the environmental issues and help to place them in perspective for the regulatory authorities.

#### 6.4.2.2 Resource Evaluation

In FY 1979, DOE cooperated with USGS to determine HDR resource potential; it also conducted geological and geophysical studies in 34 states. Sites that warrant detailed resource

Exhibit III-I-14

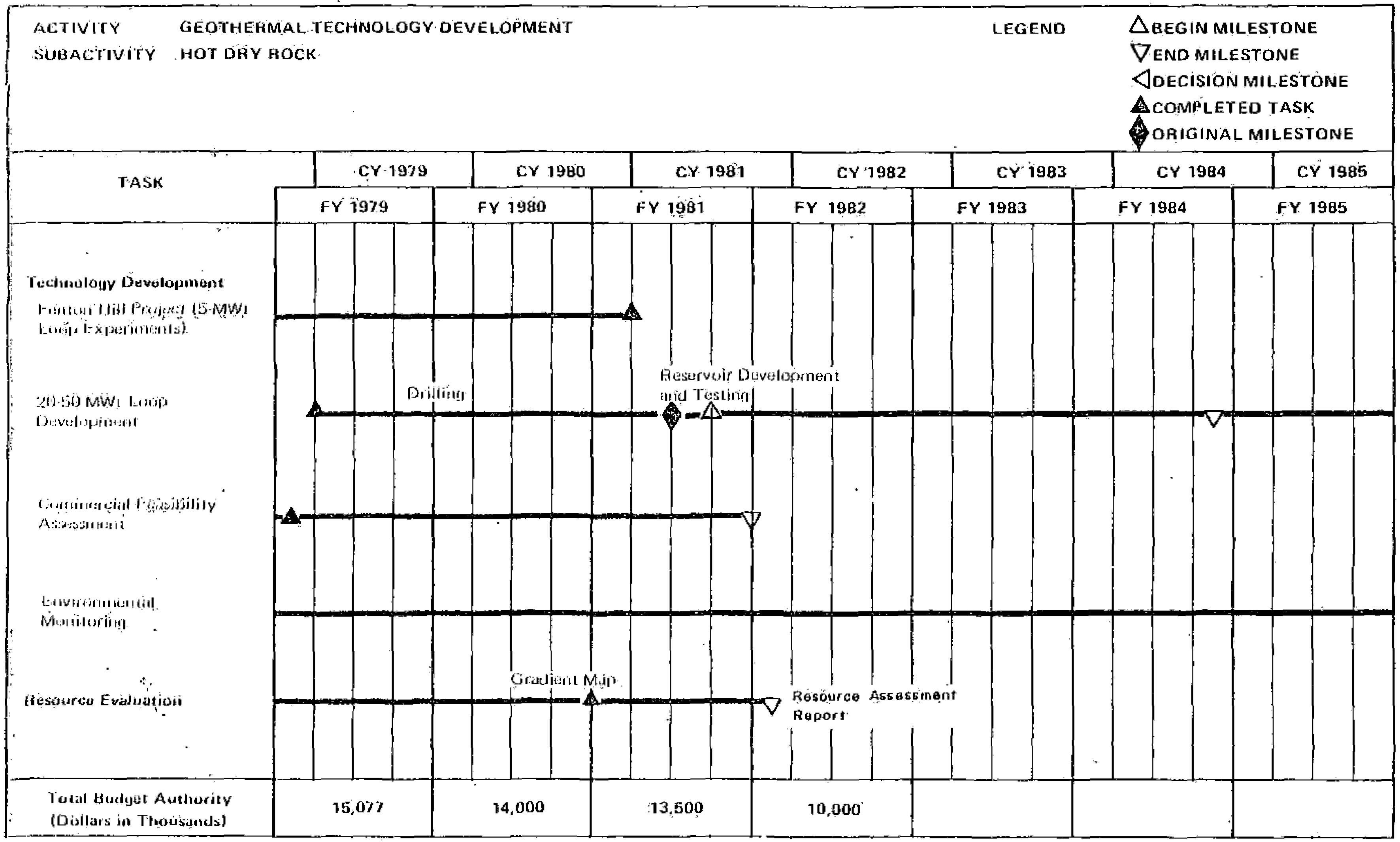


Table III-I-13

## Funding Levels for Hot Dry Rock Tasks FY 1980 through FY 1982

| Task | Budget Authority (Dollars in Thousands) | | | |
|---|---|---|---|---|
| | Actual FY 1980 | Estimate FY 1981 | Estimate FY 1982 | Increase (Decrease) |
| Technology Development | 11,272 | 12,375 | 9,700 | (2,675) |
| Resource Evaluation | 2,728 | 1,125 | 0 | (1,125) |
| Capital Equipment | 1,000 | 500 | 300 | (200) |
| **Total** | **15,000** | **14,000** | **10,000** | **(4,000)** |

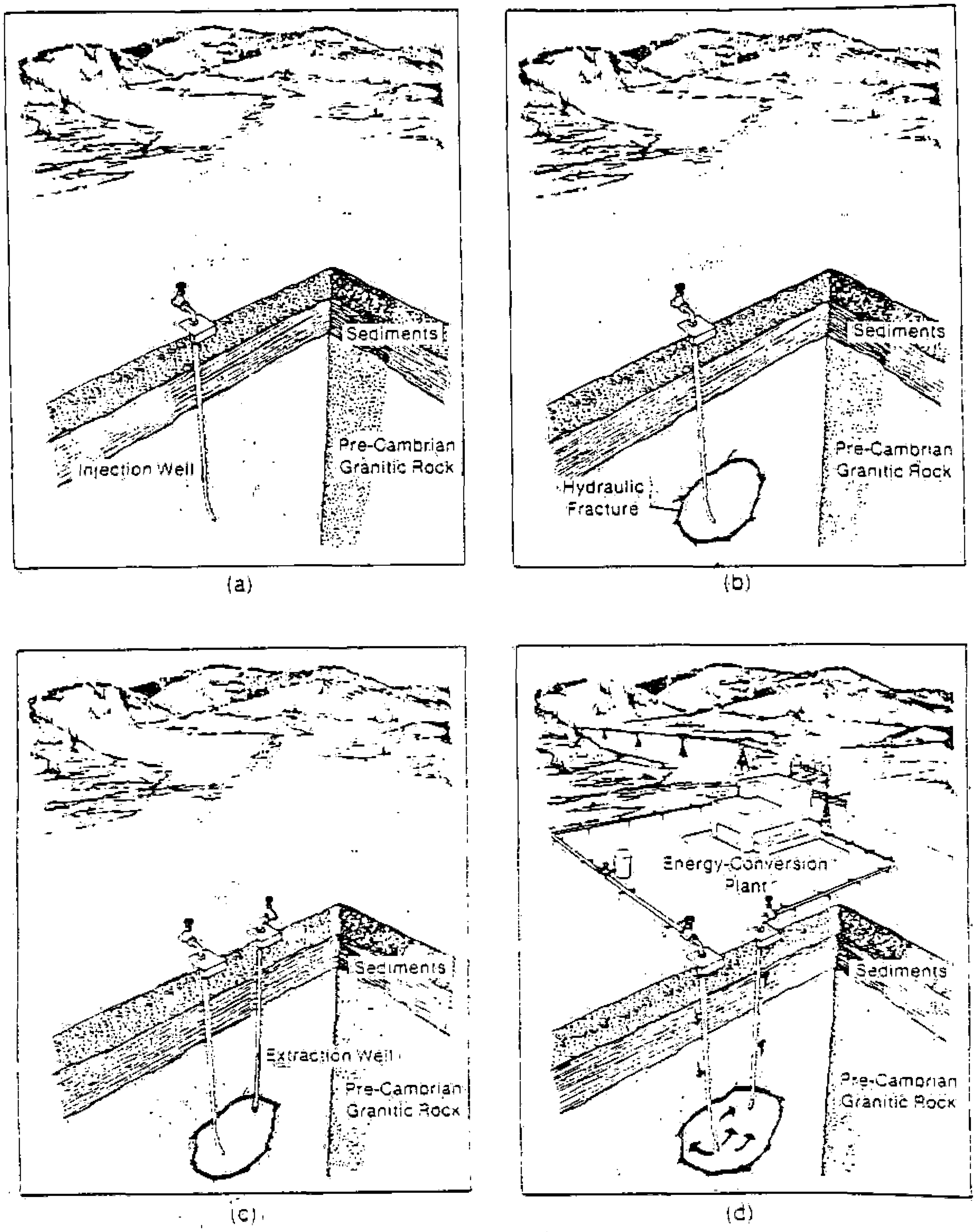



Figure III-I-5

Hot Dry Rock Site Development

investigations have been identified near Boise, Idaho, and on the Delmarva Peninsula. In addition, a geothermal gradient has been published by the Los Alamos National Scientific Laboratory.

## 6.5 PROGRAM DIRECTION

The geothermal energy programs described in this report will require federal funding of about $48 million in FY 1982. Several hundred active DOE contracts, involving projects being carried out throughout the United States and abroad, are supported by these funds. In addition, DOE has significant intragovernmental coordination responsibilities for geothermal energy.

DOE is designated by Congress as the lead agency for federal geothermal energy programs, while several other federal agencies also have substantial responsibilities related to geothermal energy. The U.S. Department of Interior, for example, has custody of millions of acres of federal land containing geothermal resources and is responsible for leasing them as appropriate for commercial geothermal development. Leasing must be coordinated with DOE programs in reservoir definition and technology development in order to meet federal goals for commercial geothermal development.

Management of such a complex program requires an organization that is geographically extensive and employs a wide range of professional skills. DOE's management approach is to concentrate policy, planning, overall budget definition, and program defense activities at its Washington, D.C. headquarters. DOE field organizations (i.e., operations offices, national laboratories, and regional representatives) are responsible for project definition, day-to-day project management in the field, and coordination with state and local authorities.