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THE ROLE OF THE NATIONAL LABORATORIES IN GEOTHERMAL RESERVOIR ENGINEERING

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INTRODUCTION The national laboratories, since the beginning of the national geothermal energy development program, have played an important research role for the U. S. Department of Energy (DOE) and its predecessor agencies. These laboratories, specifically, Lawrence Berkeley Laboratory (LBL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), Brookhaven National Laboratory (BNL), Argonne National Laboratory (ANL), and the Idaho National Eng. Laboratory (INEL), have large, multidisciplined scientific, engineering and technical support staff, and excellent research facilities, enabling the laboratories to conduct and manage research projects beyond the abilities of university departments and many geothermal developers. LBL has the unique feature of being located adjacent to the Berkeley campus of the University of California. As a result, faculty, graduate students and staff augment the Laboratory staff and make significant contributions.

In general, the boundary relationship between the national laboratories and industry is defined by the laboratories' focus on long-term, high-risk generic research and their facilities and special capabilities, many of which are lacking in industrial laboratories and are nonexistent within the organizations of many private geothermal energy developers. At the same time, the national laboratories maintain close contact with industry, thus ensuring relevancy of the research and the transfer of technology.

Because we are most familiar with LBL and the research performed there, and because LBL has been the lead laboratory in geothermal reservoir engineering research, this paper will deal largely with LBL's role. From our perspective, however, we see the following basic strengths within most of the national laboratories:

1. Starting with initial strengths in computer technology and advanced engineering facilities, the laboratories are able to design, build, and test new or improved tools together with supporting methodologies and numerical analyses.

2. With their multidisciplinary staffs, the national laboratories have the proper mix of scientists, engineers, technicians and managers needed to conduct longer-term research, and to respond more quickly to the emergency needs of DOE and other government agencies.

3. Because public service and high-quality research are central to the functioning of national laboratories, they are capable of providing independent and unbiased assessments and solutions to problems brought to them. They are committed to the transfer of technology to the private sector.

RECENT ACCOMPLISHMENTS OF THE NATIONAL LABORATORIES The current work performed by the national laboratories addresses various aspects of geothermal energy developnent in nearly all important areas. These areas and the corresponding involvement of the various laboratories are reviewed below, with emphasis being placed on the laboratories most involved with the respective research area.

Reservoir Engineering The primary work in geothermal reservoir engineering is being done by Lawrence Berkeley Laboratory (LBL). LBL is also carrying out studies that correlate geophysics with reservoir engineering. Details on LBL's role in reservoir engineering follow in the next section.

Geochemistry Lawrence Livermore National Laboratory (LLNL) has carried out a comprehensive R&D program at the Salton Sea geothermal field in the Imperial Valley, California. The program included reservoir evaluation, scale control, corrosion, H_2S abatement, and brine injection studies. More recently LLNL assessed the injectability of brines and methane extraction from geopressured resources of the Gulf Coast.

High Temperature Drilling and Completion Technology and Tools The development of drilling completion and well testing technology has been considerably advanced by the work of the national laboratories. New drilling hardware and fluids have been developed by Sandia

National Laboratory (SNL). They have made advances in completion technology that include downhole perforation, cementing, and well-cleaning.

As the lead laboratory for high-temperature component developnent, SNL has been instrumental in providing, through both in-house projects and subcontractors, components needed for logging high-temperature geothermal wells. They have advanced hybrid circuit technology, and developed prototype logging tools (275°C) and a metal sheath cable. Sandia has also worked with the General Electric Company to produce a 275°C multiplexer and with the Harris Semiconductor Company to develop high-temperature (275°C) electronic components.

Materials Brookhaven National Laboratory (BNL) has developed and tested several high-temperature polymer concrete systems for cementing geothermal wells. BNL has also investigated nonmetallic materials such as plastics, ceramics, and refracting cements for handling hot brines and steam.

Direct-Use Idaho National Eng. Laboratory (INEL) has developed several direct-use demonstration projects at Raft River, Idaho. The laboratory has also provided technical assistance for the direct-use geothermal projects.

Hot Dry Rock Sponsored by DOE/DGE, the Hot Dry Rock (HDR) Geothermal Energy Development Program is managed through a field office at the Los Alamos National Laboratory (LANL). The HDR Program was established to investigate--and, if possible, to demonstrate--the usefulness of natural heat in the earth's crust as a commercial source of energy.

Fenton Hill, located in a geothermal area approximately 30 km west of Los Alamos, is the site of LANL's pioneering HDR heat-extraction experiments. In May 1980, HDR technology was used to produce electricity in an injection demonstration experiment at Fenton Hill. A 60-kVA, binary-cycle electrical generator was installed in the Phase I surface system and heat from about 3 kg/s of geothermal fluid at 132°C was used to boil Freon R-114. The produced vapor was used to drive a turbo-alternator.

A Phase II system that should approach commercial requirements, consisting of a pair of 3-km deep wells into granite at 275°C, is now being constructed at Fenton Hill. other work at Fenton Hill includes environmental monitoring, development of equipment, instruments and materials for technical support, developnent of several kinds of mathematical models, and analysis of data collection from extensive resource investigations which was then assembled into a geothermal gradient map of the U.S.

National Energy Software Center (NESC) Argonne National Laboratory (ANL) operates the National Energy Software Center (NESC) which makes computer programs available to interested users in all areas of energy research. NESC maintains a software library with full documentation. software codes can be requested by all types of organizations worldwide, and NESC's services are provided at very nominal cost with no royalty charges for the programs. As an example, NESC has evaluated and adapted for distribution five computer programs developed at LBL for geothermal reservoir engineering applications (reservoir simulation, wellbore flow, well test analysis). Numerous requests for these programs have shown that NESC can be effective in transferring new methodology into engineering practice.

LBL'S ROLE AND ACCOMPLISHMENTS IN THE FIELD OF GEOTHERMAL RESERVOIR ENGINEERING Since the emphasis of this conference is on reservoir engineering, this section will be limited to a summary of LBL's past and present work in this area. This work is classified into several sections and discussed below.

Cerro Prieto Cooperative Project LBL is coordinating the U.S. technical activities being carried out at Cerro Prieto under an agreement between WE and Comisión Federal de Electricidad of Mexico. This multidisciplinary program includes geological, geophysical, geochemical, subsidence, and reservoir engineering studies with the purpose of developing a hydrogeological model of the geothermal system and to analyze its response to large-scale fluid production.

Some of the more important results obtained by the various American (e.g., U.S.G.S., U.C. Riverside and LBL) and Mexican groups involved in the program are as follows:

(1) The lateral boundaries and the temperature distribution within the geothermal anomaly have been generally established.

(2) The general distribution of deltaic and marine lithofacies in the field has been determined and is continuously revised as new well data become available.

(3) A general picture of the heat and mass flow pattern in the system has been developed. The hot fluids are recharged from the east and northeast and are moving laterally towards the west along the base of shale units. The fluids move upward through gaps in these shale units until they finally leak to the surface. After large-scale production began in 1973, colder waters began moving into the geothermal reservoir from shallower aquifers and from the edges of the field. A more detailed flow regime is being presently developed.

(4) Repeated surface geophysical surveys (dipole-dipole resistivity) have monitored changes in the reservoir caused by its exploitation. Apparent resistivity increases have

been detected over the older (western) part of the field at depths of 1 km or greater. On the other hand, large zones of decreased apparent resistivities have been observed west and east of that area. Modeling studies are being made to establish whether changes in salinity, temperature, and/or steam saturations of the reservoir fluids can explain the observed changes.

(5) Based on chemical and reservoir engineering data it was concluded that mixture with cooler waters rather than boiling is the dominant cooling process in the natural state, and that production causes displacement of hot water by cooler water, and not by vapor. Local boiling occurs near most wells in response to pressure decreases, but no general vapor zone has formed.

It is felt that the success of a multidisciplinary project like the Cerro Prieto study will strongly depend on the technical and managerial capabilities of the organization coordinating the effort and flow of information between the participating groups, as well as this organization's ability to be actively involved in the research phase. A national laboratory with its resources in manpower, laboratories, and shops is well suited for such technical and managerial roles.

Low-Temperature Research In 1981, DOE asked LBL and INEL to develop and implement jointly a new program in reservoir engineering methodology and reservoir assessment techniques specific to low- and moderate-temperature hydrothermal systems. Until that time, little effort had been devoted to the understanding of these reservoirs. Accomplishments to date include development of a computational model for thin, fault-charged hydrothermal reservoirs, development of well testing instrumentation, compilation and publication of case studies of low to moderate-temperature reservoirs and preparation of a handbook with reservoir engineering guidelines for potential developers.

High-temperature Research Since 1976, LBL has conducted a sizeable research effort in high-temperature geothermal reservoir engineering. Some of the highlights are as follows:

(1) International cooperation - Through a number of international cooperative projects (Italy, Iceland, Mexico, New Zealand), it has been possible to obtain access to geothermal operating experience and field performance data. This has facilitated recognition of technological problems and has made possible the development of novel methods for geothermal reservoir engineering. Much valuable information has been made available to the geothermal community in the United States.

(2) GREMP - LBL developed the Geothermal Reservoir Engineering Management Plan (GREMP) for DOE as a guidance for R&D policy in geothermal reservoir engineering. A comprehensive extramural research program was implemented, and LBL administered and technically monitored research contracts and disseminated the results to the geothermal industry.

(3) Reservoir Modeling - LBL's in-house research efforts have integrated talent from various disciplines (geology, hydrology, geophysics, reservoir engineering, physics, mathematics) to develop quantitative methods for geothermal reservoir evaluation and performance analysis. Emphasis has been placed on the developnent of sophisticated yet easy-to-use computer programs such as SHAFT79 and PT (or CCC), which would be viable tools for engineering applications. Novel methods have been demonstrated through generic studies, as well as through applications to field data. A workshop was held to instruct engineers from the geothermal industry in the use of these computer programs. LBL staff continues to advise interested individuals and organizations in the application of advanced geothermal reservoir engineering methods.

We believe that our reservoir modeling work has already had a significant impact on geothermal development planning in the United States, and will continue to facilitate design and optimization of exploitation strategies.

Energy Utilization - The Utilization Technology Group at LBL has had as its focus the binary-cycle energy conversion process. The binary-cycle is the leading candidate for utilization of moderate and low-temperature resources for electricity generation. Optimization of the working fluid and cycle state point as functions of resource temperature and economic conditions has been studied using the powerful code "GEOTHM" developed at LBL. Cycles using supercritical mixtures of light hydrocarbons have been shown to be optimal at present cost levels.

Heat exchangers constitute a major portion of the binary-cycle power plant cost, and the performances of both novel and conventional heat exchangers have been studied under field conditions. Laboratory measurements have also been performed to establish heat transfer coefficients for butane/isopentane mixtures. A 500-kW direct-contact heat exchanger pilot plant has been designed, built, and tested at East Mesa. LBL is presently supporting the Heber Binary Demonstration Power Plant by participating in design reviews and in the design of the data acquisition system for the plant.

Field Testing - At the onset of government programs to stimulate the developnent of geothermal resources in the United States, there was a need to develop improved methodology for testing geothermal wells and geothermal reservoirs. Because well testing is the most common and reliable technique for providing data on the in situ reservoir parameters, it is essential to have a well-developed test methodology. As part of the LBL Geothermal Reservoir Engineering Program, well testing methods, procedure, instrumentation, and interpretation have been investigated.

Well testing methods developed for geothermal well testing have followed the lead of the petroleum industry. Three types of tests--production tests, injection tests, and interference tests--assimilated from the petroleum industry were determined to be the most suitable to geothermal reservoirs. To make these techniques applicable to geothermal reservoirs, the theory has been modified to include the effects of two-phase (steam-water) nonisothermal flow in the reservoir, two-phase and non-isothermal wellbore flow with variable rate, and fracture flow. For highly saline or gas eous reservoirs, an accurate equation of state must be developed and included in the calculations. To date very little data exist on the properties of saline and gaseous brines at elevated temperatures and pressures. This is a major area of on-going research intended to facilitate the development of geothermal reservoirs.

In the past, a major obstacle to the implementation of well testing techniques has been the lack of instrumentation and measurement devices for high-temperature and high-pressure application. Temperature, pressure, and flow must be measurable both downhole and at the surface, at sufficient accuracy to obtain reliable estimates of the reservoir parameters. In 1976, there were only two systems available for obtaining downhole pressure: a mechanical device designed for the oil and gas industry, and an electronic device rated to 150°C. Obtaining downhole pressure, temperature, and flow data at temperatures greater than 150°C was limited by lack of high temperature electronics, transducers, seals, cable heads, and cable. Now, as the result of the development of high temperature electronics at Sandia, the potential exists to develop instruments suitable for use at temperatures of up to 275°C. Concurrent to the Sandia program, the reservoir engineering group at LBL has concentrated on developing tools that use only surface electronics. Using this philosophy, a downhole pressure/temperature/flow tool rated to 225°C has been developed. It incorporates a Bell and Howell CEC 1000-4 series pressure transducer, an RTD, and a modified Kuster spinner. A spinner (downhole flow meter) and a temperature tool, both rated to 300°C, have also been developed and fabricated.

FUTURE POSSIBLE RESEARCH AREAS A great deal of important work remains to be done by the national laboratories in geothermal reservoir engineering. Future challenging areas of research are:

(1) Injection studies - Many geothermal fields require injection in the very near future, and many important problems in this area have to be addressed as soon as possible.

(2) Fractured porous media studies - Because most geothermal reservoirs are highly fractured, it is important that pioneering work on fractured porous media done at LBL be continued.

(3) Geophysics - There is continued need for the monitoring of reservoir changes by geophysical means.

(4) Geochemical studies - There is great potential for future developnent and application of geochemical methods in reservoir engineering.

(5) Gas chemistry effects - Gas chemistry effects on reservoir analysis must be more thoroughly studied.

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