

The Hot Dry Rock Program

by Morton C. Smith

It is not often possible to trace the ancestry and list the immediate family of a new idea, but in this regard—and some others—the Hot Dry Rock Geothermal Energy program is exceptional.

Since its establishment as Site Y of the Manhattan Project, the primary mission of Los Alamos National Laboratory has required information that could be acquired only from experiments done in nuclear reactors, and reactor expertise has always been one of its greatest strengths. It was therefore quite natural, when a national need appeared for higher-performance rocket-propulsion systems, that the Laboratory should propose the use of compact, gas-cooled nuclear reactors. The result was the Rover program.

One of the reactor concepts considered in the early days of the Rover program was Dumbo, a fast reactor with a refractory-metal-composite core built as a honeycomb structure. To demonstrate the heat-transfer characteristics of such a structure, a resistively heated laboratory-scale model of a core section was built and used to heat a hydrogen jet to above 3000 degrees Celsius. The demonstration was impressive, and when Dumbo was abandoned in favor of a graphite-core reactor, some of the Dumbo advocates felt that a gadget that good must have other uses. In particular, Robert M. Potter (now a Laboratory Fellow), after rereading the Edgar Rice Burroughs novel, *At the Earth's Core*, concluded that something like it could as well be pointed down as up and used to melt holes in rock more rapidly and efficiently than they could be produced by drilling or tunneling. The result, some years later, was the Subterrene program—development of a rock-melting earth penetrator.

In 1970 the late Eugene S. Robinson assembled an *ad hoc* committee from several Laboratory divisions and disciplines to examine the possibilities and problems of the Subterrene. One of the obvious problems was disposal of the molten glass produced when a rock is melted. Again Potter had a

suggestion. He had been reading about drilling in oil and gas fields and had learned about hydraulic fracturing—the use of fluid pressure to produce large cracks extending outward from the well to facilitate drainage of fluids into it. He proposed that sufficient pressure could be developed in the melt ahead of a penetrator to produce such cracks and force the glass into them, where it would freeze and remain. This idea was never actively pursued in the Subterrene program, but it appeared to the committee that hydraulic fracturing had many other possibilities. One of the most important of these, they concluded, was its use to create flow passages and heat-transfer surface in naturally heated crustal rock whose initial permeability was too low to be usefully productive of natural steam or hot water—"dry hot rock."

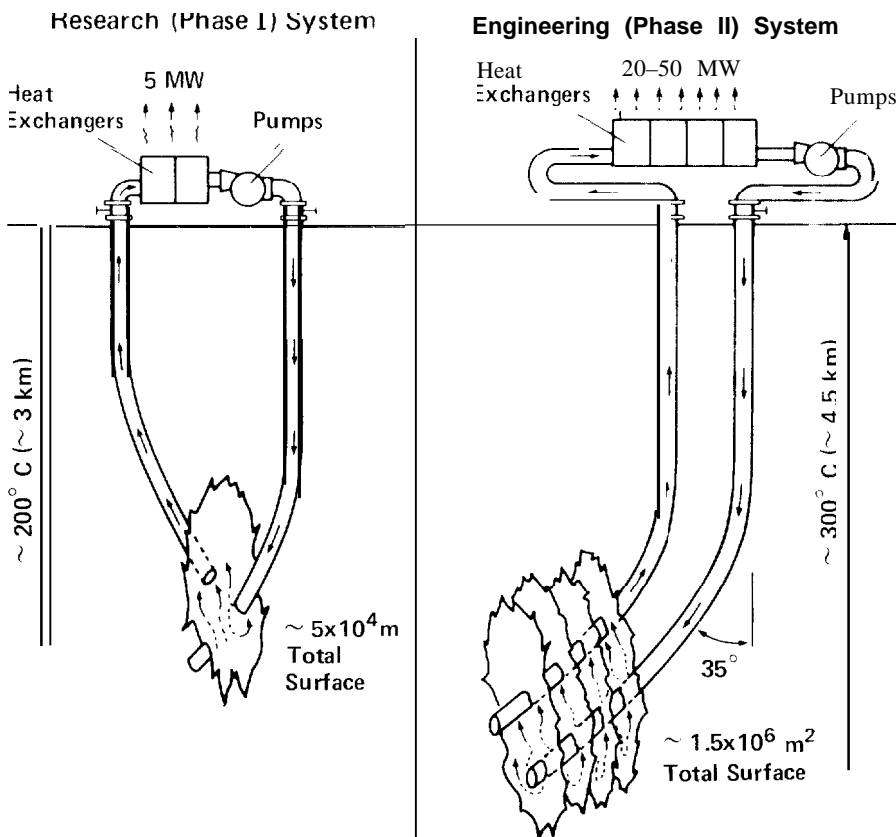
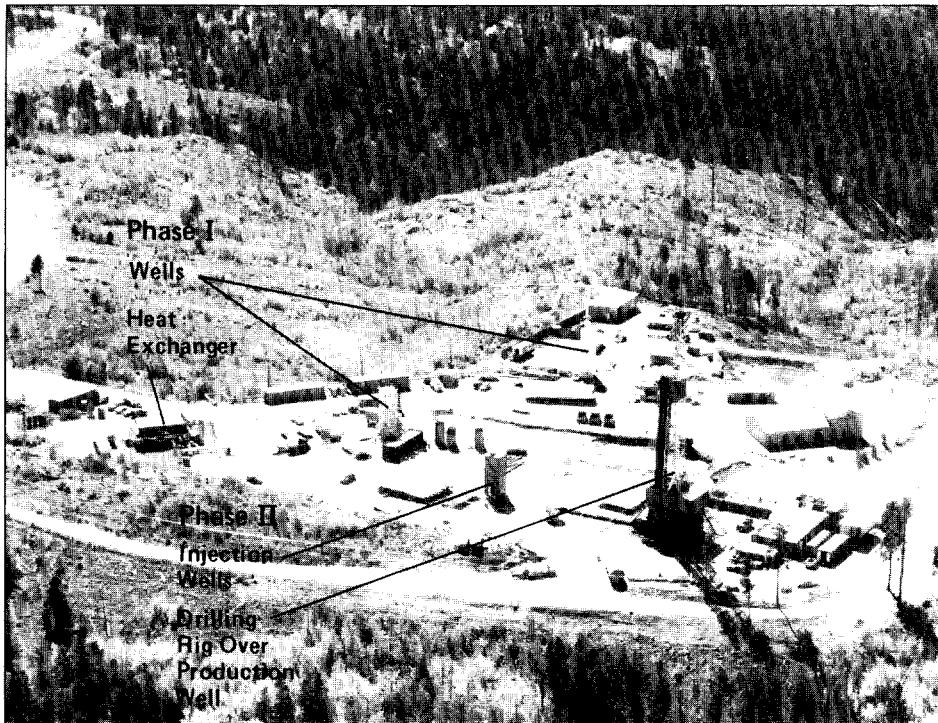
The method proposed by the committee was to drill a hole from the earth's surface to a sufficient depth to reach essentially impermeable rock at a usefully high temperature; to produce a large hydraulic fracture near the bottom of the hole; to drill a second hole from the surface to intersect that fracture; to pump water down the first hole to circulate through the fracture and extract heat from the rock around it; to recover the hot water through the second hole under sufficient pressure to prevent boiling; to extract its useful heat; to then return the water to the first hole to recirculate and extract more heat.

When the Subterrene program had been launched, Bob Potter and I assembled a group of volunteers and initiated a "Dry Hot Rock Geothermal Energy program" to investigate this concept. (The name was subsequently changed by someone in Washington who thought that "Hot Dry Rock" was more euphonious.) Initially the program was unofficial, unfunded, and supported largely by faith and the tolerance of Laboratory management. Most of the first year's work was done on weekends and holidays, and much of it in snow up to there. However, in 1971 the group managed to digest much of the

existing information on geothermal areas and the equipment and techniques needed to create a dry hot rock energy system, and to begin a terrestrial heat flow study in the Jemez Mountains west of Los Alamos. In 1972 that study was concluded and, with discretionary research and development funds provided to the Laboratory by the Division of Military Application of the AEC, an exploratory hole was drilled in Barley Canyon—about 30 kilometers west of the Laboratory. The hole reached a final depth of 785 meters, penetrated about 143 meters of granitic basement rock, and had a bottomhole temperature of 100.4 degrees Celsius. With additional funding from the Division of Physical Research of the AEC, hydraulic-fracturing and pressurization tests were run in the lower part of the hole, and it was concluded that the basement rock was well suited to creation and containment of a pressurized-water heat-extraction loop.

With this encouragement and the prospect of substantial funding from the newly formed Division of Applied Technology of the AEC, an official 'Los Alamos Geothermal Energy Group' was formed early in 1973, with myself as Group Leader. The anticipated funds materialized, and in 1974 a deeper exploratory hole was drilled at a more accessible and convenient location—on Fenton Hill, about 2.5 kilometers south of Barley Canyon. This hole reached a depth of 2930 meters and a rock temperature of 197 degrees Celsius. Experiments in it confirmed the observations previously made in Barley Canyon, but at greater depth and higher temperature.

In 1975 a second hole was drilled at Fenton Hill (photograph and figure) to a final depth of 3064 meters and a rock temperature of 205 degrees Celsius. A poor connection was made between hydraulic fractures produced from the two holes. After considerable experimentation and much development of new equipment and instruments, the connection was improved in 1977 by redrilling one of the holes, and in 1979 the



The photograph shows the hot dry rock geothermal site at Fenton Hill, looking southwest. Phase I of the project, shown schematically on the left side of the figure and with its two wells and heat exchangers labeled in the photograph, was completed in 1979 and has been producing heat at rates high enough that several hundred homes could be heated. It is hoped that when Phase II (labeled in photograph and right side of figure) is completed, heat production will be sufficient to demonstrate that a commercial electric power plant could be supported.

underground loop was enlarged by additional hydraulic fracturing (Phase I). With an air-cooled heat exchanger at the surface to dissipate the heat, this pioneering hot dry rock energy system has been operated intermittently since 1978 as a closed, recirculating pressurized-water loop. Heat has been produced at rates up to 5 megawatts (thermal), which would heat several hundred homes if there were that many nearby. The longest continuous run lasted nine months and had no detectable environmental effect. Some of the heat has been used to generate electricity in a 60-kilowatt binary cycle plant, but neither the temperature nor the rate of heat production was sufficient to support a commercial power plant. Therefore, a larger, deeper, hotter system (Phase II) designed to demonstrate that capability is now being constructed at Fenton Hill.

While the objective of the Hot Dry Rock program has always been the very practical one of making a vast, indigenous energy supply useful to man, the effort to do so has necessarily included a wide variety of supporting research and development activities—many of them done cooperatively with industrial organizations, university groups, and complementary programs at other laboratories and in other countries. To justify existence of the program, the very large resource base of thermal energy at accessible depths across the entire United States had to be evaluated. To implement the field program, it was necessary to develop drilling, well-completion, and hydraulic-fracturing equipment and techniques usable in very hot, inclined geothermal wells and also downhole instruments to log such wells and collect data in them. And to analyze and understand the information collected in the field has required both theoretical and laboratory studies of rock-water interactions, fluid and rock mechanics, heat transfer and transport, acoustic emissions, and other subjects. The program is broadly interdisciplinary and covers the entire spectrum from basic research to engineering application.

Since its inception, the Hot Dry Rock program has been supported primarily by the AEC and its successor agencies, ERDA and DOE, with supplementary support since 1980 by agencies of the governments of West Germany and Japan. However, the most important support has come from people like Harold Agnew, Director of the Laboratory during most of the history of the Hot Dry Rock program and always its most personable, articulate, and effective advocate. ■