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AUTHOR(S): PAUL R. FRANKE

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Los Alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

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HOT DRY ROCK GEOTHERMAL ENERGY DEVELOPMENT PROGRAM

P. R. Franke
Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545, U.S.A.

ABSTRACT

The overall objective of the Hot Dry Rock (HDR) Geothermal Energy Development Program is to determine the technical and economic feasibility of HDR as a significant energy source and to provide a basis for its timely commercial development, if warranted. Program motivation is derived from the enormous potential of the geothermal resource. Most all of this energy exists as heat in "dry" rock. If 2% of this resource could be economically recoverable, it would be sufficient to provide the entire nontransportation energy requirements of the United States for over 2000 years at the present rate of consumption.

Principal operational tasks are those activities required to enable a decision to be made by FY86 on the ultimate commercialization of HDR. These include development and analysis of a 20- to 50-MW Phase II HDR reservoir at Site 1 (Fenton Hill) with the potential construction of a pilot electric generating station, Phase III; selection of a second site with subsequent reservoir development and possible construction of a direct heat utilization pilot plant of at least 30 MW thermal thereon; the determination of the overall domestic HDR energy potential; and the evaluation of 10 or more target prospect areas for future HDR plant development by commerical developers.

Supporting technology and institutional tasks will involve design and testing of advanced downhole instruments, equipment, and materials; drilling techniques; fracture studies; reservoir evaluation; engineering studies; regulatory studies to identify those factors necessary for widespread industrial utilization; and aggressive transfer of technology and information to industry, academic, and governmental organizations.

Progress to date includes the completion of Phase I of the Los Alamos Scientific Laboratory's Fenton Hill project. Phase I evaluated a small subterranean system comprised of two boreholes connected at a depth of 3 km by hydraulic fracturing. A closed-loop surface system has been constructed and tests involving round-the-clock operation have yielded promising data on heat extraction, geofluid chemistry, flow impedance, and loss of water through the underground reservoir between the two holes, leading to cautious optimism for the future prospects of private-sector HDR power plants.

I. INTRODUCTION

The natural heat available from the accessible part of the earth's crust is recognized as one of the major potential sources of energy in the United States. This heat is transferred to relatively shallow depths by conduction or by circulation of fluids, where it can be developed through various geothermal systems.

Geothermal systems may be hydrothermal, geopressured, or hot dry rock. Hydrothermal systems can often be developed by drilling to relatively shallow depths and, at present, are the object of most commercial geothermal developments. They are, however, limited in size and distribution. Geopressured reservoirs are generally much deeper, but are potential sources of methane, as well as heat. Elsewhere, due to the low permeability of rock units or insufficient ground-water circulation, the heat contained in the hot rock can be extracted only by artificially creating reservoir systems and introducing a geofluid. This principal concept, with its various subconcepts, is the basis for the Hot Dry Rock (HDR) Geothermal Energy Development Program.[1]

Information on geologic environments in which the HDR techniques might be used to extract thermal energy is provided by an assessment of geothermal resources in the United States by the U.S. Geological Survey (USGS). Within conduction-related thermal regimes, the heat (at temperatures above the mean annual surface temperature) stored in the outer 10 km of the earth beneath the United States is about $33 \pm 4 \times 10^6$ EJ.*

A temperature of 150°C is generally considered to be the minimum required for economically competitive electricity generation, while temperatures as low as 100°C have been commercially exploited for space heating, agricultural or process heat, and air conditioning. Since much of the potential geothermal heat cited in USGS Circulars 726 and 790 is contained at depths that are not economically attainable with present or near-future drilling technology, new design and testing of equipment and materials capable of long-term operations in pressures of 10^7 to 10^8 pascals will be required.** However, when measured against the present domestic energy consumption of about 75 EJ annually, even the fraction of the resource base extractable with present technology represents a major source of energy. This is the justification for a federal program to investigate the extent of and the feasibility of recovering the heat contained in hot dry rock.

The high-grade component of the hot dry rock resource base occurs in localized areas of high heat flow. These might be utilized either for local production of electricity for adjacent load centers or for nonelectric applications. In many cases, however, these high-grade resources are distant from population and industry centers or are located in areas of environmental concern, which might preclude their widespread exploitation. The lower grade HDR resource base is widely dispersed throughout the country and, with the development of appropriate technology, could be developed to serve many existing population and load centers.

Within the Western United States there are large areas of regionally high heat flow associated with crustal thinning, major crustal "basement" structures, or converging crustal plate boundaries. Within <u>both</u> the Western

* EJ (exajoule) = 10^{18}J = 1 quad = 334 megawatt-centuries.

**Pa (pascal) = 1.45×10^{-4} psi.

and Eastern United States there are thermal anomalies that result from radiogenic heat sources buried under a blanket of insulating sediments. These widespread regions are potential targets for development by the HDR techniques.

The Department of Energy, Division of Geothermal Energy (DOE/DGE), working with the Los Alamos Scientific Laboratory (LASL), has been investigating this resource base and developing HDR technology for several years. Initial experiments have resulted in proof of the heat-extraction concept at the Fenton Hill site near Los Alamos, New Mexico. For the first time, an artificial, manmade, geothermal system was created by drilling a borehole into hot basement rock, creating a fracture system in the rock near the bottom of the hole, drilling a second borehole to intersect the top of the fracture system, and circulating a fluid (water) to extract heat and bring it to the surface as shown in Fig. 1.[2] The success of these experiments created a need for a comprehensive federal program to fully investigate HDR systems and to determine their potential impact on the nation's energy supply. Consequently, the HDR Geothermal Energy Development Program was formally constituted by the Department of Energy in October 1978.

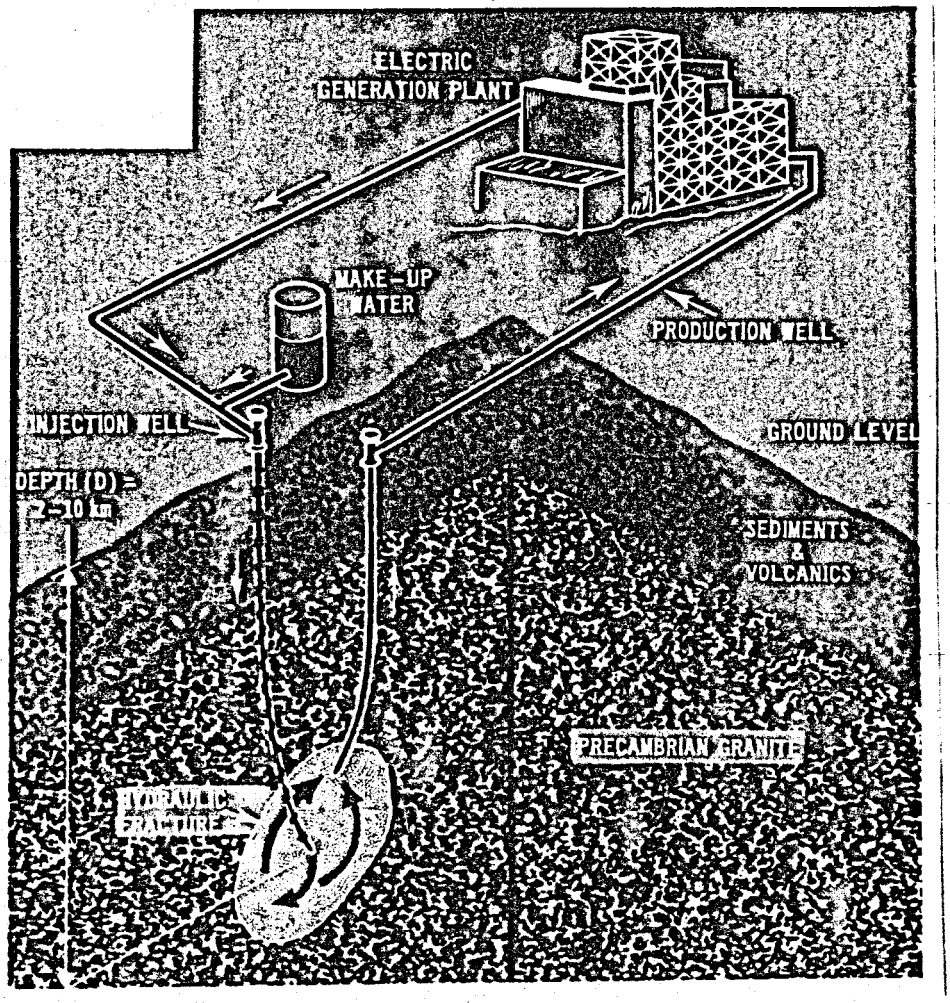

Fig. 1. Hot Dry Rock Geothermal Concept

II. Program Objectives

The successful realization of the HDR Geothermal Energy Development Program has dictated the following principal objective.

> Determine the potential of hot dry rock geothermal energy as a significant alternate energy source and to provide for its timely development, if warranted.

Consistent with this salient objective, the following specific sequential subobjectives are established for the program.

(1) Near-Term (early 1980's)

> Determine the potential of the HDR resource beneath the United States in cooperation with the USGS, emphasizing the fraction available at shallow depths and near load centers. Provide a preliminary assessment that all requisite technologies either already exist in a commercial sense or are within reach of engineering development; that is, that no technological "breakthroughs" are needed.

(2) Mid-Term (mid-1980's)

> Provide a more detailed evaluation of the HDR resource potential, including a descriptive catalog of prospective sites for commercial development and demonstrate all requisite technologies.

(3) Long-Term (late 1980's and beyond)

> Define and conduct program activities and projects--technical and/or institutional--necessary to promote the establishment of an HDR energy industry.

III. Scope

The HDR Geothermal Energy Development Program includes the Site 1 HDR Geothermal Energy Development Project (Fenton Hill Project), and will subsequently include another HDR demonstration project(s) elsewhere in the nation. The program is intended to embrace all of the activities necessary to create an industrial structure that can and will proceed expeditiously with commercialization of the HDR resource. Major Federal involvement in a succesful HDR program would continue through FY 1990, then diminish to a liaison, coordination, and technical-support role by FY 2000.

The program will comprise two main, parallel streams of effort--one, a system-development sequence leading from field experiments through evaluative systems and promotion of commercial pilot plants or full-scale systems; the second, a continuing group of supporting activities including laboratory work, reservoir modeling, instrument and equipment development, and environmental, legal, and institutional support.

Ideally, the program will be limited only by technology, time, and resources. It is expected that a great deal of management expertise and technical imagination and innovation will be required to exercise the DOE directive sufficiently to realize eventual commercialization of HDR technology.

Cost-sharing with industry is an integral part of the national HDR program. Federal expenditure is expected to peak in the mid-1980's and, if the program is successful, to decline quickly thereafter as commercial interests provide a rapidly increasing part of the total funds required for continued development of HDR systems.

IV. MAJOR PROGRAM ELEMENTS

The long-range program plan shown in Fig. 2 lists the major program elements and their schedule.

A. Determination of Resource Potential

To ensure that geothermal energy can be a substantial alternative energy source, HDR potential must be shown to have a wide distribution in a variety of geographic and geologic settings. It is also important that HDR resource estimates identify the fraction of the resource that exists at depths sufficiently shallow and at locations sufficiently close to major energy consumers to be economically attractive to potential investors interested in developing HDR systems. Only when this has been shown is industry likely to move into the field of HDR energy development.

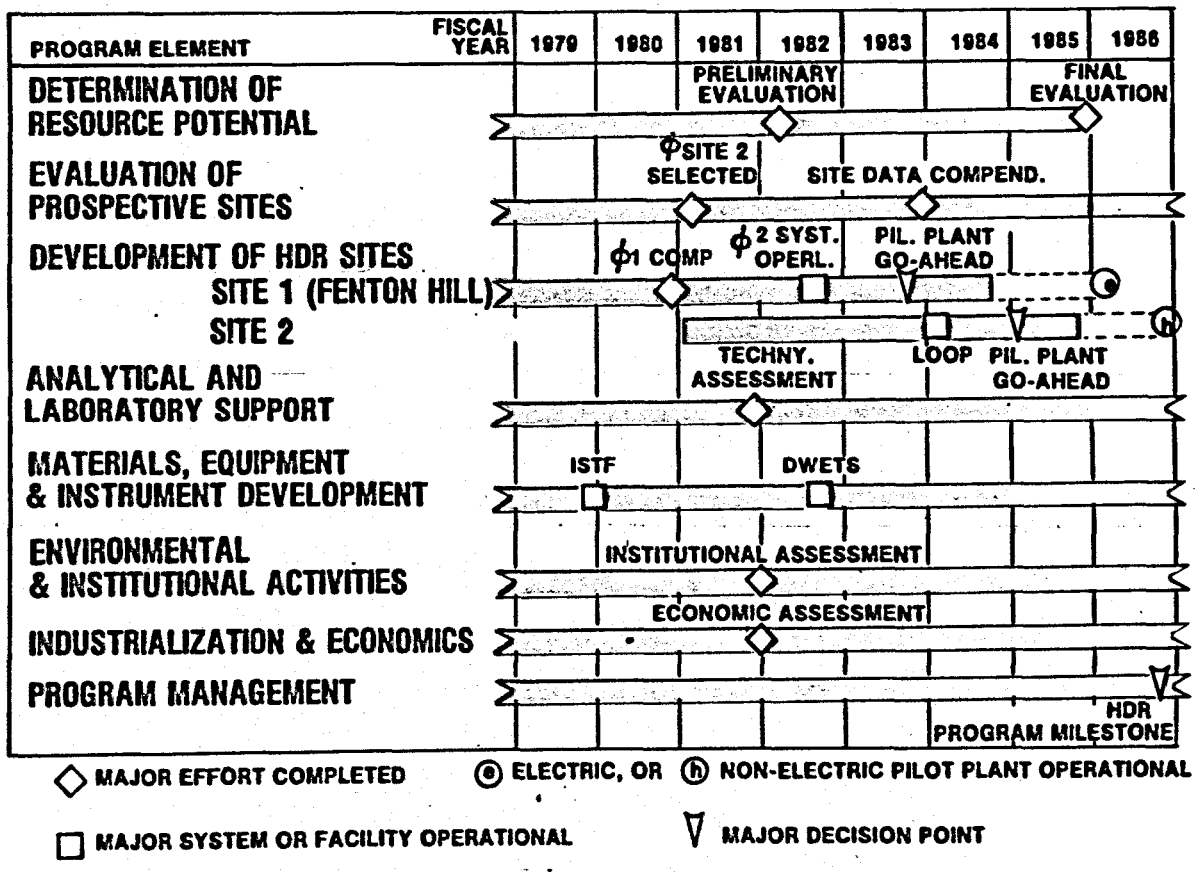

Fig. 2. Hot Dry Rock Geothermal Energy Development Program Long-Range Plan

It is thus imperative that reliable estimates of the magnitude, nature, location, and depth of the hot dry rock be obtained as rapidly as possible. The staff of the HDR program is dedicated to achieving this goal, utilizing the expertise of the USGS supplemented by that of LASL, and relying on data from a variety of additional sources, including other DOE/DGE-funded geothermal programs. In particular, data generated by the states, industry-coupled, and pre-commercial DOE programs will be of great benefit to this resource evaluation. Valuable data will also undoubtedly be contributed by the regional hydrothermal-resource assessments now being made under DOE sponsorship. Principal responsibility for this assessment rests with the Department of Interior, USGS. Primary attention of the USGS is necessarily focused on the broad regional and national energy picture rather than on identification and evaluation of local geological situations. Accordingly and in part as contribution to the USGS resource assessment, LASL has for some years been engaged in a low-level exploration effort for areas that appear particularly promising for HDR development, and this activity has now been absorbed into and broadened by the expanded HDR program.

Evaluation of the magnitude and nature of hot dry rock must be considered as consisting of two major activities. The first entails generation of accurate, detailed, geothermal-gradient maps of the entire United States. Such maps are clearly necessary to estimate rock temperatures existing at any drilling depth determined to be potentially economic at a particular time. This activity must be given initial consideration because the occurrence of sufficiently high heat content in the rocks is fundamental for any useful geothermal resource. The second activity is an evaluation of the permeability and fluid content of the potential reservoir rock. This evaluation may well be in the most difficult part of the task and the part most subject to error.

B. Evaluation of Prospective Sites

Another major objective of the HDR Program is to define and implement drilling and other field activities leading to the early selection and development of a second HDR site (and the cataloguing of additional sites) at locations other than at Fenton Hill. This second site will be developed to demonstrate that: (a) the HDR resource is not limited to the geologic environment typified by Fenton Hill and (b) the techniques, equipment, and instrumentation developed at Fenton Hill, or modifications of that technology, can be successfully and economically applied in other natural environments.

Field measurements indicate that the HDR resource is large and widespread, and the program objective, therefore, is to provide usable energy to a large part of the U.S. To do this we must encourage industrial investment in and use of HDR technology. To give industry the confidence to use this technology, it is necessary for the DOE to prove that HDR geothermal energy can be extracted economically in a variety of geologic environments with a wide geographic distribution and for a variety of uses (both beneficial heat and electrical generation).

The main reasons for development of additional HDR demonstration sites are:

(1) to instill confidence within the developer and user of the potential of HDR by refining, developing, and testing the extraction concept in a variety of geologic environments,

(2) to evaluate the resource base throughout the U.S.,

(3) to develop and evaluate HDR exploration rationales and techniques,

(4) to demonstrate versatility of HDR by locating separate sites for process heat and electrical power generation,

(5) to establish economics under real-world conditions, and

(6) to provide an alternate site if Fenton Hill proves unsuccessful during redrill.

Our objective is to evaluate adequately small sections of the country individually and collect site-specific data so that drilling decisions can be made. A Site Selection Committee comprised of representatives from industry, universities, and federal agencies has been established to help in the selection process. Contracts for initial evaluation of two 260 km^2 (100 mi^2) target prospect areas located in the eastern and western parts of the country were awarded in the last quarter of FY 79; LASL will evaluate additional prospects during FY 80. Conclusions regarding the desirability of drilling exploratory holes for proposed Site 2 are expected by mid- to late FY 80. In addition to the geological aspects of the prospect areas, consideration will be given to land use constraints, proximity to markets, geographic and political dispersion, and overall visibility before selection of the Site 2 location is made. The plan calls for the consideration of perhaps ten sites each year, with one or two target prospects evaluated each year through 1986. These additional sites will be fully characterized and would be considered ready for exploratory development after 1986.

Additional HDR sites may be developed, at minimal cost, by using existing geothermal wells that were drilled for development of hydrothermal systems, but have turned out to have limited permeability. This approach may expand production in hydrothermal fields by utilizing hot but "dry" sections of those fields or by going below present steam producing horizons.

C. Development of HDR Sites

To ensure that HDR geothermal energy can be a substantial alternative energy source, several prototype systems representing proposed combinations of geological situations, heat extraction methods, and energy conversion/utilization schemes will be constructed and operated to investigate and develop the technologies required to produce geothermal energy whenever it is needed and in sufficient quantities and quality to satisfy the specific needs of its potential users.

The first such system at Fenton Hill has progressed from a research and development effort to an engineering effort. Fenton Hill is located about 55 km west of Los Alamos, New Mexico. The site is on the western rim of the Valles Caldera, a young silicic volcano, which was active as recently as fifty thousand years ago. This site has successfully demonstrated the use of hydrofracturing as a technique to create a connecting circulation system through hot granitic rock and the extraction of heat at rates up to about 5 MW (thermal).

Fenton Hill is unusual, vis-a-vis future sites, in several respects. First, until the present it has been the only energy extraction experiment in the United States carried as a project initially by the Atomic Energy Commission, then the Energy Research and Development Administration, and currently by DOE. As such, its role has gradually evolved. Second, it has been

and will continue to be a multiple-function site, serving not only as an HDR concept demonstration, but also as a research arena for reservoir technique development and for the development and test of materials, drilling related equipment, and downhole instrumentation. Finally, it is staffed and operated directly by LASL personnel and, therefore, partakes of the characteristics of a laboratory technical area.

With the expansion in FY 79 of the HDR effort to a federal program of national scope, the Fenton Hill Project has become one among several such projects which will eventually be conducted within that program. However, by virtue of the foregoing unusual aspects, the Fenton Hill site presents some unique opportunities to the program, which will be exploited in its future development.

1. Fenton Hill Phase I. The Phase I reservoir presently being evaluated at Fenton Hill resulted from early drilling and fracturing experiments followed by a workover operation. It consists of two wells, referred to as GT-2 and EE-1, both of which are drilled to a depth of about 3 km (10,000 ft) where the rock temperature is 200°C. The manmade fracture system intersected by these two wells is currently believed to consist of a large, near-vertical fracture and a number of inclined connective joints, the whole system having a total effective surface area of about 8000 m^2. This relatively small reservoir was established, in its present configuration, in FY 77 and the associated experimental program is presently ongoing. To date, this small system has been used to: (a) demonstrate initial technical feasibility (96-h Segment 1 test); (b) provide short-term information on predictability of drawdown, time variation of impedance, water loss rate, geofluid chemistry, and stop/start transients (1700-h Segment 2 test); and (c) serve as a test bed for evaluation of reservoir enhancement techniques, such as operation under high back pressure (800-h Segment 3) test.[3] A hiatus of several months was engendered by the need to recement the lower casing in the EE-1 well and then to attempt the experimental workover techniques. This work has been accomplished and evaluative testing (Run Segment 4) began in August 1979. Among the items being evaluated in this fourth run segment are: (a) the results of attempted deflagrative pneumatic fracture initiation; (b) massive hydraulic fracturing in virgin rock; and (c) operation of modified cement-inflated casing packers.

In the near future, this reservoir will continue to provide an expendable system for evaluating high-risk/high-payoff reservoir extension workover techniques and for conducting a small preliminary electric generation experiment.

2. Fenton Hill Phase II. In parallel with the completion of the Phase I effort ~~as described in the preceding section, planning and initiation of a~~ Phase II system has been proceeding. The primary objective of this effort is to demonstrate reservoir scale-up and longevity by creating a pilot plant sized system (30 to 50 MWt) with a projected life in excess of 10 years. A third well, EE-2, is being drilled at the site to a bottom-hole temperature of 250° to 275°C and will serve as the injection well for the Phase II system. Drilling of EE-2 began in April 1979 during preparations for the Segment 4 test of the Phase I system. Before the rig is released, it will be skidded to a location about 300 m east of EE-2 to drill a fourth well, EE-3, which will serve as the Phase II production well. It is anticipated that the drilling of EE-3 will begin in the first quarter of FY 80. A nine-month period, devoted to completion of a subterranean system and a comprehensive set of communication tests, will follow. A comparison of the Phase I and Phase II system is shown in Fig. 3.

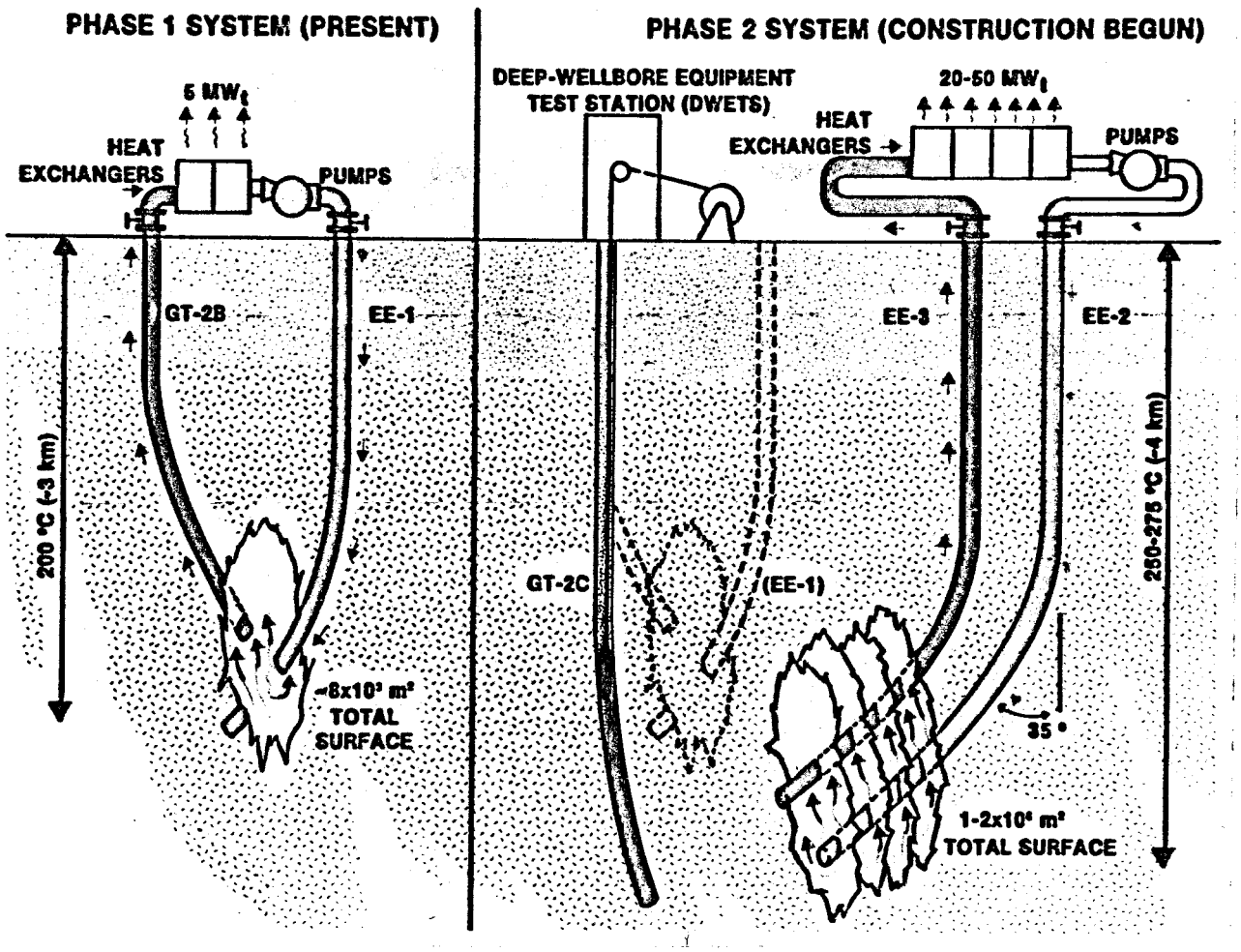

Fig. 3. Comparison of Fenton Hill Phase I and Phase II Systems

3. Fenton Hill Possible Phase III: Commercial Electric Power Plant. Fenton Hill is an excellent candidate site, and because of time constraints can probably be the only candidate HDR site, for the construction and operation of an electric generation pilot plant by the mid-1980's (by which time the commercial viability of the HDR energy source must be judged). It may be asked whether there is a need for the government to promote the establishment of an electric generation pilot plant for HDR derived power anywhere. The answer appears to be unequivocally "yes, at least once." Whereas the DOE is not committed to the design and construction of such a pilot power plant, nor enfranchised to operate one, it is appropriate within the objectives of the HDR program for the DOE to prepare the way for, and to promote, subsequent commercial development of HDR reservoirs whose capacity and lifetime have been demonstrated within the program.

Under mandate from the Rural Electrification Association (REA) to allocate a fraction of incremental generation capacity between now and 1985 to alternate energy sources, Plains Electric Generation and Transmission Cooperative in northern New Mexico is seriously interested in establishment of a power plant on a proven HDR reservoir, given a favorable economic analysis. It is therefore appropriate to plan for an electric pilot plant at Fenton Hill. In the early part of FY 80, formal liaison will be established among the cognizant parties in DOE/DGE, DOE/Research Applications, the HDR Program Office, the utility/ies

involved, the REA, and the U.S. Forest Service (USFS) to determine the nature of required agreements, studies, and documentation. The first key decision milestone occurs in mid-FY 81 (DOE and utility/REA), that is, whether or not to proceed with power-plant design. As more and more positive data are obtained on the reservoir, design effort will become more intensive and long-lead procurements (for example, turboalternator, pumps, condenser) and permit acquisition will proceed. The next major milestone is the decision (utility/REA) to proceed or not with plant construction and this should occur in FY 83. Plant construction would begin immediately thereafter and be completed by the end of the first quarter of FY 86. The plant would then be checked out and on-line in mid-FY 86.

D. Materials, Equipment, and Instrument Development

In addition to demonstrating the HDR utilization scheme, Fenton Hill is also a research site. One major research area is development of downhole instruments and equipment for geothermal wells, specifically those either peculiar to HDR needs or for which the need arises earliest in the HDR program. These developments are, of course, coordinated with developments and needs in the other DOE geothermal programs to produce hardware of greatest transprogrammatic utility and obviate duplication.

The creation and subsequent study of HDR geothermal reservoirs requires sophisticated tools and instruments that can function for relatively long periods in the hostile downhole environment. Determination of fracture dimensions and orientation in the geothermal reservoir is important for successful completion of an HDR energy extraction system. To ensure downhole instrumentation capable of characterizing the hydraulically fractured system, its development must emphasize the reliability of sensors and electromechanical components in functioning properly at borehole temperatures greater than 275°C and pressures up to 69 MPa (10,000 psi).

A long recognized need in the instrument and equipment development area is for a captive and dedicated wellbore with suitable data acquisition and surface handling equipment wherein controlled in situ tests of such prototypical hardware can be conducted. It is therefore planned, when experiments with the Phase I system have been completed, to deepen and straighten wellbore GT-2, to a GT-2C configuration with a bottom-hole temperature of 275° to 300°C. This wellbore will then become the heart of a dedicated national test facility, Deep Wellbore Equipment Testing Station (DWETS).

E. Analytic and Laboratory Support

Experience at Fenton Hill has demonstrated the need for significant improvements in technologies involved in creating HDR energy systems. Such technology advances not only require materials, equipment, and instrumentation development, but also depend upon analytical and laboratory support. Key areas in which the HDR Program must maintain support capabilities are:

(1) reservoir definition,
(2) rock mechanics, fluid mechanics, and heat transfer,
(3) geochemistry,
(4) geology, geophysics, and hydrology, and
(5) analysis and modeling.

The HDR Program will use the instruments, equipment, techniques, and analyses developed elsewhere by industrial organizations, universities, and research institutes. Other available sources of expertise to be utilized are DOE-sponsored programs such as the Geothermal Drilling and Instrumentation Programs at Sandia Laboratories and the Reservoir Engineering Program at Lawrence Berkeley Laboratory. However, where special needs or schedule requirements of the HDR Program exist, developments will be undertaken either at LASL or through subcontracts or cooperative arrangements to meet the needs. The results and products will, of course, in many cases be directly useful to other geothermal programs and to the industry.

New techniques will be needed to deal with the novel types of problems already experienced and anticipated in the development and operation of manmade geothermal systems. Among these are directional drilling in harder rock and at higher temperatures than have previously been encountered, and with an accuracy that has not heretofore been required. Improved sidetracking methods are also needed for holes in very hard rock. Hydraulic and explosive fracturing methods require much additional investigation and development, together with other potential means of increasing formation permeability such as pressure cycling, selective chemical attack (leaching) and introduction of special proppants into existing fractures. Highly accurate techniques of borehole and fracture mapping are presently needed, and must be adapted for use in a single hole. Again, several of these developments will require relatively large efforts, which must likewise be carefully coordinated with the similar needs of other programs.

The capability to predict system characteristics and performance, initially and as a function of time, is necessary to direct the course of future developmental studies as well as to provide industry with a reliable basis for assessing the value of investment in HDR systems. A typical economic analysis may cover a project life up to 25 years, and the reservoir behavior in terms of useful energy output, thermal drawdown, and pumping requirements must be accurately predictable throughout this period.

Continuing analysis of experimental data is the basis for understanding system performance, planning future experiments, and developing useful predictive models. Advanced modeling techniques are also required for design of subsurface components such as flow control devices, and to develop optimum strategy for reservoir management. Complex issues such as the preferred type of downhole energy extraction system and of power cycle at the surface, the desirability of redrilling or refracturing on a periodic basis, and the annualized power output, must all be investigated analytically.

F. Institutional and Environmental Activities. Unlike the exploration and exploitation technology development required for commercialization of HDR geothermal energy systems, the institutional and environmental aspects of their development are those portions which are characteristically variable from one area to another and are based more on social perceptions and political compromises than on science and engineering. Variable social perception is exemplified by the differences in the legislative definitions of "geothermal resource" promulgated by Congress and several states, wherein some relate this thermal resource to water and others to mineral. Variability also exists in the requirements for assessing the wide range of impacts among the many federal and state agencies involved in the siting of any energy resource production or conversion facility, including geothermal. Additionally, jurisdictional overlap and regulatory control practices and procedures vary among the state and federal agencies, resulting in confusion and misunderstanding of requirements and timing of action by both government and industry.

1. Legal Requirements. During the early regional resource exploration, no permit or licensing activity will be required. However, it is expected that the time period between regional and more localized area evaluations will be quite short. Therefore, the initial activity will be to assemble the available state land status maps for those states of the nation presently thought to contain the more promising HDR areas. These include Arizona, Idaho, Nebraska, Nevada, New Mexico, New York, North Carolina, Oregon, South Carolina, and Washington. (Other states in the eastern and western regions of the nation are also under consideration by DOE and the USGS).[4] This early information is required prior to any detailed exploration, to assess the type of ownership and to identify the governmental management agencies involved in the selected local target areas. Notable is the fact that not all public lands (federal or state) are available to exploration for or development of the HDR resource because of existing leases, agency withdrawals, wildlife refuges, military reservations, wilderness areas, wild and scenic rivers, parks and monuments, etc. Other federal and state public lands, although available for lease, are operationally restricted, as for example are Known Geothermal Resource Areas (KGRAs) and some areas classified as being valuable prospectively for geothermal steam and associated geothermal resources, but which are actively being considered for change to KGRA, national forests, or grazing lands. These areas must be identified.

Activities involving available state lands are subject to requirements which, in some instances, are similar to those of the Federal government and in others are quite different. Some states have legislation similar to the National Environmental Policy Act (NEPA); others have limited legislative authority, but have developed administrative procedures and regulations that include most of NEPA's provisions; still others act under a series of legislative statutes and attendant regulations, with some including requirements more stringent than those of NEPA.

2. Environmental Considerations. Exploration or development activities involving available government lands may require Environmental Assessment Reports (EAR) and/or Environmental Impact Statements (EIS) as part of the administrative permit or lease decision process.

NEPA, together with the relevant court decisions and agency regulations and procedures, prescribe the various federal requirements. For example, the issuance of an exploration permit covering national-forest lands wherein shallow temperature gradient holes are to be drilled, requires that an application be made to the USFS.

Environmental effects beyond those that are presently embodied in existing regulations, but which in some quarters are considered as being adverse (aesthetics, noise, etc.), require investigation and mitigating strategy development. Recent DOE Environmental Development Plans (EDP) have described environmental issues thought to be constraining to the point of requiring either new control technology development or, as a minimum, the description of existing control technology which, before the fact, can reduce the potential for adverse impact. Those EDP-defined issues relevant to HDR will be incorporated in the environmental effects activity, as will any other known investigations helpful to adverse environmental impact mitigation, including those of the EPA and its state counterparts.

3. Industrialization and Economics. This program element is designed to reach the major objective of "providing for the timely development of the HDR resource." Its strategy is that of "market pull" in terms of user industries and the public wanting the technology based on demonstrated desirability, as compared to a "technology push" wherein the developed technology is "pushed" to users. Its approach is similar to that successfully used by industry in introducing a major new product to the market.

Requirements include the needs to identify commercial markets near realistic HDR energy sources; the need for industrial capitalization and the availability of money for such purposes; the need to coordinate technical and operational activities on an intra- and international basis; and the necessity for public acceptance of HDR techniques as important means for converting geothermal energy into a power-on-line commercial source of energy to meet public and private consumption needs in the immediate future.

Emphasis will be placed on matching the lower grade HDR resources with nearby process heat users (by company) and the local space heating potential, and on the needs of electricity generating utilities should a sufficient HDR resource be more remotely located. This will reveal those industries most amenable to establishment and/or conversion to an alternative resource.

An additional activity, state targeting, concerns the agency perspective or attitude of the selected states toward a change in resource base. The information sought would include the favorability of state agencies toward industrial development, the perspective and agressiveness of consumer and environmental groups, and the projected changes in population and industry. This information will reveal those states having a more favorable attitude toward HDR development and a reduced potential for adverse or delayed action.

All activity to this point constitutes the first phase of a focused market pull development whose purpose is to raise industry and government agency interest to the point of acquiring detailed information which would support a change to HDR. In those states with suitable HDR resources and the highest potential for oil, gas, and/or electricity shortage in the near term, the industries having the greatest need and highest potential interest will be targeted. These industries, plus the state and local government agencies involved, will become the primary targets for publication, seminars, media editorials, and local conference presentations specifically designed to develop interest.

The major purpose of the economics study effort is to describe quantitatively those conditions under which HDR geothermal energy systems can be made commercially feasible. Therefore, the initial thrust will be to conduct studies and analysis by and for the private sector that addresses such factors as resource size, utilization, development costs, profitability, risks, and other potential problems. Obviously, the absence of credible information in these areas would markedly constrain the program's major goal of providing for the timely development of an HDR industry.

These economic analyses, which include exploration, exploitation, resource management, end uses, and all portions of the HDR geothermal system, when compared to alternative energy resource system analyses, will provide the data necessary for sensitivity analyses, which in turn become valuable input to legislative bodies, industry, and the public, for establishing the priorities necessary for implementive decisions. Such sensitivity analyses will point out

those areas requiring further research and development to reduce costs or to expand end-use production in order to increase economic efficiency. An analyses comparing the HDR subsystem components to alternative energy resource system components will also provide the input necessary to establish more appropriate address to capital investment problems presently faced by utilities and the financial community.

IV. SUMMARY

Major achievements and decision points of the program are projected as follows:

FY 1979: Completion of Phase 1 (nominal 5 MWt) operation of the Fenton Hill energy extraction system; initiate construction of the Phase 2 (20 to 50 MWt) loop at Fenton Hill; begin detailed investigations of prospect areas for Site 2.

FY 1980: Complete detailed investigations of prospective sites in Eastern and Western United States and initiate development of experimental energy extraction system at one of them.

FY 1981: Complete initial technology, economic, and institutional assessment. Preliminary evaluation of U.S. hot dry rock resource potential.

FY 1982: Initial operation of Phase 2 loop at Fenton Hill. Complete evaluation for possible pilot plant Site 1.

FY 1983: Decision concerning construction of electrical generation pilot plant at Fenton Hill. Initial operation of experimental loops at Site 2. Begin evaluative loop operative at Site 2.

FY 1984: Possible detailed investigation of additional future sites. Compendium of site data completed. Evaluate pilot plant potential of Site 2.

FY 1985: Final evaluation of resource potential. Final decision on possible pilot plant at Site 2.

FY 1986: Major decision concerning probable technical and economic viability of hot dry rock energy systems and, if positive, the appropriate federal role in encouraging their further development by industry.

VI. CONCLUSION

Under the cognizance of DOE/DGE program direction, HDR geothermal technology has now moved from the research stage into a phase of "precommercialization" engineering development. The technical and economic issues facing it should be resolved within the next seven years. Therefore, with positive program results, it will be possible to begin delivering commercial HDR-derived power-on-line in the final decade of this century; this then constitutes the goal of the formalized program.

REFERENCES

1. Program Plan, Hot Dry Rock Geothermal Energy Development Program, Department of Energy, Division of Geothermal Energy, Draft, September 1979.

2. Nunz, Gregory J., "The Federal Hot Dry Rock Geothermal Energy Development Program: An Overview." Paper presented at ASME Conference, June 1979.

3. Hot Dry Rock Geothermal Energy Development Program. Annual Report FY 1978. Los Alamos Scientific Laboratory report LA-7807-HDR (April 1979).

4. McNamara, J. and Kaufman, E., "Hot Dry Rock Geothermal Resource Ownership and the Law." Los Alamos Scientific Laboratory report LA-8027-HDR (September 1979).