A Decade of Geothermal Development in the United States 1974 — 1984: A Federal Perspective

— Part 3 —

Progress in Experimental Geothermal Technologies

EDITOR'S NOTE: Part 3 of this series is authored by Gene Beeland. The article was prepared and published in the Progress Monitor by the Meridian Corporation of Falls Church, VA under a contract with the U.S. Department of Energy (DOE). It recaps and underscores the positive development that has taken place in both research and field development in the U.S. Geothermal Community from 1974 to 1984. Because of the size of this volume, it will be run in the BULLETIN in three parts. This is part three.

STATUS IN 1974 — GEOPRESSURED

The federal geopressured geothermal R&D program began in 1974. It was initiated to determine whether the geopressured brine aquifers of the U.S. Gulf Coast could be exploited as a major domestic source of energy. As estimated by the USGS, these aquifers contain 170,000 quads of methane and thermal energy. In addition, the high pressure of the brines also provides opportunities for utilizing their hydraulic energy. By comparison, U.S. energy consumption is about 75 quads per year.

The initial research was limited to geologic studies of the Gulf Coast sedimentary basins and preliminary investigations into methods for using the energy in the brines for power generation and direct uses. However, the program was the early beneficiary of the logs of thousands of wells drilled in the area by the oil and gas industry which were to provide invaluable subsurface information.

Hot Dry Rock

The hot dry rock program was launched in 1971 with discretionary funding for the Los Alamos National Laboratory where the concept of extracting heat from hot dry rock was developed in 1970. By 1974, two exploratory holes had been drilled at the Fenton Hill, New Mexico, experimental site that confirmed its two basic principles. In this concept, fluid is circulated through a man-made fracture between two wells, absorbing the heat of the rock. The nation's hot dry rock resources are estimated to contain nearly 500,000 quads of energy.

Magma

While the potential of magma as an alternative source of energy had been recognized for some years, it was not until mid-1973 that Sandia National Laboratories proposed active investigation. In 1974, a Conference on the Utilization of Volcano Energy was sponsored by the Japanese and the National Science Foundation at Hilo, Hawaii. This conference attracted international attention to the concept of magma energy use, and an increased level of scientific interest began to develop. This resource is estimated to be even larger than the hot dry rock resource.

STATUS IN 1984 — GEOPRESSURED

A practical technology for recovering thermal, chemical, and hydraulic energy from geopressured geothermal brines is likely to be available by the end of this decade. Very large quantities of these brines are contained in porous sandstone formations beneath the U.S. Gulf of Mexico Coast. The brines are hot 120-205°C (250-400°F), contained at abnormally high pressures (typically thousands of pounds per square inch at the wellhead), and saturated with dissolved natural gas (twenty or more cubic feet of methane per barrel of brine).

The geopressured geothermal research program initiated and carried out by DOE and its predecessor agencies in the past ten years has established that:

- The quantity of methane contained in this resource is large — the U.S. Geological Survey estimates 5700 quads in the sandstone reservoirs. The quantity of thermal energy in place is larger.
- It is possible to find such reservoirs as drilling targets, using geophysical logs from previously drilled wells and active seismic data.
- It is possible to adapt U.S. petroleum industry drilling and production technology to the production of geopressured brines.
- It is possible to extract most of the methane from the brine by a simple and economical gravity separation technique.

- It is possible to dispose of the spent brine by injecting it into empty geologic formations at relatively shallow depths.

This information has come from extensive field and laboratory research. First, the basic reservoir properties were inferred by analysis of the geophysical logs from thousands of wells drilled by industry in the search for conventional oil and gas resources. Then brine production tests of a few weeks duration were run in several of the industry-drilled wells at diverse locations. Finally, four especially designed DOE wells were drilled for long-term brine production tests at high rates. Reservoir "stress tests" have been completed in some of these wells and are underway in others. The recent successful trial of an experimental scale control technique has opened the door for flow tests at potentially commercial flow rates.

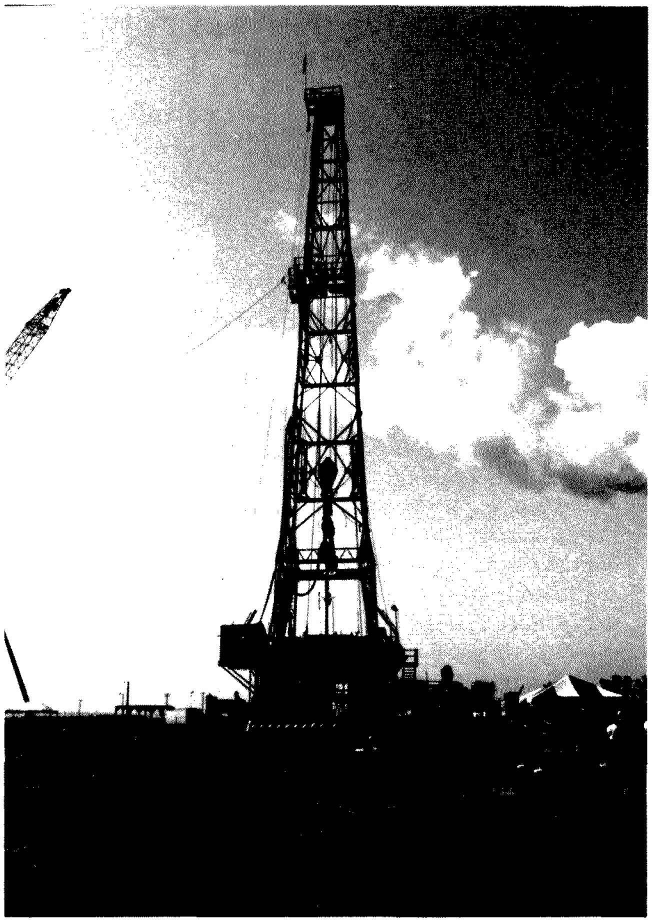
In the laboratory, samples of reservoir rocks and fluids are subjected to temperature and pressure conditions that mimic those in the reservoirs. The response of samples to changes that simulate production conditions (reduction of pore fluid pressure) reveal how actual reservoirs behave. Mathematical descriptions of that response then are used in computer codes developed to model reservoir behavior and thus to predict reservoir performance.

Field operations have shown that the environmental impact of geopressured geothermal well operations is likely to be benign, except that the possibility for land surface subsidence remains uncertain. Measurements of seismic activity around geopressured geothermal production wells, some downhole measurements, active seismic work, and periodic land surface leveling are employed to evaluate the subsidence question.

In addition to hot brine and methane, the geopressured geothermal reservoirs produce small amounts of heavier organic compounds. These are sampled and analyzed to determine their role in the complex and dynamic system of geopressured geothermal reservoir behavior.

Field operations with the DOE wells designed for long-term testing have revealed calcium carbonate scaling to be a major problem. The scaling occurs when the pressure of the brine is reduced to below a threshold value. Within a few days, scale deposits can severely restrict brine flow in a well. The tendency of a brine to precipitate scale can be controlled by very small concentrations of chemicals called scale inhibitors. In a recent experiment at the DOE Gladys McCall well in Louisiana, an inhibitor solution was forced down the well and out into the geologic formation containing the brine. The theory was that some of the inhibitor would adhere to rock and be released gradually as brine was produced. The subsequent performance of the well seems to support theory. In 90 days after treatment, the well produced at up to 31,000 bbl/day with no sign of scaling.

Future plans include DOE cooperation with industry in an experimental program to test advanced technologies for electric power from the heat contained in geopressured geothermal brines. These tests will be carried out with brine and gas from one of the DOE geopressured test wells. The Electric Power Research Institute (EPRI) is representing industry in the conduct of the experiments.



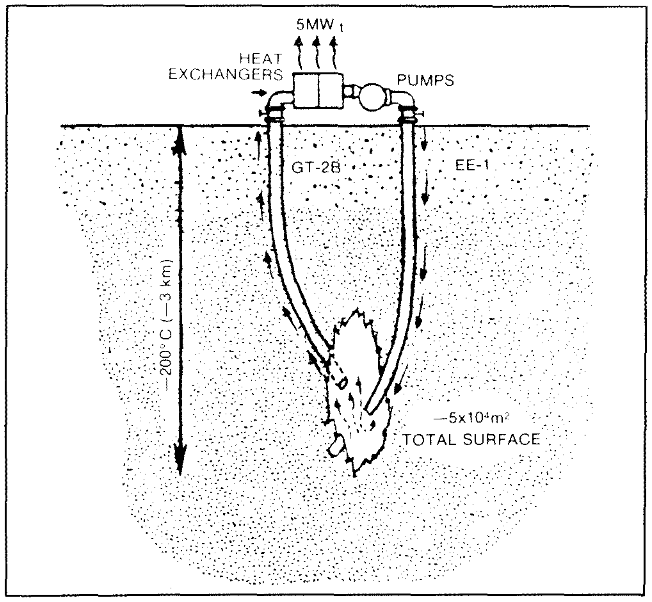
Drilling rig on Chevron Resources well at Heber geothermal field, Imperial Valley, California.

Hot Dry Rock

1984 found the hot dry rock experiment at Fenton Hill on the threshold of tests to determine whether an industrial-scale artificial reservoir can be created and operated economically to supply sufficient energy for commercial power generation. It has already been proven by experiments completed in 1981 that energy can be extracted from this source at rates capable of small-scale power production — up to 5 MW_t. If the initial system had been located near a populus area during successful short-term tests, the power produced could have heated several hundred homes.

A new, and much larger than expected, reservoir was created at the end of 1983 by large volume flow pumping of 5.7 million gallons of water under high pressure into the rock. The new reservoir's capacity is estimated at 50 to 150 MW_t, although only 35 MW had been predicted. However, the underground loop needed to inject and recover fluids was not completed in this operation, and current efforts center on intercepting the new reservoir. Once this is accomplished and a continuous loop is established, long-term heat extraction experiments will be performed. (*EDITOR'S NOTE: The interception was successfully completed in May 1985*).

The Los Alamos National Laboratory scientific and engineering support team for Fenton Hill performs such functions as reservoir engineering, instrument calibration and maintenance, reservoir size assessments, and geochemical studies. A unique support function completed this year was the development of a series of "slime line" tools needed to fit in the small diameter — 4½ inch — wells used in the project. The components of all of the tools developed, including electronic devices, are constructed of materials that will withstand the high downhole temperatures of the final system — about 325°C (648°F) at 14,000 feet.



Phase I, 5 MWt hot dry rock experiment.

Magma

In only 10 years after interest in the concept of extracting heat from magma sources began to develop, the scientific feasibility of doing so has been demonstrated. DOE is proceeding to test the economic and technological feasibility of utilizing the heat of this resource.

During a DOE-funded seven-year research project conducted by Sandia National Laboratories, experimental boreholes were drilled into buried molten rock at temperatures up to 1100°C, and specially designed downhole heat extraction equipment was successfully demonstrated. The Kilauea Iki crater in the Hawaii Volcanoes National Park, which was filled with molten lava to a depth of about 400 feet, was used as a field laboratory. Although not a true magma deposit, Sandia reported that the only significant differences between this ponded lava flow and that of a magma body is size, gas content, and depth. Temperatures and other material properties were close enough to real magma to provide a realistic laboratory.

It was concluded that there are no known insurmountable theoretical or physical barriers that invalidate the concept of extracting heat from magma. Existing geophysical exploration systems are believed capable of locating and defining magma bodies and were demonstrated at Kilauea Iki. Drilling rigs that can drill to the depths to tap magma and engineering materials compatible with the buried magma environment are available. Sandia reported that energy can be extracted at attractive rates from magma resources in all petrologic compositions and physical configurations.

Geothermal R&D — The Present And Future

The DOE geothermal program is managed by the Department's Geothermal Technology Division (GTD), with the Department's field offices responsible for direct technical project management. The national laboratories serve the program as its main research arm (Table 7).

The program is divided into two major elements: Geothermal Geosciences Research and Geothermal Conversion Research.

The major thrusts of the hydrothermal R&D are in response to industry consensus that four factors constitute the remaining technological and economic impediments to development of hydrothermal reservoirs:

- drilling costs
- lack of confidence in reservoir definition
- uncertain behavior of injected fluids
- capital costs of power plant construction.

The hydrothermal activities addressing these problems can assist industry development in the near future. The other hydrothermal activities are long-range R&D targeted on increasing the knowledge of hydrothermal reservoirs through developing techniques for defining the large hydrothermal reservoirs in the Cascades Mountains in the Pacific Northwest and investigating the origins of hydrothermal reservoirs through studies at the Salton Sea Scientific Drilling Project. The balance of the R&D is designed to prove the feasibility and economics of using geothermal energy other than hydrothermal fluids.

The next step in geopressured geothermal R&D is experimental power generation, the first with this form of energy anywhere in the world. The experiment is a cooperative effort of DOE and the Electric Power Research Institute. DOE will furnish the well, the Pleasant Bayou, in Brazoria County, Texas, and some of the plant's component parts, and EPRI will assume the balance of the cost to furnish a hybrid generating system. The system will use both a geothermal binary cycle and a gas engine powered by the liberated methane.

Long-term, high-rate flow testing of geopressured wells will continue until 1988 to provide sufficient data to

Table 7

U.S. DEPARTMENT OF ENERGY GEOTHERMAL PROGRAM

GEOTHERMAL SCIENCE TECHNOLOGY

Hard Rock Penetration Research

Objective	Activities
Develop components and field test an advanced drilling system to reduce well costs by 50%.	• Non-Conventional drilling • Fluid Loss Control • Mechanics of Rock Penetration • Borehole Mapping • DOE/Industry Cost-Shared Drilling

Hydrothermal Reservoir Research

Objective	Activities
Develop improved reservoir understanding and prediction methods to provide management tools and reduce uncertainty in behavior prediction by a factor of 5.	• Reservoir Definition — Reservoir productivity assessment — Fracture mapping • Brine Injection — Fluid migration — Monitoring and prediction — Well completion techniques • Techniques for defining Cascades Reservoirs • Salton Sea Scientific Drilling Project • Reservoir Permeability Enhancement • State Reservoir Assessment programs

GEOTHERMAL GEOSCIENCE TECHNOLOGY

Geopressured Production Research

Objective	Activities
Complete 1) the develement of predictive models for geopressured reservoir performance based on long-term flow testing, and 2) economic analysis of the total geopressured energy recovery system.	• Geopressured Design Well Tests • Environmental Monitoring University and Industrial Research

Hot Dry Rock Research

Objective	Activities
Complete the development of 1) microseismic technology for characterizing deep hydraulic fractures in stressed crystalline rock, and 2) methodology for creation of high surface area heat exchanger systems in deep, hot geosystems.	• Hot Dry Rock Energy Extraction • Scientific and Engineering Support

Magma Energy Extraction Research

Objective	Activities
Identify potentially accessible magma bodies and determine the engineering and economic feasibility of extracting their heat.	• System Integration • Geophysics • Geochemistry and Materials • Drilling Technology

GEOTHERMAL CONVERSION TECHNOLOGY

Hydrothermal Conversion Research

Objective	Activities
Make significant improvements in conversion systems for hydrothermal electric and direct heat uses which can be applied by industry in the near term.	• Heat Cycle Research — Improved working fluids — Improved heat transfer — Improved downhole pumps • Geothermal Test Facility • Brine Injection-Surface Treatment • Hyrbrid Binary Technology • Materials/Brine Chemistry • Direct Heat Field Experiments

Binary Conversion Technology Verification

Objective	Activities
Evaluate the operational viability and establish the economics of large size binary cycle electric plants.	• Heber, California 24 MW_e Binary 1 plant • R&D Support for plant

Geopressured Conversion Research

Objective	Activities
Determine 1) the efficiency of electric energy conversion that can be obtained with geopressured brines, and 2) the engineering and economic feasibility *of direct uses of geopressured brines.*	• Power Generation Experiment in Cooperation with Electric Power Research Institute • Selected Direct Heat Experiment(s)

Hot Dry Rock Conversion Research

Objective	Activities
Determine the economic feasibility of commercial use of the recovered heat of hot dry rock reservoirs to generate electricity.	• 9000 - Hour Power Generation Experiment

Magma Energy Conversion Research

Conversion - oriented R&D will not be undertaken unless the technical and economic feasibility of extracting magma energy is favorable.

Technology Transfer

- Cost-Shared Projects
- Technical Conferences and Publications
- Topical Seminars and Workshops
- Industry Observation of Prototype Technology Field Experiments
- Technical Assistance to Technology Users

determine the economics of the production and utilization of geopressured brines. If the results are favorable, this resource could become a significant factor in the Gulf Coast energy mix by the 1990's.

Drilling has just begun at the hot dry rock experiment site at Fenton Hill, New Mexico, to connect two wells — one for injection of surface water and one for recovery of heated water — so that the large reservoir created last year can be used for power generation experiments of commercial-size capacity. (*EDITOR'S NOTE: The connection was successfully completed in May 1985*).

The ultimate goal of the magma energy extraction project is to intercept a magma body with prototype hardware designed to drill to as deep as 10,000 feet at temperatures up to 1000°C (1900°F). Some 20 sites were evaluated, and the Coso and Mono-Long Valley KGRA's in California have been selected for further study. If preliminary systems analysis and cost estimates are encouraging, one of the two sites will be selected for drilling, probably around 1990 (see Table 7).

Lease Issuance

The Geothermal Steam Act was enacted on 24 December 1970. It provided the Department of Interior its first statutory authority to lease federally-owned lands for geothermal exploitation although such lands had been available for decades for oil and gas, coal, and other minerals. The major provisions of the Act are listed in brief here for the benefit of newcomers to the geothermal field:

- Lands under the jurisdiction of the Bureau of Land Management (BLM) in Interior and the U.S. Forest Service (Department of Agriculture) may be leased for geothermal purposes, except for designated wilderness areas, national parks, and similarly protected lands. *The consent of the Forest Service is required before BLM can issue leases on its lands.*
- The amount of acreage that may be held under leases issued to any one person or corporation in any one state is limited to 20,480 acres; after 15 years the Secretary of the Interior may administratively increase the maximum to 51,200 acres. (*EDITOR'S NOTE: This was done in January 1986*).
- Areas where the geology, nearby discoveries, competitive interests, or other indicia provide strong evidence that a commercial resource is present must be designated "Known Geothermal Resource Areas" (KGRA's).
- Lands in KGRA's must be leased competitively; non-competitive applications may be filed for leases on other available land at any time.
- The primary lease term is 10 years; to qualify for an extension, the lessee must have completed one or more wells producing or capable of producing geothermal resources in commercial quantities *and* must have a contract for sale of the resources.
- Royalty payments for geothermal resource production on leases are initially set at between 10 and 15 percent, but can be increased at 20-year intervals beginning 35 years after commencement of production by up to one-half of the existing rate to a maximum of 22.5 percent.
- The terms and conditions of a lease may be adjusted at 10-year intervals except for royalty rates as described above.

The Steam Act was the first major programmatic legislation to fall under Interior's jurisdiction subsequent to passage of the National Environmental Policy Act of 1970 (NEPA). As a result, the leasing program got off to an extremely slow start. A massive, multi-volume generic Environmental Impact Statement (EIS) was prepared by BLM covering the potential effects of the entire program. As a result of the time spent on that project, the regulations were not forthcoming until January 1974, and the first lease sale was not held until over three years after enactment of the Act.

The drafters of the regulations exercised extreme caution in meeting NEPA requirements. This strict interpretation of the Act has seriously impeded geothermal leasing up to the very recent past, and its effects are not entirely dissipated today.

In implementing the regulations, competitive tracts were not offered for sale and non-competitive leases were not issued until an environmental review was completed on the acreage involved. This pre-lease review evaluated the potential effects of full development, from exploration through production and utilization as a "worst case" situation, despite official estimates that 24 out of 25 geothermal leases would never be developed because no commercially exploitable resource would be found. Postulating the end use at this point was, according to one BLM spokesman, "an exercise in futility, wasting the taxpayer's time, dollars, and resources."

By 1978, the leasing program was moving so sluggishly that the President directed the agencies to streamline the process, and an Interagency Geothermal Streamlining Task Force was funded by DOE to develop remedial measures. A statistical study conducted to support the Task Force conclusions found that nearly eight years after enactment of the Act, only 35 percent of KGRA land available for leasing under Bureau of Land Management jurisdiction had been offered for lease sale, and only two percent of that administered by the Forest Service.

At the same time, over 60 percent of the noncompetitive applications for BLM land had been pending three years or longer. Over 70 percent of the Forest Service applications fell into the same category, and the percentage would have been much higher except for the large number of applications withdrawn due to the excessive delay.

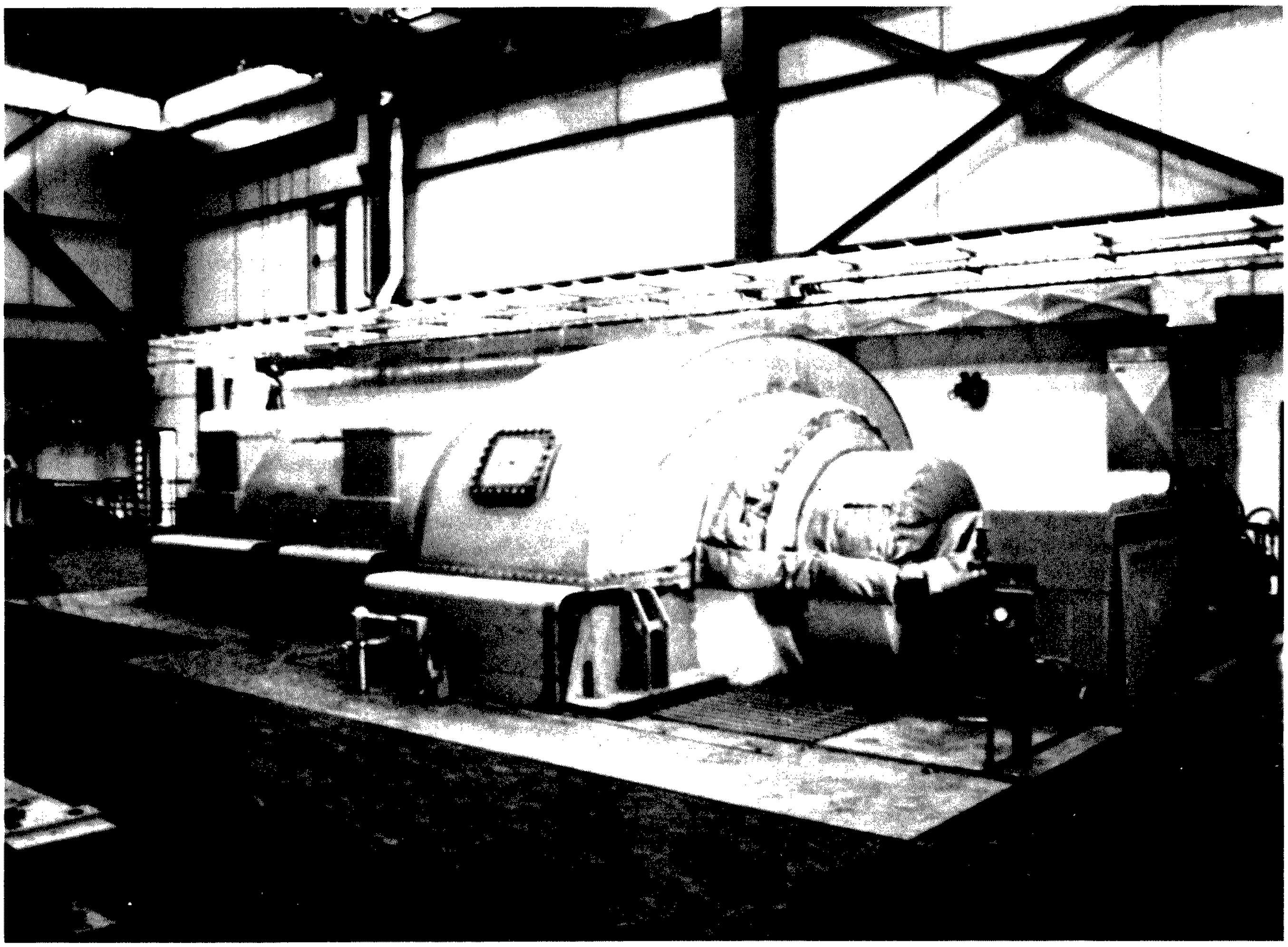
Through a series of public meetings in the "geothermal" states, the Task Force found that a number of problems were impeding geothermal development on federal lands, but without exception industry pointed to the excessive environmental review — including repetitive post-lease permit reviews — as the primary culprit. As a result, in January 1979, the Task Force made 19 recommendations for remedial measures to the Interagency Geothermal Coordinating Council. Of the 19, four are provisions in geothermal omnibus legislation that has been pending in Congress for over four years. The remaining recommendations called for administrative or regulatory changes for which amendments to the Geothermal Steam Act were not necessary.

Although few of these have been formally implemented, the Department of the Interior has attempted to meet the objective of perhaps the most important one. This was to separate exploration and development in the environmental review process to expedite exploration while assuring ample environmental protection for developmental activities. BLM first offered, in 1980, a "phased" lease, but industry showed little interest in leases that did not guarantee that development would be permitted. As a result, and in spite of a number of procedural/conceptual changes during intervening years, phased leasing was discounted early in 1984. In the meantime, in 1982, the Department declared non-competitive geothermal leases eligible for categorical exclusion from the NEPA process where there will be subsequent NEPA compliance prior to development. Nevertheless, field offices have found the exclusion unworkable and have continued preparing environmental assessments that attempt to consider all stages of lease development.

The Forest Service carried out an experiment in four Oregon forests with leases very similar to the BLM phased lease. Instituted as a cost savings plan — a spokesman for the agency said hundreds of thousands of dollars had been spent over several years on unneeded environmental analyses — the Contingent Right Stipulation experiment has now been abandoned.

It would not have applied in any event to areas recommended for wilderness status or in sensitive areas where the Forest Service feels that resource conflicst would limit enegy development opportunities. Acreage in these areas, according to a spokesman for the agency, accounts for the remaining backlog of Forest Service geothermal lease applications. Otherwise, the spokesman reported, it is reasonably current in issuing leases.

There are many competing interests among users of the national forests which make mineral decisions very



General Electric Co. Steam Turbine/Generator (20 MW) in use at Roosevelt Hot Springs geothermal field near Milford, Utah.

difficult in many cases. It is reported in the *Technology Transfer* section that the Forest Service is holding geothermal workshops for its field personnel in an effort to increase their understanding of these problems.

The Forest Service spokesman stated that leases on Forest Service applications filed today for acreage in forests where the environmental impact statement has been prepared will be issued in about two months — unless they are rejected because the particular acreage applied for is designated as unavailable for leasing for environmental reasons or for procedural reasons requiring rejection. If the EIS has not been done, the spokesman said, it would take about a year to obtain a lease, except in "sensitive areas" which are still subject to considerable controversy.

BLM has essentially finished its environmental assessment and land planning for the geothermal areas of interest. While there may be some variation among BLM state offices, non-competitive leases should be expected to be issued in a timely manner.

Nearly all competitive acreage the surface of which is administered by BLM has been offered, some several times, and the lack of bids on some tracts after being offered twice resulted in the declassification of several KGRA's. They include:

Gillard Hot Springs, AZ
Ford Dry Lake, CA
Little Horse Mountain, CA
Lovelady Ridge, CA
Witter Springs, CA
Conda, ID
Fly Ranch Northeast, NV
Gerlach Northeast, NV
Monte Neva Hot Springs, NV
Salt Wells Basin, NV

All of these revoked KGRA's except Monte Neva were originally defined on the basis of "competitive interest," or the overlapping by at least 50 percent of two or more non-competitive lease applications, and not on the basis of geothermal indicia.

As of June 1984, BLM had issued 2365 leases for lands administered by that agency compared with 523 for Forest Service lands. Over half of the total leases issued have been relinquished by the lessee or terminated by BLM, leaving a total of 1393 active leases. Of these, only 30 leases embrace producible wells, three in California, 17 in Nevada, and 10 in Utah. There are 12 producing leases, 11 in California and one in New Mexico.

It can be concluded that progress has been made in the timely issuance of geothermal leases, but that it was slow in coming.

Lease Extension

As of this year on the 10th anniversary of the first leases issued, the problem became one of keeping the leases beyond the 10-year primary term. Among the conditions required by the Geothermal Steam Act for an additional 40-year term is a contract for the sale of the resource from one or more wells producing or capable of producing the resource. Despite substantial development investment on a number of leases, the developers could not find a market for the resource, due to reduced power demand and a poor economic climate. This situation has been remedied for the present with stopgap legislation to provide for a two-year extension of affected leases. Legislation has been introduced by Senator Chic Hecht of Nevada to incorporate the stopgap language in the Steam Act as extension conditions for all leases. The Bill is currently still active.

Acreage Limitation

As noted above, the amount of acreage that may be held under lease by any one person or corporation in any one state was limited to 20,480 acrea. The Secretary of the Interior used his administrative authority to increase the limitation to 51,200 acres in December of 1985. ☐