HOT DRY ROCK PROGRAM IN THE EASTERN U. S.

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ABSTRACT

The Los Alamos Scientific Laboratory (LASL) Hot Dry Rock Geothermal Energy Project is the first U. S. field test of this huge geothermal resource base. In the concept developed by LASL, a man-made geothermal reservoir is formed by drilling a deep hole into relatively impermeable hot rock, creating a large surface area for heat transfer by fracturing the rock with hydraulic pressure, then drilling a second hole to intersect the fracture to complete the circulation loop. Such a demonstration system has been completed at Fenton Hill in north-central New Mexico, at a depth of 3050 m (10 000 ft) and a bottomhole temperature of 205°C (402°F). The system has been successfully circulated for approximately 2800 h to determine temperature drawdown, permeation water loss and flow characteristics of the pressurized reservoir, to examine chemistry changes in the circulating fluid, and to monitor for induced seismic effects. As a result of these successful experiments, a national program for development of the hot dry rock potential is now being conducted by LASL. Additional sites are being evaluated in the U. S. for prospective demonstration plants. Two of the most promising eastern locations at this time appear to be northcentral New York State and the eastern shore of Maryland and Virginia. Hot dry rock sites in the east will probably closely follow the technology developed in New Mexico--at least for the first several projects. Several areas in the east have geothermal gradients that are high enough to be considered for electrical power generation, as well as nonelectrical uses.

INTRODUCTION

At sufficient depths, rock hot enough to be a potentially useful energy source exists everywhere. Formerly, it was thought that only the western third of the United States possessed a significant potential for the near-term utilization of manmade hot dry rock (HDR) geothermal reservoirs. Regional heat flow data indicate that about 95 000 square miles in the west is underlain by hot dry rock at temperatures above 290°C (554°F) at a depth of 5 km (16 400 ft). Recently, several regions of the eastern U. S. have also been identified for possible development of HDR reservoirs of moderate depth. Although probably of somewhat lower temperatures than the western sites, these eastern HDR reservoirs can also be used to produce electricity or for direct heat utilization.

The total amount of potentially useful energy stored in the hot dry rock beneath the continental "lower" United States--at depths less than 10 km (32 000 ft) and temperatures greater than 150°C (302°F)--is estimated to be 13 million quads assuming an average gradient of 22°C/km. By contrast, the current energy usage by the United States is about 75 quads per year from all sources. Of these 75 quads, approximately 28 quads are used for low temperature (less than 300°C), nonelectrical uses; the remainder being used for high-grade electrical generation, primary metals reduction, and the transportation sector. Figure 1 depicts the energy use spectra of the low temperature nonelectrical portion of our total energy consumption. It is with this portion of U. S. consumption that HDR energy systems will have the biggest impact.

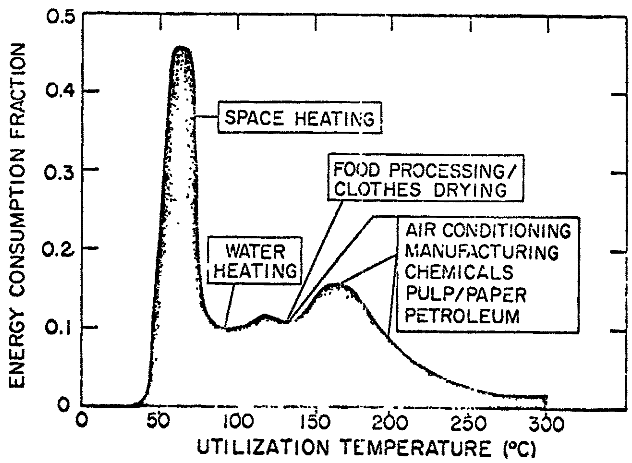

Fig. 1 The shaded area under the curve depicts the integrated energy use spectra of the total U.S. energy consumption below 300°C, amounting to approximately 28 quads (1 quad = 10^{15} BTU).

LOS ALAMOS HDR PROJECT

The LASL HDR Geothermal Project at Fenton Hill, New Mexico, is the first attempt to demonstrate the technical and economic feasibility of extracting heat from hot dry rock. In the Los Alamos concept, a manmade geothermal reservoir is formed by drilling a borehole into hot impermeable rock, creating a large vertical fracture at the bottom, than intersecting the fractured area with a second borehole. The fracture is formed by large-scale hydraulic-fracturing techniques developed by the oil and gas industry, and provides a very large surface area for heat transfer. The heat contained in the rock is brought to the surface by circulation of water through the system. Buoyant circulation of the fluid within the vertical fracture assists in pumping the fluid through the loop. The water in the loop is pressurized to avoid boiling, thereby increasing the rate of heat transport up the withdrawal holes compared to that possible with steam.

Preliminary experiments and analyses indicate that thermal stresses created by cooling of the hot dry rock in such a manmade reservoir may gradually enlarge the fracture system so that its useful lifetime may be extended to 30 to 40 years--far beyond the potential of the original reservoir. If these thermal stress cracks grow preferentially downward and outward into hotter, uncooled rock, as seems probable, the quality of the geothermal source may actually improve as energy is withdrawn from it (Fig. 2).

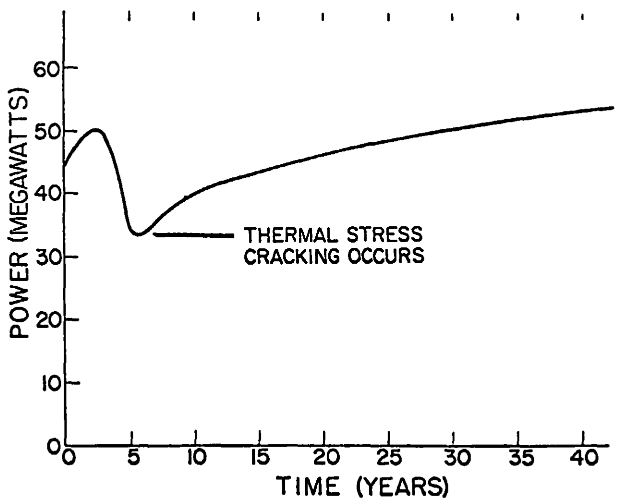

Fig. 2 Thermal stress cracking may occur in the hot dry rock system as the fractured zone is cooled by circulating water. This phenomena would permit water to remove the heat from a larger volume of rock, thereby greatly extending the life and size of the geothermal reservoir.

FENTON HILL SITE

To test the concept, a location in northern New Mexico at Fenton Hill (now identified as HDR Site No. 1) was selected as being geologically appropriate for the development of the first HDR experiment. The area is located about 20 air miles west of Los Alamos. A million years ago, the Valles Caldera was formed when a huge volcano erupted and then subsided into its own empty magma chamber. As a result of this relatively recent volcanism, a large amount of heat is still retained in the underlying rock within a few kilometers of the surface.

The first deep exploratory hole (GT-2) was begun at Fenton Hill in February 1974. It was completed at a depth of 2929 m (9610 ft), with a diameter of 24.4 cm (9-5/8 in) and a bottomhole temperature of 197°C (387°F). A near-vertical, 122 m radius (400 ft) fracture was thought to have been created near the bottom of the hole. Although the Precambrian granitic rock seemed to be broken by extensive natural fractures at various depths in the hole, the water leakoff was slight.

The second hole (EE-1) was located 72 m (252 ft) northeast of the first. Drilling began in May 1975 and was completed at a depth of 3064 m (10 053 ft), with a bottomhole temperature of 205°C (402°F). Directional drilling techniques were used to angle EE-1 toward the fracture at the bottom of GT-2. The hole was drilled through a 205° spiral, turning counterclockwise from an initial northwest heading to a northeast heading, in the attempt to intersect the fracture. On October 14, 1975, flow between the two boreholes was established, creating for the first time a manmade connection in hot, nearly impermeable basement rock.

However, because of inaccuracies in locating the fracture when the intersection was attempted, EE-1 missed the fracture by about 8 m (27 ft). At that time, instruments did not exist which could locate the boreholes with respect to each other at the extreme conditions of temperature and pressure in the bottom of the holes. In April 1977, GT-2 was directionally redrilled to intercept a fracture system produced from EE-1, and a connection with a relatively low impedance was achieved (Fig. 3).

The predominant Precambrian rock in both holes is banded granitic gneiss. A relatively extensive and homogeneous biotite-granodiorite body was encountered at depth. Fractures were usually well healed or sealed, as determined by coring and geophysical logging. Nearly all drilling in the crystalline basement was done with full-face tricone rock bits, except for coring. For standard drilling, penetration rates ranged from 0.9 m/h (2.8 ft/h) to a maximum of 11.6 m/h (38 ft/h). The maximum standard drilling interval for a single bit was 205 m (672 ft) in 75 h. These holes now constitute the bulk of existing U. S. drilling experience in hot granitic rock using conventional oil-field equipment.

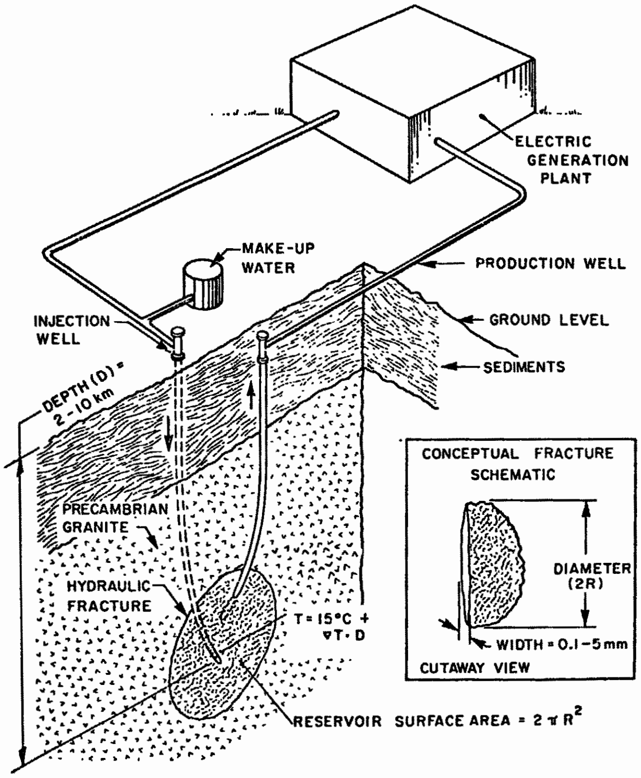

Fig. 3 Conceptual diagram of an experimental hot dry rock geothermal system, similar to HDR Site No. 1 at Fenton Hill.

CIRCULATION EXPERIMENTS

On June 3, 1977, during a 20 h pumping experiment, cold water pumped down EE-1 at 6.9 MPa (1000 psi) was returned to the surface in GT-2 at 130°C (266°F). In January 1978, and continuing into April, a prolonged circulation and heat extraction experiment was begun to determine the mechanical, physical, and chemical properties of the reservoir and the heat exchanger system. After 1800 h (75 days) of continuous circulation, the results from this test have been very encouraging. Water losses have been low (average less than 5 gpm), while the reservoir flow impedance decreased from 15 psi/gpm to less than 3 psi/gpm with an increase in the size of and the degree of mixing within the fractured system. Power production was 5 MW (t), with heat being wasted to the atmosphere. The thermal drawdown could be modeled using an 8000 m^2 (86 000 ft^2) fracture surface area. Several aspects of the flow and chemical behavior indicate that thermal contraction and pore fluid pressurization may have enlarged the volume of rock accessible for heat extraction during the circulation test.

Replumbing of the surface circulation equipment to allow greater flow rates occurred during the summer of 1978, and pumping began again in September to further characterize reservoir behavior. After circulating for 950 h, the experiments were terminated due to excessive water losses from failure of the cement behind the casing in EE-1.

PROJECTED DEVELOPMENT

With a total of more than 2800 h of operation in the energy extraction mode, the HDR circulation tests have experienced no particular problems. Water chemistry has remained quite manageable, and no induced seismicity has been detected by the surrounding seismic network. In April 1979, drilling will begin again at Fenton Hill, to expand the system to depths of 4262 m (14 000 ft), where temperature of 275°C (528°F) are expected. Such a system might be able to produce electricity for 10 000 customers and would provide valuable information for the design and construction of a small scale electrical generating plant that uses this new energy source.

If success continues at Fenton Hill, then the first demonstrations of the use of HDR geothermal energy, both for generating electricity and for nonelectrical purposes, could be in progress by 1985. The first systems will probably be small, each producing about 50-100 MW (thermal) or 10 MW (electrical) but they will conform to the new idea of decentralization of energy production using "neighborhood" power plants.

FEDERAL HDR GEOTHERMAL ENERGY DEVELOPMENT PROGRAM

On a national basis, LASL has been designated by DOE/DGE to be the lead agency in developing the nation's HDR resource. Investigations are presently underway in both eastern and western states, some near large load centers, to identify additional HDR sites with different geologic conditions as the next experimental energy extraction locations. Within the next several months, two 100-square-mile areas in the United States will be chosen as prospective sites for prototype development. Choice of the sites will be made by LASL working with the Federal HDR Program Development Council. Industrial firms, under contract to DOE and LASL, will investigate the sites for technical feasibility, and one or more areas will be pinpointed for a deep drilling test and possibly a subsequent demonstration plant. Drilling at other sites in following years may proceed after additional field studies. The Federal Program will determine the potential of HDR geothermal energy as a significant energy source and provide a basis for its timely commercial development. The manager for the program is Dr. Gregory Nunz of the Los Alamos Scientific Laboratory.

EASTERN HDR PARAMETERS

The first one of several eastern HDR sites will probably closely follow the technology successfully developed at Fenton Hill in New Mexico: two wells will be drilled, and a hydraulic fracture created in low permeability crystalline basement rock. However, a different heat source from Fenton Hill will be sought, in order to broaden our knowledge of the HDR resource base. We would hope to find and explore a more widely distributed type of heat source than the young silicic volcanoes of the west--mantle upwarp, crustal thinning, radiogenic decay, or tectonic areas. Also, a different type of reservoir rock, other than granitic, would make for a logical, but not too far-out, extension of our present experience.

Either electric or nonelectric sites would be satisfactory. A site with temperatures high enough for electrical power generation (200°C) would be preferred, but a site with a basement temperature more than 100°C would be suitable for space heating, food processing, etc. From the standpoint of strict economics (disregarding the worth of technological advancement), the nonelectric reservoir rock would probably have to be within 3 to 3.5 km (9800 to 11 500 ft) of the surface to offset drilling costs. Rock temperatures suitable for power generation could probably be as deep as 4 to 5 km (13 000 to 16 000 ft) to be economically feasible. In addition, the power generation site could be located almost anywhere and still tie into the local power line grid, for distribution to the regional network. The nonelectric site however, would have to be located within 15 km (9 miles) of potential users to make the heat-transmission pipelines economically feasible.

EASTERN HDR EXPLORATION

Without the surface manifestations of hot springs (and occasionally geysers and fumaroles) that are the western indicators of subterranean heat, exploration methods for HDR heat sources in the east have to be more sophisticated. It's true that even slightly warm springs and chemical geothermometers are good initial starting points for exploration for geothermal potential, but we're learning in the west how to apply the geophysical prospecting methods that have been developed by the mining, petroleum, and hydrothermal industries. These methods are now being applied with promising results in the east.

An outline for HDR exploration in the east follows the same rationale as in the west:

(1) Collection of available water temperature, geothermal gradient and heat flow data from existing springs and wells.

(2) Determination of promising reservoir heat sources by examination of chemical geothermometry data from those waters.

(3) Use of geophysical prospecting surveys to determine geologic structure, rock density anomalies, and indicators of high temperatures:

a. Seismic reflection and refraction
b. Gravity
c. Magnetic
d. Electrical
e. Magnetotelluric

(4) Drill shallow holes to determine heat flows in areas of interest.

(5) Conduct detailed comprehensive geological and geophysical explorations in a limited 100-square-mile area.

(6) Drill a deep hole to confirm gradient, heat flow, and existence of suitable basement rock.

In general, the work indicated in steps 1 and 2 is already well along, having been initiated by individual State Geological Surveys or universities, although some states are just getting started. Work through step 4 has been in progress for nearly four years along the Atlantic Coastal Plain and Piedmont by John Costain and his group at Virginia Polytechnic Institute. As a result of the VPI work, a deep hole is scheduled to start this spring at Crisfield, Maryland, as the first test in the Atlantic Coastal Plain. Under the National HDR Program, LASL will provide funding to drill the bottom 700 ft to investigate the hot dry rock reservoir potential.

NEAR-TERM EASTERN POSSIBILITIES

Geothermal gradients in the east normally range from 10°C/km to 40°C/km. By contrast, the gradient at Fenton Hill is 60°C/km and throughout much of the west it averages more than 30°C/km.

In the Buffalo-Syracruse area of New York State, gradients have been estimated at 36°C/km, which would produce a bottomhole temperature of about 125°C at 3 km (10 000 ft). This area is being considered by the HDR Program Development Council as a site for detailed exploration as listed in step 5 above.

At Stumpy Point, NC, and Wallops Island, VA, geothermal gradients of 47°C/km and 35°C/km respectively, have been estimated. This area is also a strong candidate for one of the next HDR geothermal demonstration projects. With continued interest and exploration, new promising areas are being discovered. There may be hundreds of plutons, containing relatively high amounts of radioactive elements, along the Atlantic Coastal Plain, hiding under thick sediments.

The New England Conway granite is the most recent known pluton in the east, and contains heat-generating uranium, thorium, and potassium. In local areas where alluvial blankets have prevented this radiogenic heat from escaping into the atmosphere, gradients may be high enough to warrant HDR consideration.

OTHER HDR SYSTEMS

The picture of HDR energy systems that continues to appear the most feasible at this time is one of at least two deep, large diameter drilled holes through which cool water is introduced into a natural thermal reservoir and hot water is recovered. Variations on this general theme are possible however, in the nature of the natural thermal reservoir, how it is developed and stimulated, and how flow through it is handled in the operating mode. The low matrix permeability of the reservoir rock is considered to be a critical factor, although instances can be envisioned where flow between parallel fractures, through thin permeable layers, or even thick permeable formations could be successfully controlled even though the matrix permeability was significantly higher. A number of these possibilities have been described in a recent paper by M. C. Smith of LASL.

CONCLUSIONS

With the successful implementation of the first HDR Energy Demonstration Project (HDR Site No. 1) at Fenton Hill, the Federal Program is now underway, actively investigating new prospective sites. A large number of areas of promising geothermal interest have already been identified across the United States, including several in the east. These sites represent a variety of geologic environments and will permit a slow, but ever increasing extension of our knowledge of extracting energy from the hot dry rocks of the earth. The more we look for promising additional sites, the more we seem to find. The relative engineering simplicity of this type of energy system and the sheer abundance of the potential resource make it inevitable that it will be economically developed in many parts of the world.

REFERENCES

LASL HDR Project Staff, 1978, Hot Dry Rock Geothermal Energy Development Project, Annual Report, Fiscal Year 1977: Los Alamos Scientific Laboratory report LA-7109-PR.

Charles, R. W., 1978, Experimental Geothermal Loop: I, 295°C: Los Alamos Scientific Laboratory report LA-7334-MS.

Cummings, R. G., Morris, G. E., Tester, J. W., Bivins, R. C., 1978, Electricity from Hot Dry Rock Geothermal Energy: Technical and Economic Issues: Los Alamos Scientific Laboratory report LA-UR-78-1374.

HDR Assessment Panel, 1977, Hot Dry Rock Geothermal Energy: Status of Exploration and Assessment Report No. 1: ERDA/DGE report ERDA 77-74.

Murphy, H. D., 1978, Thermal Stress Cracking and the Enhancement of Heat Extraction from Fractured Geothermal Reservoirs: Los Alamos Scientific Laboratory report LA-7235-MS.

Overton, H. L., and Hanold, R. J., 1977, Geothermal Reservoir Categorization and Stimulation Study: Los Alamos Scientific Laboratory report LA-6889-MS.

Pettitt, R. A., 1976, Environmental Monitoring for the HDR Geothermal Energy Development Project, Annual Report, July 1975-June 1976: Los Alamos Scientific Laboratory report LA-6504-SR.

Pettitt, R. A., 1978, Testing, Planning, and Redrilling of Geothermal Test Hole GT-2, Phases IV and V: Los Alamos Scientific Laboratory report LA-7586-PR.

Rea, K. H., 1977, Environmental Investigations Associated with the LASL HDR Geothermal Energy Development Project: Los Alamos Scientific Laboratory report LA-6972.

Smith, M. C., 1978, The Future of HDR Geothermal Energy Systems: Los Alamos Scientific Laboratory report LA-UR-78-3329.

West, F. G., and Shankland, T. J., 1977, Exploration Methods for HDR; Report of the Panel Held June 22, 1976: Los Alamos Scientific Laboratory report LA-6659-MS.