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AN OVERVIEW OF THE DEPARTMENT OF ENERGY GEOTHERMAL PROGRAM

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It is a pleasure to be here again for the 13th Annual Stanford Geothermal Reservoir Engineering Workshop. At No. 13, your workshop goes back almost as far as the federal geothermal research and development program about which I am here to speak with you today. I don't need to remind many of you that the earliest Congressional mandates for federal geothermal R&D were to the Atomic Energy Commission and the National Science Foundation in the early 1970's. Many of our on-going programs have their origins in those agencies. And, still we're "at it."

Sometimes I have asked myself why this is so. Why are we still researching certain technologies after 15 years or more? Why does the structure of our R&D program not look much different from year to year?

In order to answer these and related questions, we are, in fact, currently assessing the performance of our program elements against technology objectives set 15 years ago, and defining the impact of each in solving important technical barriers, and in promoting the national goal of increased geothermal use. From this retrospective analysis we are redefining the goals and objectives for our future R&D program. We have developed three levels of quantitative objectives from this exercise:

- Level I reflecting goals for, and anticipated impacts of, the overall R&D program categories upon the cost of power from geothermal energy systems.
- Level II reflecting estimates of the impacts of the R&D on the performance and costs of the major subsystems of a geothermal energy development project, thus providing an overview of R&D program balance across the geothermal technologies.
- Level III objectives providing the mechanisms for assessing the progress of research elements, or groups of R&D elements.

As our assessment nears completion, I will look forward to an opportunity to discuss it with you and soliciting your valuable inputs.

Today however, I shall undertake to bring you up-to-date on the current emphasis of the various elements of our R&D program. Due to the limits on space and time on my presentation, this will necessarily be limited to an overview, as the title suggests.

RESERVOIR TECHNOLOGY

This R&D category embraces three major tasks -- reservoir definition, brine injection, and exploration techniques. The major goals of these tasks are, respectively, to:

- enable industry to maximize energy recovery from a resource
- reduce the adverse thermal and chemical effects of injection on geothermal reservoirs
- verify new techniques for identifying geothermal reservoirs associated with young volcanic terrains.

In FY 1988, reservoir definition R&D will be focused on reservoir technology research areas that have a direct impact on the characterization and assessment of geothermal reservoirs, topics of fundamental importance to industry. Representative activities include:

- development and testing of improved reservoir monitoring techniques to help characterize the effects of fluid recharge and pressure maintenance at producing geothermal fields
- development and testing of improved methods for determining fracture characteristics of geothermal reservoir rocks

- development and incorporation into existing computer models of realistic descriptions of geothermal brines and rock-fluid interactions.

The major emphasis of the brine injection R&D continues to be the development of high performance tracers, the analysis of tracer flow through fractures, and the interpretation of tracer return profiles. Interpretation of the profiles can indicate the speed of movement of the injected fluids through the reservoir and preferential flow between specific injection and production wells. Analysis of tracer transport is complicated by the fractured nature of many geothermal reservoirs and requires detailed investigation. The most recent success in tracer performance evaluation is the identification of 15 suitable hydrocarbon candidates for liquid-phase application which survived at 250^{o}C; work in gas-phase tracer research is in preliminary stages.

Another focus of the injection R&D is developing modeling and measurement techniques for determining the location of and predicting the evolution of pressure, fluid, and thermal fronts which occur during injection. The ultimate purpose of these studies is to provide additional information to the reservoir engineers who model the behavior of the field and predict its performance.

The development of exploration techniques for identifying geothermal reservoirs in young volcanic environments is centered in the Cascades Range of the Pacific Northwest, specifically in the vicinity of Newberry Crater, Mt. Jefferson, and Crater Lake in Oregon. DOE has cost-shared deep thermal gradient holes with industry at these locations, obtaining core samples and geophysical well logs. Geophysical measurements from the samples and logs are compared with surface geophysical observations which helps to determine what conditions in the subsurface cause the observed surface geophysical responses. The comparison also serves to calibrate various surface and borehole geophysical tools and evaluate their performance in young volcanic environments.

HARD ROCK PENETRATION

The goal of the hard rock penetration R&D is to develop drilling/coring, lost circulation control, and wellbore technology for current and advanced geothermal application in order to decrease costs and increase the economic resource. The borehole mechanics element is emphasizing research in borehole stability, well completion, and fluid sampling. A major FY 1988 effort is construction of a flow visualization experiment to study the two-phase flow phenomenon that dictates fracture plugging mechanics for single particle, high temperature, and multiple constituent lost circulation materials.

In cooperation with industry, deficiencies in the prototype radar fracture mapping tool found during testing last year will be corrected with design changes during FY 1988. The tests, in a rock quarry, also revealed, however, that the tool does perform as predicted and has promise for locating fractures.

The Geothermal Drilling Organization (GDO), an industry/DOE non-profit cooperative formed to fund projects of value to geothermal operators, is continuing development and field testing of an acoustic borehole televiewer, field testing of hardware and procedures for deploying an expanding foam in geothermal lost circulation zones, and field testing of a downhole air turbine for drilling geothermal wells. Development of high temperature elastomers for use as drill pipe protectors and rotating head seals is also continuing.

CONVERSION TECHNOLOGY

The conversion technology R&D consists of three major tasks: heat cycle research, advanced brine chemistry, and materials research. Heat cycle R&D is focused on the development of technology for effecting the improved utilization of moderate-temperature geothermal fluids. Thus, a major emphasis of the research is improvement of the performance of geothermal binary cycles to levels approaching the practicable thermodynamic maximum. Tests are being conducted at the Heat Cycle Research Facility at East Mesa, California, to investigate the use of mixtures of non-adjacent hydrocarbons as the working fluid, with supercritical vaporization and in-tube condensation of the working fluid. Preparations are also being made to investigate the binary cycle improvements which can be achieved by allowing supersaturated vapor expansions in the turbine. These efforts are anticipated to verify that improvements of up to 28 percent in the net geofluid effectiveness (net watt hours plant output per pound of geofluid) over conventional binary power plants can be achieved. Future efforts will include testing of direct contact heat exchangers with fluids "too dirty" for conventional heat exchangers and heat rejection systems which will minimize cooling water make-up requirements while retaining a performance level approaching that of conventional wet cooling systems.

Two approaches are being pursued to define the costly operating problems associated with brine chemistry. First, numerical modeling of complex brines will allow improved prediction of the thermodynamic conditions under which problems will occur in geothermal power plants from scale deposition, corrosion, and suspended solids. Second, research is focused on detection and monitoring of constituents in the brine stream which can damage piping, valves, and wells as brine flows through the power plant and is injected back into the wellfield. Chemistry monitoring instrumentation is inserted in the brine flow lines to detect serious corrosion, scaling, and particulate matter before these problems result in plant failure.

An offshoot of the brine chemistry research is the effort to find economical means for detoxifying sludges created by treatment of hypersaline brines prior to injection. The presence of toxic metals, though small in quantity, invokes federal/state environmental requirements for disposal as hazardous wastes. This type of disposal is costly and is becoming highly uncertain with the closure of many such sites due to tightening restrictions. Thus, experiments are underway on the use of biochemical techniques to concentrate and remove the metals from the wastes. Two methods are being addressed: 1) solubilization of metals by micro-organisms which leach them out, and 2) concentration and removal by sorption on cellular materials. Both processes are applicable in situations where metals are present in large volumes of waste at concentrations unsuitable for conventional technology.

Research and development continues on materials for use in the harsh geothermal environment so that geothermal development is not constrained by the lack of such materials. Further cost reductions and extension of service life are being sought for such materials an nonmetallic heat exchanger tubing, very high temperature well completion materials, and metallic liners for well casings.

GEOPRESSURED RESEARCH

The geopressured R&D has successfully completed estimating the size and magnitude of geopressured reservoirs and is in the process of developing technology for producing and utilizing them. The Gladys McCall well in Louisiana is under test at the present time and has successfully produced over 25 million barrels of brine. The reservoir has proven larger than initial test data predicted, and research is concentrated on identifying reservoir drive mechanisms in order to improve test procedures. A comprehensive test program of variable flow rates, pressure recovery, logging, and coring is planned.

Testing will start in FY 1988 on the Pleasant Bayou well near Houston, Texas, where an Electric Power Research Institute hybrid electrical power generation experiment will be conducted. It incorporates both a geothermal binary cycle to utilize the heat of the brine and gas combustion to utilize the produced methane. This type system can produce in excess of 15 percent more electricity than the same amount of fuel and geothermal fluid used in separate power plants.

It is our hope that we can complete geopressured R&D with the testing of a former gas well contributed by industry which, at 21,000 feet, is much deeper than any tested to date. It has the potential to be economical in the near future and will serve as verification of the geopressured technology developed throughout the life of the program.

HOT DRY ROCK RESEARCH

While other methods for creating a man-made reservoir are possible in different geologic environments, our program has so far concentrated on hot crystalline rock of low initial permeability; the use of fluid pressure (hydraulic fracturing) to create flow passages and heat-transfer surface in the rock; and operation of a closed, recirculating, pressurized-water loop to extract heat from the rock and transport it to the earth's surface. Large-scale field experiments are conducted at Fenton Hill in the Jemez Mountains of northern New Mexico. Concomitant supporting activities include development of new or improved downhole equipment and instruments, field and laboratory experimental techniques, and analytical and numerical data analyses and modeling procedures. Many of these developments have been found useful in other experimental programs and in a variety of industrial applications.

The technical issues faced in HDR development are demanding. Wells must be drilled to depths where temperatures are likely to be 200 to 300°C (392-572°F), suitable for electricity generation. Even in regions with favorable geothermal gradients, such temperatures are found only at great depths, 10,000-16,000 feet. The rock formation must then be fractured at great stress, and the fractures held open so that the permeability remains high and flow resistance is low. Furthermore, large areas of hot rock must be adequately bathed by the injected water to result in high heat production. At the same time, since all water must be provided from an external source, excessive water losses to the rock formation surrounding the fractured reservoir must be avoided.

The small Phase I reservoir created at Fenton Hill in 1977 was the world's first hot dry rock geothermal energy system. Water was produced from the man-made reservoir at temperatures and thermal power rates as high as 175°C (347°F) and 5 MW_t. A much larger Phase II reservoir was created at the site in 1983, and has been flow tested briefly. A long-term flow test is planned in order to evaluate the longevity of a hydraulically fractured HDR reservoir with power capacity of about 35 thermal megawatts. The target design for the system is a lifetime of at least 10 years with less than 20 percent thermal drawdown.

MAGMA ENERGY RESEARCH

The thrust of the magma energy extraction R&D is to determine the engineering feasibility of locating, accessing, and utilizing magma as a viable resource. This effort is a follow-on to the DOE/OBES-funded Magma Energy Research Project that determined the scientific feasibility of the magma energy concept.

Ongoing research in the area of magma energy extraction is directed at developing a fundamental understanding of the establishment and long-term operation of both closed-loop and open, direct-contact heat exchangers in a crustal magma body. The energy extraction rate has a direct influence on the economic viability of the concept. An open heat exchanger, in which fluid is circulated through the interconnecting fissures and fractures in the solidified region around drilling tubing, offers the promise of very high rates of heat transfers. Studies show that an open heat exchanger can be formed by solidifying magma around a cooled borehole and that the resulting mass will be extensively fractured by thermally-induced stresses. Numerical models indicate that high quality thermal energy can be delivered at the wellhead at nominal power levels from 25 to 30 MW electric.

Previous heat extraction research indicated that magma can be utilized at energy extraction rates that are comparable to or better than those in conventional geothermal fluids. The high temperatures of the magma resource and the corresponding high temperatures of the working fluid lead directly to efficient, conventional techniques for generating electricity. Processes have been considered for using this high-quality energy to generate transportable fuels in addition to electricity.

A primary long range target of this effort is to conduct an energy extraction experiment directly in a molten, crustal magma body. Several key technology tasks are critical to determining engineering feasibility of this undertaking: obtaining detailed geophysical definition of potential magma targets; characterizing the magma environment and selecting compatible engineering materials; developing drilling and completion techniques for entry into a magma body; and developing heat extraction technology.

DOE GEOTHERMAL PROGRAM REVIEW

Once a year the Geothermal Technology Division sponsors a DOE Geothermal Program Review. These sessions are designed to focus the attention of personnel from DOE headquarters and operations offices, national laboratories, and contractors, as well as state and local government representatives and the private sector, exclusively on the DOE geothermal R&D program. The Reviews have functioned as an excellent mechanism for ensuring a continued high degree of interest and participation in the program.

Program Review VI, which will focus on the redefined goals and objectives for the GTD R&D program I spoke about at the beginning of my talk, is to be held in San Francisco April 12-14, and I hereby invite all of you to attend. The discussions are typically quite lively, and I believe you will enjoy the gathering while you lend assistance to our planning and R&D priority assessment. I would also like especially to urge that you encourage junior level technical personnel in your organizations to attend and become acquainted with the R&D program and its interaction with industry and academia since we need to plan now for the continuity of the interaction.

However, may I add that the list of participants in this meeting gives me a good sense of security about the future of the program. If I were to ask for a show of hands by those who have worked, in one capacity or another, for or with the Geothermal Technology Division or its predecessors for five to 10 years or more, I believe that at least half of you would so indicate. It is reassuring that the geothermal community continues to retain the knowledge, experience, and dedication of its long-time participants. Our "corporate memory" would be considerably lessened without you.