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Geothermal Implementing Agreement, Annex VII: Advanced Geothermal Drilling and Logging Technology

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ABSTRACT

The objective of Annex VII, Advanced Geothermal Drilling and Logging Technology, as part of the Geothermal Implementing Agreement is to promote ways and means to reduce the cost of geothermal drilling. This is being accomplished through an integrated effort which involves developing an understanding of geothermal drilling needs, elucidating best practices, and fostering an environment and mechanisms to share methods and means to advance the state of the art. Drilling is an essential and expensive part of geothermal exploration, development, and utilization. Drilling, logging, and completing geothermal wells are expensive because of high temperatures and hard, fractured formations. The consequences of reducing cost are often impressive, because drilling and well completion can account for more than half of the capital cost for a geothermal power project.

Geothermal drilling cost reduction can take many forms, for example faster drilling rates, increased bit or tool life, less trouble (twist-offs, stuck pipe, etc.), higher per-well production through multi-laterals, and others. Activities in the Advanced Geothermal Drilling and Logging Annex address aspects of geothermal well construction including development of a detailed understanding of worldwide geothermal drilling costs, a compilation of a directory of geothermal drilling practices and how they vary across the globe, and communications of developments of improved drilling technologies.

The Annex VII activities of the Geothermal Implementing Agreement were developed to foster advanced geothermal drilling research that addresses all aspects of geothermal well construction. These activities include development of ways to quantitatively understand geothermal drilling costs from around the world and identify ways to reduce those costs, while maintaining or enhancing productivity, identification and development of new and improved technologies for significantly reducing the cost of geothermal well construction to lower the cost of electricity and/or heat produced with geothermal resources, act as a means to inform the international geothermal community about these drilling technologies and provide a vehicle for international cooperation, field tests, etc. toward the development and demonstration of improved geothermal drilling technology

1. INTRODUCTION

In 1997, the International Energy Agency (IEA) approved a Geothermal Implementing Agreement to foster research, development and technology transfer. Annex VII, which was initiated in 2001, was one of the four Annexes as part of this Implementing Agreement. Annex VII, Advanced Geothermal Drilling and Logging Technologies, focuses on improvements in geothermal drilling. Annex VII participants include Australia, Iceland, the European Union, Mexico, New Zealand, and the United States.

Annex VII and each task is currently led by the US/DOE through S.J. Bauer, sjbauer@sandia.gov, at the Geothermal Research Department, Sandia National Laboratories, http://www.sandia.gov/geothermal. The Annex VII committee typically meets at least annually, in conjunction with the GIA Executive Committee.

Drilling is an essential and expensive aspect of geothermal exploration, production and maintenance. Drilling and completion of the production and injection well field can account for a significant portion of the capital cost for a geothermal power project. The objectives of the Annex are to achieve enhanced productivity by quantitatively understanding and improving word wide geothermal drilling costs and performance, to identify and develop technology advancements to significantly reduce the cost of geothermal well construction, and to inform the international community about new drilling and logging technologies.

2. ANNEX VII TASK DESCRIPTIONS

The "work" of the Annex is divided into three tasks: Task 1: Compile Geothermal Well Drilling Cost and Performance Information, Task 2: Identification and Publication of "Best Practices" for Geothermal Drilling, and Task 3: Advanced Drilling and Logging Collaboration.

Task 1 is described as follows: this activity is a compilation of drilling cost information associated with the development, construction and operation of geothermal wells. This information/data will be maintained in a single database, so that all participants can use it to identify key cost components that might be reduced by new technology or by different drilling practices. Data could include R&D cost, project cost, operation and maintenance cost and overall cost of energy. The focus is to obtain/include drilling information from 1990 to date, however some older drilling data is in the data base. The key modification sought in this time period, based on the realization that operators do not want to openly share costs, is to collect depth-time data, from which, performance may be estimated.

Task 2 is described as follows: the participants identify and catalogue the technologies that have been most successfully used for drilling, logging and completing geothermal wells. The completed Handbook will contain drilling practices for electrical generation (high temperature) wells; it will also eventually include, but is not limited to: design criteria for the drilling and completion programs, drilling practices for cost avoidance, trouble avoidance, well testing, geophysical logging, and wellbore preservation.

Task 3 is described as follows: the Participants monitor and exchange information on drilling and logging technology development and new applications in their respective countries. The Participants also identify activities and projects for collaboration, and then collaboration plans will be developed. For example, the Participants anticipate identifying opportunities to field test in one country a technology/system that is being developed in another participant's country.

2.1 Drilling Costs

The primary focus of Task 1 thus far has been to collect/ compile drilling cost information associated with the development, construction and operation of geothermal wells. In the past five years, the data base has double in size with data from about sixty wells from five countries represented. Thus far only limited analysis of the data has taken place.

In **Figure** 1 we present some typical cost versus depth data. Cost versus depth may be readily understood if all of the wells are vertical (**Figure** 1), of the same diameter, in the same geology.

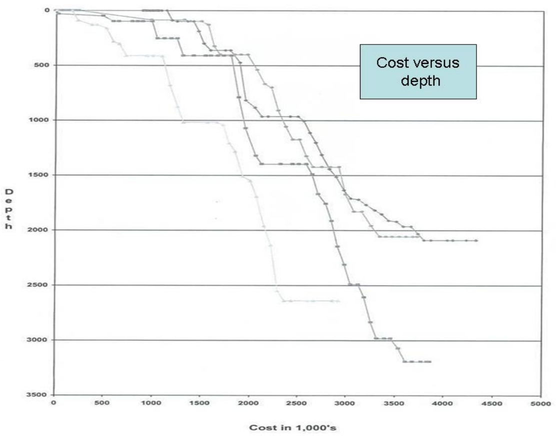

Figure 1: Example cost versus depth plot for geothermal wells.

Well costs are very dependent upon the field or geologic section in which they are drilled. In **Figure** 2, data from seven geothermal fields, representing seven different geologic environments are represented; each set of data is fit with a best fit curve. The exponential growth factor of the brown curve on **Figure** 2 is over twice that of the yellow curve. The expected well cost in the "brown geology" at 6,000 feet is over 300% the expected well cost in the "yellow geology." Thus, predicting well cost without specifying the geologic setting is impractical; from one site to the next physical and mechanical rock properties, as well as in situ conditions (stress, temperature, fluid conditions, etc.) change significantly. Unfortunately, there is no single parameter, such as rock hardness that captures the effects of geology. One can say, in general, that sedimentary lithologies tend to have lower well costs than crystalline rocks, but one of the biggest factors making some fields more costly is trouble (unanticipated problems that are inefficiently handled resulting in protracted flat time) and trouble can occur in almost any geologic setting. At this time, the only way to account for the effects of geology is to start with a description of the geology that includes rock hardness, the window between pore pressure and frac-gradient, trouble frequency, etc and estimate the effects of these parameters on well cost based on existing wells with similar properties.

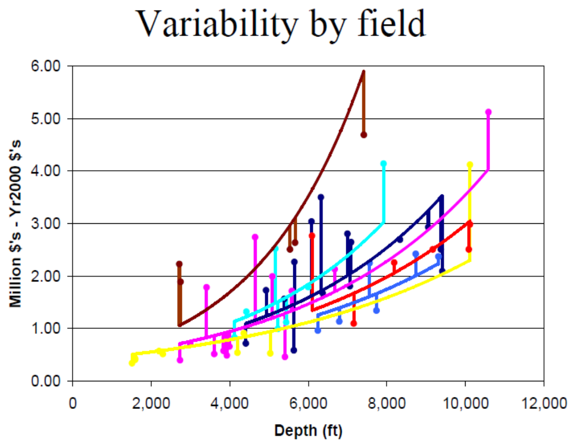

Figure 2: Example comparison of total cost versus depth for geothermal wells for different fields, different geologic settings (from Mansure et al, 2006).

It is anticipated that in the coming year(s) that presentations and analyses of geothermal well cost data similar to that presented herein will be a "product" of this Annex VII task.

2.2 Drilling Handbook

Literature on drilling has decreased – far less than 10% of papers at GRC and international meetings are on drilling and completion. Substantial geothermal drilling information is publicly available but it needs to be organized, edited, and distributed. Many geothermal projects are in developing countries without extensive geothermal experience or a strong research infrastructure. In response to the need to communicate the appropriate information, it was decided to write a drilling handbook. An outline for the drilling handbook was developed. In 2007, that outline was posted on the web on the GIA website. A comment and response period followed. The outline and handbook have had significant contributions from Mexico and the U.S.; it is anticipated that all participants in the Annex will participate in the review.

The current outline that was developed for the handbook is as follows:

Introduction:

- Define the audience – drilling engineers, students, and general use
- Focus on the differences between geothermal and other drilling

Well design:

- Purpose of the well – production, injection, exploration, or workover
- Reservoir conditions – previous temperature and pressure logs, thermal gradient holes, offset wells, other geophysical information
- Logistical requirements – schedule, budget, lease or regulatory stipulations
- Technical requirements – required production rate, casing diameter at production zone, expected

depth, available tools or technology, are tools required to operate at high temperature
- What are the likely problems - lost circulation, stuck pipe, twist-off, corrosion/erosion, tool failure from high temperature
- Well trajectory – vertical, directional, or multi-leg? Where is the kick-off point, and how accurately must well path be controlled?
- Casing design – number of strings, depths, diameters, strength, connections, and materials
- Completion – open hole or slotted liner? Slotted liner design.
- Wellhead design – pressure requirements, expansion spool, welding, testing.

Drilling system selection:

- Conventional rotary, top-drive, or coring
- Maximum hook load
- Rig footprint. Number of loads to mobilize.
- Pump capacity
- Fluid cleaning requirements
- Drill string and BHA design
- Drill bit selection
- Downhole motors or hammers
- Availability of fishing tools
- Define the information that will be on the request for bids

Drilling fluids:

- Can water be used as drilling fluid? Advantages and disadvantages.
- If not water, then do we need more than simple bentonite mud?
- Are mud coolers needed
- Polymers for viscosity, lubricity, yield – temperature limits
- Need lost circulation material (LCM)
- Aerated drilling fluids - pore-pressure gradient known
- Can the hole be drilled with air or mist

Well Control:

- Principal causes of blow-outs, and ways to avoid them
- Estimate well temperature profile during drilling – maximum-reading thermometers, on-board logging tools, inflow/outflow temperature measurements.
- Accurate measurement of inflow and outflow is valuable.
- Establish a standard well-killing procedure.
- Blowout preventers (BOPs) – pressure and temperature requirements, choke and kill lines, kill water

Lost circulation:

- Causes, treatments, costs.
- Locating loss zones by logging.
- Develop a lost-circulation strategy before drilling.

Cementing casing or loss zones:

- Regulatory requirements
- Selection of cement types and additives
- Placement problems and techniques

Instrumentation (drilling and mud-logging):

- Minimum instrumentation, and optional additions, on the rig
- Use logging tools to solve drilling problems.
- Preparation for injection or discharge tests.

Well cost:

- Factors that affect well cost
- Examples/case histories of actual wells or projected costs
- Table of well costs for a hypothetical well with varying drilling parameters such as ROP, bit life, trouble, casing program, etc.

Emerging technologies:

- Casing drilling
- Spallation drilling
- Better downhole feedback for trouble avoidance and higher performance

It is anticipated that a draft of the handbook will be available a few months from this meeting for review and comment, with publication by the GIA on their website shortly thereafter.

2.3 Drilling and Logging Technology Collaborations

The focus of this task for the past five years has been for participants to exchange information on drilling and logging technology development and new applications in their respective countries. This has been done through presentations, workshops, and conference organization. The next step to collaboration was not realized during the past five years. Examples of the information exchanges are as follows:

2005:
The New Zealand and USA participants collaborated to develop a cost shared information exchange. A Workshop sponsored by the New Zealand Geothermal Association, "Life Cycle Considerations for Geothermal Wells," by Keith Lichti, Paul Bixley, and Steve Bauer was held, attended by about 40 industry, government and university individuals.

Randy Normann (Sandia) was invited and presented, "Geothermal Strategies at Sandia" at the HITEN (High-Temperature European Network) conference, Paris, France, September 6-8, 2005.

Geothermal Research Session organized at American Rock Mechanics Association Annual meeting (Anchorage, Alaska: S. Bauer)

2006:
Roy Baria, representing the Soultz HDR Project visited Sandia National Laboratories (January) and presented "Current Status of EGS Technology with a Particular Reference to the European HDR Programme". An information exchange took place pertinent to the geophysical response observed during the Soultz injection testing.

High Temperature Electronics Conferences (HiTEN and HiTEC) are high temperature electronics conference held annually, alternating between Europe and the U.S. These conferences focus on high temperature components, packaging, devices, and systems. The next meeting is scheduled for June, 2010, in Albuquerque, NM, USA.

During the Annex VII meeting (March 15, Paris, France), three presentations were made in the spirit of fostering international communications and technology sharing:

"European Union program: ENGINE", S. Thorhallsson, Iceland GeoSurvey:

The **EN**hanced **G**eothermal **I**nnovative **N**etwork for **E**urope ENGINE, **http://engine.brgm.fr,** was a co-ordination action supported by the 6th Research and Development framework of the European Union. The main objective is a co-ordination of the present research and development initiatives for **Unconventional Geothermal Resources** and **Enhanced Geothermal Systems**, from resource investigation and assessment stage through to exploitation monitoring. The ENGINE conferences and workshops took place from February, 2006 through February, 2008 and the workshops and conferences covered topics that included: stimulation of reservoir and induced microseismicity, electricity generation, combined heat and power, defining, exploring, imaging and assessing reservoirs for potential heat exchange, exploring supercritical fluid reservoir: a new challenge for geothermal energy, drilling cost effectiveness and feasibility of high-temperature drilling, increasing policy makers awareness and the public acceptance, and risk analysis for development of geothermal energy.

"Downhole Motors and Ideas Concerning Geothermal Drilling" Evgeny Murtola, Swiss Federal Institute of Technology (ETH)

"Current Direction of Sandia's Drilling Research Efforts", S. Bauer, Sandia National Laboratories, USA

"Potential New Directions/Frontiers for Annex VII" Sverrir Thorhallsson, Iceland GeoSurvey, S. Bauer

Geothermal Research Session were organized at American Rock Mechanics Association Annual meetings, (S. Bauer: Golden, Colorado).

2007:
S. J. Bauer visited L. Rybach at Geowatt in Switzerland and ETH Zurich to discuss geothermal technologies, including advance drilling methods and tools with ETH

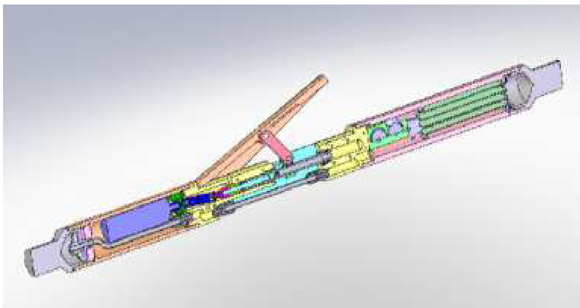

Figure 3: High Temperature Sandia designed seismic tool.

2009:
Annex VII Fall meeting: J. Henfling presented "Sandia/DOE recent successes and plans for the immediate future for downhole tools". The focus of Sandia/DOE work this year in high temperature tool development is upon high temperature Seismic Tool-monitoring for long term (years) deployment in borehole (**Figure** 3). Two tools are being developed: Type 1- 200°C high resolution (24 bit A:D; > 1000 hour operation Three axis, 1 uG/ 1000 Hz seismic sensitivity (Texas Components; Texas Instruments 24 bit ADC convertor); Type 2- 240°C lower resolution (18 bit ADC; > year operation). Three axis, 1 uG/ 100 Hz seismic sensitivity (Honeywell 18 bit A/D convertor). The tool is scheduled to be fielded in late 2009.

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