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HDR GEOTHERMAL ENERGY - A PROGRESS REPORT

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ABSTRACT

This paper presents a description of the Hot Dry Rock Geothermal Energy Program and a summary of the work completed to date. The Fenton Hill Project is reviewed starting with the research system (Phase I) established in its initial configuration in 1977 with the research work completed in mid-1981. The engineering system (Phase II) initiated in parallel with the completion of the Phase I is now being developed in its interim configuration. The final system is planned for completion in FY 1985 with about one year of testing extending through FY 1986. Technical evaluations and test data to date are encouraging. The foreign involvement (FRG and Japan) is expected to continue along with positive support in the U.S.

INTRODUCTION

The Hot Dry Rock Geothermal Energy Program began in 1972 as a research, development and demonstration project at the Los Alamos National Laboratory ("Los Alamos"). That project is known as the Fenton Hill Project and derives its name from that of the test site, Fenton Hill, located about 55 km west of Los Alamos, New Mexico. This site is situated on the western rim of the Valles Caldera, a comparatively young silicic volcano which was active as recently as one hundred thousand years ago.

The Fenton Hill project was supported entirely by the United States Government, through the U.S. Department of Energy (DOE) and its predecessor organizations, until U.S. Fiscal year (FY) 1980. Beginning in that year and continuing to the present, the Government of West Germany through the Kernforschungsanlage-Jülich GmbH (KFA) and the Government of Japan through the New Energy Development Organization (NEDO) became cosponsors of the Project with the DOE.

The overall objective of the Project is to develop and demonstrate the technology required for the commercial extraction of energy from geothermal sources, hot rock formations that contain insufficient natural geofluid for economic production and popularly called "hot dry rock" (HDR). Work in the project has proceeded in two major phases. In the first phase, the project was focussed upon confirming experimentally the feasibility of the HDR heat-energy extraction technique proposed by Los Alamos. That technique, illustrated by Fig. 1, involves artificial introduction of water into, and closed-loop circulation through, a man-made geothermal reservoir created by hydraulic fracturing at depth of the hot, low-permeability rock between two boreholes.

Fig. 1. Hot Dry Rock concept
The confirming experiment accomplished in the 1977-1981 period used a small “research” reservoir, created at a depth of about 3 km in 200°C rock and operated for short periods of time at a nominal energy extraction rate of 5 thermal megawatts. The research reservoir, accessed through wells EE-1 and GT-2, was established in its initial configuration in 1977 and enlarged to its present configuration in 1979. This reservoir was used to: (a) demonstrate initial technical feasibility; (b) provide short-term information on predictability of drawdown, time-variation of impedance, water loss rate, geofluid chemistry, and stop/start transients; (c) serve as a test bed for evaluation of reservoir enhancement techniques, such as operation under high back pressure; (d) evaluate high-risk/high-payoff reservoir-extension workover techniques; and (e) conduct a small preliminary electric generation experiment. The two lower curves in Fig. 2 (note logarithmic time scale) show the verification of performance of the research reservoir in its initial, and subsequently enlarged, configurations.

Having successfully demonstrated the technical feasibility of the concept, the HDR Program was expanded in 1978 to include activities other than the Fenton Hill Project. Those activities, since completed as shown in Fig. 3, included evaluating the United States HDR resource and some preliminary economic, environmental and other relevant institutional studies. Prominent among these activities was the resource evaluation effort, which was carried out in cooperation with the U.S. Geological Survey. This activity consisted of collecting and analyzing geothermal gradient, heat flow and other pertinent geophysical data from sites all over the conterminous 48 states. The enormity of the HDR resource was verified, as shown in Fig. 4, and indeed justifies the cost of developing this technology.

Meanwhile, the Phase I reservoir work was completed in mid-1981. While no further major operation are planned in the research system, the EE-1 and GT-2 wells are available for occasional use as laboratories for in situ field testing of downhole instruments and equipment, and as listening stations for emplacement of microseismic instrumentation during fracturing and other operations in the Phase II system.

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**Fig. 2.** Reservoir thermal drawdown performance curves under constant loading.
(Reservoir Loading Parameter, $G = \frac{\text{Circ. Mass Flow}}{\text{Effective Area}}$, kg/hr-m$^2$)
The second phase of the Fenton Hill Project continues as planned. This phase is dedicated to the development of commercially usable technology for the creation, control and useful-life assessment of a reservoir more nearly representative of an industrial application. This is being accomplished with a larger engineering reservoir, presently under construction, at a depth of over 4 km in 30°C rock. In its final configuration, the engineering reservoir is expected to have a performance characteristic at least as good as the upper curve in Fig. 2 and produce a nominal 35 MWt of power.

Construction of the Phase II system was initiated in parallel with completion of the Phase I system testing. The planned sequence of activities in the execution of the remainder of the Project is shown in Fig. 3. This effort consists of completing the staged construction and testing of the engineering reservoir, spanning the period through FY 1983, followed by a six-month period for shutdown and restoration of the test site and for final documentation of the HDR Program.

The primary objective of the Phase II effort is to demonstrate creation and control of a multiple-fractured reservoir with extended longevity by creating a larger system (35 ± 15 MWt) with a projected life in excess of 10 years. A third well, EE-2, was completed in FY 1980 to a vertical depth of 4.4 km and a bottom-hole temperature of 327 degrees C. This well will serve as the injection well for the Phase II system. A fourth well, EE-3, was completed in FY 1981 to a vertical depth of 4.0 km and a bottom-hole temperature of 266°C. It will serve as the Phase II production well. Using these wells, the engineering reservoir will be constructed in two stages: the interim configuration and the final configuration.

In the interim configuration, only a portion of the ultimate fractured region will be created. A temporary surface flow loop will then be established to conduct a circulation test (IER-1) of about six months duration. This test will provide early information pertinent to the engineering reservoir on: (a) flow impedance stability in a multifracture zone, (b) water loss rate, and (c) possible intrareservoir scaling or deposition effects. It will also serve to calibrate one or more proposed tracer methods of reservoir size assessment against a measurable thermal drawdown. Interim configuration fracturing operations are presently in progress and targeted for completion in the fourth quarter of FY 1983. After installation and connection of the required surface plumbing, flow test IER-1 will commence near the start of the first quarter, and terminate in the third quarter, of FY 1984.

Immediately following testing of the Interim System, and guided by the results thereof, construction of the final configuration will proceed. After dismantlement of the temporary surface system and other requisite preparations, a large workover rig will be contracted to perform the remaining fracturing operations to produce the final reservoir configuration in the second quarter of FY 1985.

Design and construction of the permanent Phase II surface system will begin in parallel with establishment of the final-configuration reservoir. Construction of the surface system will begin in the third quarter of FY 1984 and is scheduled to be completed in FY 1986. The installation will be designed such that most of it, other than rejection to air heat exchangers, is configurationally representative of an industrial pilot plant application. Upon completion of this work, the Phase II loop will be activated for a protracted energy-extraction test (FER-1).

Testing of the Phase II reservoir will continue for about one year beyond this point, through the end of FY 1986. After six to eight months of continuous operation, it is expected that assessment of the minimum reservoir lifetime will be possible.

Careful environmental surveillance will continue throughout Phase II, particularly for...
possible seismic and hydrologic effects. This effort will not only ensure protection of the Fenton Hill environment, but also provide a documented case history for use in future environmental analyses, assessments, and impact statements.

SCIENTIFIC AND ENGINEERING SUPPORT

The Fenton Hill Project serves a dual purpose: first, as the HDR energy extraction demonstration per se, and secondly, as a field laboratory for development and testing of special materials, drilling- and fracturing-related equipment, downhole instrumentation, and reservoir interrogation techniques essential to the technology. In the latter regard, a considerable amount of offsite scientific and engineering effort is required to support various aspects of the Phase II Fenton Hill site operations. One such support effort is reservoir engineering whose major components are theoretical analysis, data process, and modeling. This work includes not only modeling and analysis, of data on the characteristics and behavior of the existing Fenton Hill system but also predictions concerning hot dry rock geothermal systems in general.

The analytical activity is complemented by a parallel, laboratory experimental program which includes rock properties measurements, chemical analyses, and simulations. Empirical determination of physical and mechanical properties, and of heat transfer and fracturing behavior, of reservoir rocks is essential to understanding and correctly modeling reservoir behavior. Geochemical studies of rock-water interactions are being carried out, as needed, to anticipate and solve potential scaling, plugging and corrosion problems. At the same time, thermochemical tracer methods will be developed, and calibrated against positive thermal drawdown data, to provide a relatively rapid and routine method of assessing accessible reservoir size. In addition, physical modeling is being used to investigate such phenomena as thermal stress cracking and fluid flow in irregular geometries.

Another major support area is the development of critical downhole tools, equipment and techniques needed to map reservoir fracture systems and determine reservoir properties. During the Phase II effort, the key diagnostic instruments developed in Phase I are being thermally upgraded to contend with the engineering reservoir’s higher temperatures and pressures. In addition, a high-temperature sonic televlwer will be developed for joint and fracture mapping, and a biaxial extensometer will be constructed for studying changes in intrawellbore strain patterns. Of course, regular calibration and maintenance of both downhole and surface instrumentation will continue to assure accurate, reliable test data. Replacement high-temperature instrument cables will also be procured, quality-tested and mounted, as necessary.

REFERENCES


