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Report of the Geophysical Measurements in Geothermal Wells Workshop

Airport Marina Hotel, Albuquerque, New Mexico
September 17-19, 1975

Leonard E. Baker, Robert P. Baker, Robert L. Huguen

MASTER

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REPORT OF THE
GEOPHYSICAL MEASUREMENTS IN GEOTHERMAL WELLS WORKSHOP
AIRPORT MARINA HOTEL, ALBUQUERQUE, NEW MEXICO
September 17-19, 1975

Compiled and Edited by
Leonard E. Baker
Robert P. Baker
Robert L. Huguen

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ABSTRACT

This report presents results of a Workshop on Geophysical Measurements in Geothermal Wells, hosted in Albuquerque, September 17-19, by Sandia Laboratories and jointly sponsored by the United States Geological Survey and the Energy Research & Development Administration. During the workshop, tutorial papers dealing with the geothermal resource, geothermal logging, and high temperature technology were followed by working panel sessions. Three panels deliberated, respectively, well and reservoir parameters, log interpretation, and high temperature technology. In a final session, the reports of the panels were heard and discussed by the full workshop. A summary of the workshop conclusions and recommendations, as well as the complete panel statements, are presented in this report.

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Thanks are extended to all those who participated in the workshop but are especially due those who provided their time in the preplanning sessions, those who prepared and presented tutorial papers, L. C. Dutcher who served as Chairman, and to the following panel co-chairmen for their efforts in directing the work of the panels and in preparing the final panel reports: Jim Combs, M. J. Davis, M. Gearhart, W. Scott Keys, W. J. McDonald, and R. C. Ransom.

PREFACE

By

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Development of the geothermal resources of the United States during the next few decades will require a large and coordinated effort on the part of many people and institutions. Federal, state, and local agencies will be involved, as will universities, the national scientific laboratories, and many private industries. The scientific community must develop multidisciplinary programs whose objective must be understanding the factors that control the nature and distribution of the geothermal resources so that reliable and documented estimates can be made of their magnitude and location. Understanding of the reservoir characteristics must progress to the point that development can proceed according to some previously determined optimum plan and determining the environmental consequence of development must be anticipated in advance of development.

Therefore, R and D programs designed to achieve the objectives listed must encompass a broad spectrum of geological, geochemical, geophysical, and hydrological activities. As a first step, most of these activities will involve the drilling of test and production wells from which basic data can be collected.

It is imperative that capability be developed to measure physical parameters at the wells because these data serve as the basis for assessing the resources, developing the geothermal reservoirs, and managing the well fields in an economical and environmentally acceptable manner. The ability to collect and interpret reliable data from geothermal wells, then, becomes an extremely important part of any geothermal resources development program. Because the geothermal environment can be classed as hostile, in comparison to the environment of a typical petroleum reservoir, for example, the task of obtaining reliable and usable information from the wells is very difficult. Much new hardware, new technology, and new methods must be developed before the objectives can be achieved. Also, some older tools, methods, and technology must be modified for use in connection with geothermal exploration and development.

It is the need for this new and expanded capability of obtaining usable information and parameter measurements at geothermal wells that led to the workshop on well-logging and data-collecting. Results of the workshop are summarized herein. Many of the country's experts on geohydrology, well logging and data interpretation, and high-temperature materials and instruments participated. Hopefully from the summary and the recommendations contained herein, a program of research and development can be developed and financed that will lead to a capability in logging and data collection at geothermal wells that will meet the needs relative to our development and use of this important national resource.

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REPORT OF THE GEOPHYSICAL MEASUREMENTS IN GEOTHERMAL WELLS WORKSHOP

Introduction

The Geophysical Measurements in Geothermal Wells Workshop was co-sponsored by the United States Geological Survey (USGS) and the U. S. Energy Research and Development Administration (ERDA) and was organized and hosted by Sandia Laboratories. The workshop was held in Albuquerque, New Mexico, September 17-19, 1975, at the Airport Marina Hotel. A list of the participants is included in Appendix A.

The workshop was structured to provide a coordinated effort by members of private industry, the academic community, and government agencies to address the following objectives:

1. Define downhole measurement priorities;
2. Identify problems in making measurements and interpretation of data;
3. Determine the state of the art of materials, components, and equipment for use in the geothermal environment, and identify deficiencies; and
4. Recommend needed research and development activities and assign priorities.

These objectives were addressed in the immediate, near term (< 5 years) and long term time frames.

After the welcoming of the participants by Dr. Morgan Sparks, President of Sandia Laboratories, the first day was devoted to the presentation of the following invited tutorial papers intended to establish a needed broad common information base within the group.

1. Statement from Chairman	Dutcher/USGS
2. Geothermal Development - Present and Future	Conrad, Jaffe/JPL
3. ERDA Support of Geothermal Development and Patent Policy	Skalka, King/ERDA
4. Drilling and Completing Geothermal Wells	Cromling/Big Chief
5. Geothermal Reservoir Analysis	Gould/Intercomp
6. Geothermal Logging - State of the Art	Hughen/Sandia
7. Geothermal Well Logging	Keys/USGS
8. Tradeoffs for Geothermal Drilling and Logging	Rex/Republic Geothermal
9. State of the Art of High Temperature Technology	Johnson/LASL
Baker, Davis/Sandia

Following these talks, the participants split into three groups of 25 to 40 persons for the organization of three working panels. Each group concentrated its efforts on problems relating to one of the following areas: Reservoir and Well Parameters, Log Interpretation, and High Temperature Technology. Each participant had been previously assigned to one of the panels based on information response forms expressing background and interest. Information from questionnaires completed by workshop participants aided panel chairmen in organization and guidance of their respective panels. A sample questionnaire is included as an attachment at the end of the report.

The second day was devoted totally to panel discussions, with each panel spending part of the time as a single group and part of the time split into subgroups. The subgroups were established to provide a more convenient working size and to increase the opportunity for individual participation.

Recognizing that the work of the panels was interrelated, each panel was assigned a specific time-limited task to provide information exchange between groups. The Parameters Panel was asked to provide the other panels, by mid-morning, a basic priority list of needed geothermal parameters. By noon, the Log Interpretation Panel, in turn, provided a list of measurements and tools needed to determine these parameters to the High Temperature Technology Panel. The High Temperature Technology Panel then addressed the materials and component technology needed to provide the required instrumentation capability.

In the evening, following the panel discussions, each panel prepared a report on its findings. On the morning of the last day, the full workshop convened to hear the three panel reports and for a general discussion of the workshop and workshop recommendations.

Summary of Conclusions and Recommendations

The workshop participants generally agreed that presently available logging equipment is not capable of reliably operating in the geothermal environment, particularly with regard to maximum operating temperature. [The service company representatives were not in complete agreement with the Workshop's findings on the lack of existing equipment capabilities. They feel the poor service to the geothermal community is essentially a result of poor communications and lack of preparations. This minority opinion is presented in full in Appendix B.] The near term operating goals were set at 250°C to 275°C, with long term goals of 450°C to 500°C. Recognition was given to the possible eventual need for some equipment capable of operating at 1000° to 1100°C for magmatic and other applications.

Discussions of the parameters of interest and their importance to different types of geothermal resource exploitation resulted in true formation temperature being designated the top priority parameter. Priorities were derived for other parameters, but it was recognized that their relative importance would be somewhat dependent on the type of geothermal resource being evaluated and the purpose of the evaluation (e. g., exploration versus production). Determination of these parameters will require a combination of downhole logging and other evaluation techniques. Studies should be made to insure that the most cost effective combinations are used.

The workshop was able to complete all of its assigned tasks except that of assigning priorities for the implementation of its specific recommended actions and the associated equipment upgrading and development requirements. This task will be undertaken by the USGS, Sandia Laboratories, and a small committee made up of those workshop panel chairmen who wish to participate. A prioritized listing of recommended actions for equipment, materials, and component upgrading and development with associated research will be prepared by this committee. It will be based on the workshop panel and questionnaire findings and will be issued as a supplement to the present report early in 1976.

Specific recommendations are summarized below under five broad categories. The listing sequence does not imply importance or priority.

1. Data Bank

A pressing need was expressed to establish a data bank of cores, logs, production histories, and other well and reservoir information. In addition, it was suggested that data dealing with equipment capabilities and limitations, including failure reports and analyses, should be collected and catalogued. Pertinent data bank information would be available to all those involved with geothermal development; appropriate measures would be taken to protect proprietary interests.

2. Communications

An immediate step that should be taken to improve presently available geothermal logging services is to establish a single contact in each organization to provide geothermal logging program coordination.

It is recommended that a committee be established to meet on a periodic basis to provide guidance for data bank acquisitions and management. A committee(s) should also be formed to coordinate efforts relating parameters, log interpretation techniques, modeling, and equipment development.

A literature search should be undertaken to make available abstracts and bibliographies relating to geothermal development activities.

3. Equipment Development

Recommendations included:

- a. The upgrading of specific existing tools to a 250°C or higher capability and the development of other tools, especially a system for measuring true formation temperature and a downhole sampler to obtain truly representative fluid samples.
- b. Evaluation of existing tools, cables, seals, electronics, and other components to determine present limitations and failure mechanisms. A set of test standards will be needed to guide this evaluation.
- c. Development of materials and components to support future tool development, including high temperature (350-400°C) elastomeric materials and active electronics with an extended temperature range.
- d. An overall systems approach guided by studies which consider the need for and use of data as well as specific hardware design tradeoffs is recommended to guide this development for optimum cost effectiveness.

4. Test Facilities

The calibration and testing of geothermal logging tools and the development of interpretation techniques requires specialized facilities and simulation techniques, and requires cored and logged geothermal test wells available to all segments of the geothermal community.

5. Logging

Logging of selected geothermal wells should be funded as needed to obtain data for geophysical and geological research as well as to evaluate equipment capability.

The funding of logging should be included as line items in drilling and production programs to insure that planned logging activity, including that to obtain research data, does not suffer from cost overruns in other areas.

Panel Summary Reports

Each panel conducted its session in a slightly different manner, and so the results of each are presented in somewhat different formats.

The Parameters Panel, after an initial combined meeting, split into five subgroups all charged with addressing the same questions. Each subgroup submitted a separate written summary of its conclusions; these were combined into a panel summary statement by Bill McDonald. The subgroup statements are presented in Appendix C.

The Log Interpretation Panel met first as a single group and after lunch split into three subgroups, each charged with discussing a different facet of the subject. The results of these discussions were presented verbally in a final meeting of the entire panel, and no individual subgroup statements were written. Scott Keys provided a summary of the subgroup verbal reports and complete panel discussions.

The High Temperature Technology Panel split into three subgroups, each to discuss a different area of technology. The panel met as a single group to receive information from the other panels, but most discussions took place in the subgroups. Each subgroup submitted a written summary of its conclusion and these are presented in Appendix D. Mark Davis provided a summary of the subgroup reports.

Parameters Panel Summary Report
Co-chairmen Jim Combs and W. J. McDonald
Summary Prepared by W. J. McDonald

Organization

The task of the Parameters Panel was to define the well and reservoir parameters needed for effective evaluation of geothermal wells and to assign priorities to these parameters.

The parameters panel, which consisted of approximately 35 representatives from government, universities, and industry, met first in a general session to develop a preliminary list of high priority parameters. This preliminary list was provided to the other two panels. The panel then divided into five subgroups. The subgroups or committees all had the common purpose of developing a list of parameters (with priority ranking) needed to meet the objective of effectively evaluating geothermal wells.

The subgroups were charged with the following specific topics to consider:

1. Define objectives which can be met by knowledge of geophysical parameters,
2. List the parameters required to meet these objectives,
3. Rank the parameters,
4. Assign a range of parameter values if possible, and
5. Recommend procedures to assure that technology exists to meet future needs for evaluating geothermal wells.

The five subgroups met again in general session at the end of the day to report and discuss their findings. Representatives of the subgroups met during the evening to develop written reports for each of the groups.

It is interesting to note that each of the five subcommittees established a different perspective on the task of defining and assigning priorities to the parameters needed for effective evaluation of geothermal wells, yet each of the perspectives led to similar parameters and recommendations.

Objectives

The objectives of making geophysical measurements and the motivations for assuring that technology exists to make these measurements can be grouped into three classes. These are:

1. Resource Evaluation,
2. Environmental Considerations, and
3. Institutional Requirements.

These are discussed on the following page.

A detailed evaluation of the resource must be made before development of the geothermal reservoir can be undertaken. This evaluation must include assessments of such things as:

- The amount of total energy in place.
- The amount of producible energy under different development schemes.
- The unit value of the resource.
- The deliverability and how it affects development economics.
- The resource quality and alternative markets for the resource.
- The overall system economics.
- The economic value of by-products, such as agricultural water and/or minerals that may be recovered.

Each of the assessments listed above will be a function of time and market conditions. Technology and total system economics must be established, and risks must be carefully evaluated. The certainty with which well and reservoir parameters are established will affect the resource evaluation.

Environmental considerations must be included in the complete evaluation of a geothermal resource. For example, disposal of waste water presents problems whether disposal is by a surface method or by reinjection. Minerals precipitated from geothermally heated water can be either an asset or a liability depending on the value of the mineral and how it is handled in the overall system. Seismicity, which may be caused by extraction or reinjection of water, is an important environmental consideration, as is subsidence which may result from extraction of large quantities of geothermal fluids. These and other environmental considerations impact the economical evaluation of the resource and influence resource development.

Institutional requirements is the third general objective area which must be considered in the overall geothermal resource evaluation. Permits and approvals must be obtained for resource development; leasing obligations must be fulfilled; questions regarding unitization may arise during resource development and production if a single organization does not control the entire geothermal reservoir.

Parameter List

The importance of measured and inferred parameters depends on evaluation objectives and is also a function of geothermal resource type. In order of occurrence and exploitability, the types of as yet undeveloped geothermal resources were established to be:

1. Hot liquid
2. Geopressure
3. Steam

4. Dry rock

5. Magma

Priorities of parameters may vary among resource types. However, certain parameters are essential for evaluation of most geothermal resources. These are arranged to indicate ranking and importance.

1. Temperature

2. Formation Pressure

3. Flow Rate

4. Fracture System (Location, Orientation, Permeability, etc.)

5. Fluid Compositions (pH, Dissolved Solids and Gases, Redox Potential)

6. Permeability

7. Porosity (Interconnected and Isolated)

8. Formation Depth and Thickness

Other parameters which are important but which may not need to be measured in every well or which may be reliably predicted or calculated from other physical parameters include:

1. Thermal conductivity

2. Electrical conductivity or resistivity

3. Heat capacity

4. Lithology and mineralogy

5. P and S wave velocity

6. Hole size (may be critical in log interpretation)

Recommendations

In order to meet the requirement of assuring technology to measure or infer the important geothermal well and reservoir parameters, the Parameters Panel recommends the following in order of importance.

1. Logging equipment design conditions should be:

Near Term - 275°C (525°F), 7000 psi

Long Term - 500°C (930°F), 20,000 psi

2. Parameter determination should not be limited to borehole measurements.

Alternative procedures should include mud logging and laboratory evaluations such as physical properties tests on cores, cuttings, ditch samples, fluids, etc, and use of empirical relationships between parameters.

3. The importance of determining formation temperatures cannot be overstated. Attention should be given to devising a remote, instantaneous logging system capable of measuring true formation temperature. Lacking this, serious consideration should be given to determining formation temperature by the active recording of mud temperatures and flow rates with real time computer simulation of the mud thermal history during drilling.
4. Extensive data collection is strongly urged to aid in interpretation and evaluation of measured and inferred parameters. The data collection should include a data bank to archive log, core, and other geologic and reservoir data.
5. Laboratory test facilities should be established where adequate facilities are not available. Physical properties should be obtained from cores, cuttings, ditch samples, fluids, etc.
6. Geothermal test wells are needed. These wells should provide test conditions with temperature, pressure, geologic and fluid conditions similar to those encountered in geothermal prospects. These test wells should be cored, tested, logged, and explored in as great a detail as possible in order to provide detailed information for testing in them.
7. A downhole formation fluid sampler is needed. The sampler should permit collection of uncontaminated hydrothermal fluids and then retention under downhole conditions of temperature and pressure. Laboratory methods should be developed to obtain detailed chemical analyses of the fluids as they exist under formation conditions.
8. Development and application of deep investigating logging tools such as the borehole gravity meter and ULSEL (Ultra Long Spacing Electric Log) should be encouraged since, in contrast to petroleum applications, it may be possible to sacrifice some vertical resolution in order to establish better average values of formation parameters.
9. Logging while drilling has particular application to exploitation of geothermal resources. As pointed out by Bob Rex in the tutorial session, downhole measurements while drilling could allow effective determination of important parameters such as temperature before those formation parameters are strongly affected by drilling operations. Measurements while drilling could also circumvent the problems and risks of losing or damaging geothermal wells during well conditioning, logging, and testing operations.
10. Effective means of logging while producing must be developed. Many geothermal reservoirs cannot be shut-in as might normally be done for logging because of risks of damaging the reservoir or surface facilities. Time dependence of parameters such as temperature and formation pressure will be important during the life of a geothermal reservoir. Therefore, it will be necessary to log periodically during the production life.

Further Study

The Parameters Panel felt that further study is needed to:

1. Examine in detail the importance of geophysical parameters with respect to the objectives and resource type,
2. Determine the state of the art of measurements of these parameters and deficiencies that may exist,
3. Perform cost/benefit analyses of efforts to be spent on technology development, and
4. Formulate a specific program to fulfill geothermal resource technology needs listed above as items 1 through 10.

The guidance provided by this further study will help to articulate the role of parameters in meeting the objectives of resource evaluation. The further study will help to detail the state of the art in parameter determination and provide strong guidance in formulating specific near and long term programs that meet the technology needs of the geothermal resource community, including research, development, field work and testing, data collection, and dissemination of results.

Log Interpretation Panel Summary Report

Panel Co-chairmen W. Scott Keys and R. C. Ransom

Summary Prepared by W. Scott Keys

It is not enough to develop high temperature logging tools--we must also be able to interpret the data produced. Research in log interpretation as applied to the development of geothermal energy must be directed toward the major fluid component, which is hot water, not oil. In addition to the equipment shortcomings due to high temperatures, the major log interpretation problem is the lack of calibration data for the wide variety of rock types encountered by geothermal wells. Pressure and temperature relationships to the rock properties we are attempting to measure are also unknown. It was agreed that at the present time there is a lack of financial motivation for private industry to solve equipment and log interpretation problems associated with geothermal development. The following recommendations are made to solve some of these problems and are listed sequentially rather than in order of priority.

Literature Search - \$15,000-25,000

A computer search of the literature should be carried out to make available lists of references and abstracts on various aspects of geothermal well log interpretation. Broad topics intended to define the research are listed below and should be followed by more specific categories as needed.

1. Geothermal systems
2. Geopressured systems
3. Thermal properties of saturated rocks
4. Evaluation of subsurface fracture systems
5. Geochemistry of aqueous geothermal solutions
6. Thermal conductivity of rocks

Establish a Data Bank - \$150,000

A data bank for information on geothermal wells should be established with all available data from existing wells. It should be kept up to date and be made available to all. The data bank may be part of an existing information system on geothermal energy or contracted to someone with experience, such as the American Petroleum Institute. The following information should be included as a minimum: well location, drilling information (mud, penetration rates, construction, etc.), core data, fluid analyses, pressure and temperature data, production and drill stem tests, formation tops, geologic interpretation, and all logs to include, if available, unprocessed probe output, calibration data, and information about the tool and how it performed.

Develop Interpretation Techniques and Computer Software to Analyze Data Available in the Bank - \$50,000 per Man Year of Effort

This will include interpretation of case histories of wells, computer derived log calibration data, response curves, cross-plots, etc. The following general steps are recommended to define a geothermal reservoir using borehole geophysics.

1. Make several temperature logs over a sufficient period of time so that a computer can be used to predict equilibrium temperatures.
2. Measure thermal conductivity on core cuttings or interpret from logs.
3. Calculate heat flow.
4. Describe porosity and if possible permeability. Fracture location and orientation and distinguishing primary and secondary porosity are very important.
5. Define reservoir geometry-thickness and area.
6. Define mineralogy (rock-typing).
7. Define water chemistry and hydrology.

Test and Calibration Wells

This is one of the highest priority items in our recommended program. The wells are needed for both equipment operational testing and calibration. Preliminary static tests should be carried out in high temperature and pressure chambers such as those being built by Terra Tek. Criteria for selecting test and calibration wells are listed separately, but the ideal would be for all conditions to exist in one or several wells.

Test Wells - Near term goal (approximately one year), shallow well preferred - maximum temperature 250° C. Longer term goal (two-three years), 350° C and 20,000 Psi.

Calibration Wells - Include a wide variety of lithology in as few holes as possible, cored through selected sections. Open hole, stable conditions, and no large flow rate are highly desirable.

These holes should be available for anyone to log and the logs must be made available to the data bank. They should also be logged as part of the program described under the Research Logging section below and the logs studied as described under the Develop Interpretation Techniques ... section above. Wells to be selected by committee.

Research Logging - \$100,000 per Well

Money should be designated as a line item for logging of geothermal wells to assure that the logging program is carried out even when drilling and testing funds are short. A complete suite of commercial service company logs should be run in test wells and other wells with good background information in order to evaluate their usefulness in various geothermal environments.

The funds are to include core analyses for calibration and a comprehensive quantitative log interpretation program.

Specific Interpretive Techniques Not Included in the General Program

1. Interpretation of temperature and pressure changes with time (transients).
2. Effect of drilling mud and divalent cations on spontaneous potential logs in geopressured zones.
3. Radius of investigation of induction and other devices when there is a high thermal gradient perpendicular to the well bore.

Special Logging Instrumentation Development Recommended

The special logging instrumentation development recommended is shown in Table I. The first stage of development is to raise the listed tools to a 250°C capability. In addition to the tools shown in Table I, the following tools can provide refinement of reservoir evaluations. No priority is intended in this listing.

Borehole gravimeter - \$1,000,000.

Accurate, High Resolution Flowmeters for High Velocity - \$115,000.

Magnetically Oriented Induction System for Fracture Location - \$50,000 - \$100,000.

Oriented Acoustic Caliper Output from Televiewer - \$25,000.

Natural Gamma Spectrometry and Neutron Activation Analyses - \$100,000.

Tools for deep investigation such as ultralong spaced devices and those for measurements between wells and from well to surface.

TABLE I

Recommended Instrumentation Development*

R = Reliability needs improvement

N = Not available

Up to 250°C	Up to 500°C	
R	N	Continuous temperature logging equipment and maximum temperature thermometer
N	N	Flowmeters - high velocity, high resolution
N	N	Acoustic televiewer and other fracture locators
R	N	Neutron - borehole compensated
R	N	Gamma-gamma - borehole compensated
R	N	Acoustic velocity - borehole compensated
N	N	Borehole gravimeter
N	N	Nuclear magnetic resonance
R	N	Natural gamma
N	N	Gamma spectrometry and neutron activation (0-8 Mev)
R	N	Induction
R	N	Focused resistivity
N	N	Fluid sampler
N	N	Microwave tool
R	N	Improve time clocks in pressure-temperature bombs (range & accuracy)
N	N	Pressure transducers
R	N	Mechanical caliper
R	N	Hole deviation and direction
N	N	Dipmeter
N	N	Magnetometer and magnetic susceptibility

Devices for which value or technique unknown

N	N	Thermal conductivity (very important)
		Device to distinguish convective and conductive heat flow
		Photoelectric gamma-gamma

NOTE: High temperature instrumentation operation is highly dependent on suitable high temperature cable and connector availability.

*Developmental priority is not implied by listing sequence.

Continued Organized Efforts (Committees)

Two small technical committees are recommended to guide some of the progress above. These are:

Committee on literature search and data bank.

Committee on logging applied to geothermal resource evaluation. This committee will provide technical advice on recommended logging and log interpretation programs.

Basic Approach to Carrying Out the Recommended Program

1. Basic research on components and measuring techniques should be funded and carried out by existing research facilities.
2. Development and fabrication of prototype logging systems should be done by experienced logging equipment manufacturers if they will accept the job.
3. The patent rights of private industry should be protected.
4. Communication between all interested groups must be improved. A specific example is to request logging service companies to designate one contact for all geothermal logging inquiries. Government agencies and national labs may also want to establish single contacts.
5. In addition to funding the development of new logging instrumentation, ERDA should provide money for the experimental use of this equipment by others. It is also essential that personnel be trained and made available for the operation of such sophisticated equipment.
6. Research on log interpretation and evaluation of suites of commercial logs suggested in the Research Logging section above, should be funded in universities having staff members teaching borehole geophysics. This will serve the dual purpose of utilizing their less biased expertise and promote the training of graduate students in geothermal logging.

Log Interpretation Panel Membership

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High Temperature Technology Panel Summary Report

Panel Co-chairmen M. J. Davis and M. Gearhart

Summary Prepared by M. J. Davis

The panel's task was to review the current state of the art with regard to materials available for use in logging tools and to suggest what additional work was needed in terms of new instruments and/or new materials or components to meet immediate and future needs of geothermal well logging. There was not a great deal of agreement on what temperature currently marked the limit of the present technology. This is not surprising when one considers the variety of tools available and the fact that the performance of a particular tool is quite dependent on its preparation and the skill of the crew operating it. There was, however, agreement by all members of the committee that additional work toward getting more reliability and easier operation was desirable.

The concensus of the High Temperature Technology Panel was that the current needs of geothermal logging would be met with tools that would operate at 250° C.* It was more difficult to get a firm number for future needs though the consensus was generally that tools operating up to 400-425° C would be adequate, with a possible need for temperature measurements all up to 1000° C.

The panel divided into three subgroups to address the following subjects: one addressed cables, connectors, seals, and general materials of construction; the second addressed the problems of electronic components both active and passive; and the third addressed the components and detectors themselves with particular emphasis on the amount of development necessary to bring them up to a 250° C capability.

The detailed report of each of the subcommittees, along with general statements, is included later in this report. In summary, however, the following main recommendations were made.

ERDA should support the procurement of the best available cables, seals, and connectors and test these products both in the laboratory and in actual geothermal logging applications. At the conclusion of these tests, a complete postmortem should be made. Particular attention should be addressed to the effects of fabrication on stress corrosion and hydrogen embrittlement, as well as general materials performance. This program must be closely coordinated between manufacturers, designers, and users.

* This was later revised to 275° by the Parameters Panel and accepted by the workshop at the final meeting.

A second program was recommended to address the difficult problems of seals by encouraging the development of novel seal configurations using state of the art materials. A longer term recommendation was that ERDA should support the development of elastomeric materials that are suitable for use at 350-400°C.

With regard to active electronic components, commercial ceramic tubes are presently available and await a circuit demonstration at elevated temperatures. The current state of the silicon semiconductor art should allow extension of silicon device junction operating temperatures to 320°C. Integrated thermionic devices should reach these and higher temperatures. In the absence of an industrial program, it was recommended that ERDA support the extension of these relatively developed technologies to application at elevated temperatures. Once the devices have been demonstrated to be satisfactory, circuits should be designed with a specific logging tool in mind. A separate study should be carried out to select the most appropriate tool for this part of the program. It was also recommended that ERDA support development directed at the demonstration of satisfactory device design, and suitable fabrication technology for the use of gallium phosphide, gallium arsenide, and silicon depletion mode devices. Passive component development using cermet and metal-silicon or metal-carbon systems for resistance and boron nitride dielectrics for capacitors should be supported with emphasis on establishing fabrication of hybrid circuits. The work in development of new technologies and in passive components should be done in parallel with that on other active electronic components.

The components and detectors subpanel addressed the amount of effort necessary to bring existing tools to a 250°C capability. It was noted that there was a wide discrepancy between the users' experience with tools and the suppliers' rated performance of the tools with regard to their high temperature capabilities. It was recommended that a set of test standards be established by the industry and a system of testing be established for the qualification of logging tools for use in geothermal environments. It was also recommended that ERDA support research into the characterization of the behavior of current materials and components used in logging tools when they are exposed to geothermal environments (pressure, thermal and chemical). These studies should be supplemented by a detailed failure analysis and wide publication of the results.

Finally, it is recommended that ERDA support a program that would address the optimization of electronic design, mechanical design, telemetry system selection, and the design of cables and connectors. An analysis showing the advantages concerning cost and reliability that could be achieved by improving one or more of these elements in the logging system would be a valuable guide in planning future work. It is obvious that all types of logging tools cannot be developed in parallel. Some selection of priorities will have to be established to provide the maximum benefit to the industry at the minimum cost.

APPENDIX A
LIST OF ATTENDEES

Geophysical Measurements in Geothermal Wells Workshop
September 17-19, 1975

1. ANDERSON, Ronald A.	Schlumberger Technology Corporation
2. APPEGATE, Dr. James K.	Boise State University
3. ARNOLD, Charles	Sandia Laboratories
4. AXTELL, Lawrence H.	Geothermal Services, Inc.
5. BAKER, Leonard E.	Sandia Laboratories
6. BAKER, Robert P.	Sandia Laboratories
7. BALL, Lawrence	Energy Research and Development Administration
8. BLUM, Dr. Asher	Lawrence Livermore Laboratory
9. CALDWELL, Dr. Richard L.	Mobil Research & Development
10. CARLSON, Richard C.	Lawrence Livermore Laboratory
11. COLP, Dr. John L.	Sandia Laboratories
12. COMBS, Dr. Jim	University of Texas at Dallas
13. CRAWFORD, Gerald J.	Birdwell
14. CROMLING, John	Big Chief Drilling Company
15. CROSS, Robert	Raytheon Company
16. DANESHY, Dr. Ali	Halliburton Services Research
17. DAVIS, Dr. Mark J.	Sandia Laboratories
18. DEPP, Stephen	Los Alamos Scientific Laboratory
19. DEY, Dr. A.	University of California at Berkeley
20. DOLAN, William	Amax Explorations
21. DONALDSON, Dr. Paul	Boise State University
22. DONDANVILLE, Richard F.	Union Oil
23. DUTCHER, Lee C.	U. S. Geological Survey, WRD
24. GARDNER, Dr. Murray C.	Geothermal Explorations Services
25. GARNE, William E.	Rochester Corporation
26. GEARHART, Marvin	Gearhart-Owen Industries, Inc.
27. GERLACH, Terrance M.	University of Arizona
28. GOULD, Dr. Thomas L.	Intercomp Research Development
& Engineering, Inc.
29. GRAHAM, Glenn R.	Core Laboratories, Inc.
30. GREEN, Sidney J.	Terra Tek
31. GRINE, Donald R.	Systems, Science & Software
32. HARVEY, W. William	EIC, Incorporated
33. HAUSER, Dr. John R.	North Carolina State University
34. HAWTHORNE, M. Marion	SIE, Incorporated
35. HIEBERT, Dr. Richard D.	Los Alamos Scientific Laboratory

36. HOWARD, Jack H.	Lawrence Livermore Laboratory
37. HUGHEN, Robert L.	Sandia Laboratories
38. JAFFE, Dr. Leonard	Jet Propulsion Laboratory
39. JAGELER, Alfred H.	Amoco Research Center
40. JOHNS, S. Earl	Gearhart-Own Industries, Inc.
41. JOHNSON, Wade M.	Los Alamos Scientific Laboratory
42. KANE, Marty	U. S. Geological Survey
43. KASAMEYER, Paul W.	Lawrence Livermore Laboratory
44. KELLER, Dr. George V.	Colorado School of Mines
45. KELLY, Ronald D.	Mechanics Research Incorporated
46. KERWIN, Dr. William	University of Arizona
47. KEYS, W. Scott	U. S. Geological Survey
48. KING, Dudley W.	Energy Research and Development Administration
49. KINTZINGER, Paul	Los Alamos Scientific Laboratory
50. LEE, Dr. Tien	University of California, Riverside
51. LEIPER, Robert	Raymond Engineering Incorporated
52. McCORMICK, Dr. Byron	Los Alamos Scientific Laboratory
53. McDONALD, Dr. William J.	Maurer Engineering, Incorporated
54. McGETCHIN, Thomas	Los Alamos Scientific Laboratory
55. McSPADDEN, Dr. William R.	Battelle Pacific Northwest
56. MATHIAS, Kenneth E.	U. S. Bureau of Reclamation
57. MARTIN, Kelsey	Well Reconnaissance, Incorporated
58. MAYER, Robert, Jr.	Well Reconnaissance, Incorporated
59. MILLER, Lowell G.	Aerojet Nuclear Company
60. MITCHELL, F. R. (Sam)	Shell Oil
61. MOSES, Thomas H., Jr.	U. S. Geological Survey
62. NEWSOM, M. M.	Sandia Laboratories
63. NICOLSON, Dr. A. Murray	Sperry Research
64. OVERTON, Harold L.	Petroleum Engineering
65. PERCIFIELD, E. Dyane	Schlumberger Offshore
66. PRESTWICH, Susan	Aerojet Nuclear Company
67. PRINCE, Dr. John L.	Clemson University
68. RANSOM, Robert C.	Union Oil Research Center
69. REITER, Dr. Marshal W.	New Mexico Bureau of Mines
70. REX, Dr. Robert W.	Republic Geothermal, Incorporated
71. ROWLEY, John	Los Alamos Scientific Laboratory
72. SARDA, Dr. Jean Paul	Los Alamos Scientific Laboratory
73. SAWIN, Dr. Fred	Vector Cable Company
74. SCHUSTER, Carl L.	Sandia Laboratories
75. SCOTT, James H.	U. S. Geological Survey
76. SIMMONS, Dr. Gene	Massachusetts Institute of Technology

77. SKALKA, Morris B.	Energy Research and Development Administration
78. SOMERTON, Prof. Wilber H.	University of California, Berkeley
79. STOKER, Roger C.	Aerojet Nuclear Company
80. STROUD, Stanley G.	McCullough Services
81. SULLIVAN, James K.	U. S. Geological Survey
82. SUMMERS, Gerald C.	Simplec Manufacturing Company, Inc.
83. TOMS, Ronald S. H.	Energy Research and Development Administration
84. TRAINER, Frank W.	U. S. Geological Survey
85. UPTON, Joseph W.	Battelle Pacific Northwest Laboratory
86. WALLACE, Ray	U. S. Geological Survey
87. WEST, Francis G.	Los Alamos Scientific Laboratory
88. WOLKE, Roy M.	Dresser Industries, Incorporated
89. WOLLENBERG, Harold	Lawrence Berkeley Laboratory
90. YOUMANS, Arthur H.	Dresser Atlas

100-100000-100000

APPENDIX B
MINORITY OPINIONS
Minority Opinion I

"Representatives of the major service companies participated in the panel discussions and presented a somewhat divergent view as to the availability or potential availability of the required logging services. They pointed out that in the oil industry many wells with temperatures up to and beyond 250°C have been logged with several of the conventional oil well logging services. They strongly assert that such services are in fact available now for geothermal wells if time and advance warning are allowed so there can be planning and preparation as there is in the petroleum industry. They urge that reliability of logging services under adverse conditions is not solely dependent on instrument design but also requires extensive training, coordination and support from the entire organization. Because of these requirements, existing service organizations are best able to develop and provide those logging services not now available.

Service company representatives agreed that economic incentives have been lacking as far as development exclusively for geothermal well logging are concerned. The major service companies assert however that they do wish to cooperate in developing those services which are genuinely needed as opposed to those which are judged to have potential value but have yet to be investigated. It was argued that in many cases the logging companies will in fact develop the needed services at their own expense if, as an incentive, presently available services are bought and paid for at the normal rates wherever those services are applicable."

Dresser Atlas wishes to make it known that all future matters relating to geothermal wells or to ERDA requirements in general are to be coordinated by Mr. G. L. Marquis, Manager of Logging Operations, Dresser Atlas, P. O. Box 1407, Houston, Texas 77001; telephone (713) 784-6215. Mr. Marquis will welcome inquiry and discussions on any related matters.

/s/ Arthur H. Youmans
Vice President
Research and Engineering
Dresser Atlas Div.

Minority Opinion II

- "That ERDA fund an in-depth survey with the following objectives:

Provide a list of geothermal wells that will be drilled in 1976. Include in this list pertinent data on each well, such as location, approximate spud date, depth, expected bottom-hole temperature, hole size, and lithology in the zones of interest. Where possible, include a tentative logging program or a list of the important parameters. To be useful, this list needs to be completed by the end of 1975.

- On a longer-range basis, prepare a forecast of the exploration wells that will be drilled in the U. S. for each year from 1977 to 1985. The exploration wells are only the wells that need to be drilled to define the geothermal reservoirs in the U. S. This forecast should include an estimate of the percentage of wells that will have bottom-hole temperatures that exceed 250°C, 300°C, etc. In addition, the survey should delineate the important parameters that are needed to define the geothermal energy that can be delivered by the reservoir.

The priority list of needed logging equipment, page 22, needs some cost-benefit analysis. It is difficult to conceive that a geothermal reservoir, which inherently must be massive to be economical, needs the latest and most sophisticated logging tools that are aimed at locating small quantities of oil. Are we asking for a microscope to find an elephant? Also, the order of the list does not correlate very well with the order of the parameters on pages 15 and 16. For example, some of the difficult developments listed, such as the borehole Gravity Meter, Nuclear Magnetic Resonance, Microwave Tool, Gamma Spectrometry bring very little benefit when compared to the list of important parameters. Conversely, the Formation Tester mentioned on page 17 is not listed. The Ultra Long Spacing Resistivity (ULSEL), a simple development compared to the Borehole Gravity Meter (both deep investigating devices) has been overlooked in this list.

Finally, the report ignores the least expensive recommendation made during the workshop. That was to prepare a list of wells that will be drilled in 1976 and then contact the service companies to determine what logging services they can provide for these wells. This approach will highlight any technology gaps that may exist. With respect to the technology gap, the report further ignores the capability demonstrated by service companies in providing logging services consisting of Induction, Neutron, Density and Sonic on the Benavides well for Shell. Bottom-hole temperatures on this well exceeded 500°F. Schlumberger also provided the same services on the Bertha Rogers for Lone Star. The point I would like to make is that technology is not the only factor in providing a good service in these hostile environment wells. The field service people

and their preparation for these wells are equally important. The technology gap is not in fact as great as your report states."

Schlumberger Well Services wishes to make it known that all future matters relating to geothermal wells or to ERDA requirements in general are to be coordinated by Mr. John M. Jones, Senior Marketing Engineering, Schlumberger Well Services, P. O. Box 2175, Houston, Texas 77001; telephone (713) 928-2511 Ext. 331. Mr. Jones will welcome inquiry and discussions on any related matters.

/s/ R. A. Anderson
Engineering
Schlumberger Well Services

APPENDIX C
PARAMETERS PANEL
Subpanel I Report

Subpanel Members	
Ron Anderson	Schlumberger Technology Corporation
Leonard Baker	Sandia Laboratories
Jim Combs*	University of Texas at Dallas
Ken Mathias	U. S. Bureau of Reclamation
Gene Simmons	Massachusetts Institute of Technology
Morris Skalka	Energy Research and Development Administration

1. The most important physical parameters to measure on all geothermal wells are:
 - a. Temperature
 - b. Pressure
 - c. Porosity
 - d. Permeability
 - e. Fluid composition and properties
 - f. Flow profile
2. Logging equipment should be designed to operate in the near term to temperatures of 270°C and pressures of 500 bars.
3. Develop the necessary techniques to utilize well cuttings in order to obtain physical parameters. There is a need for a detailed comparison of physical parameters measured on well cuttings with those measured on cores.
4. Research effort is needed in the examination of fractures and cracks and their effects on the physical parameters that are being measured.
5. Drilling and coring of test wells in a variety of geological environments is required for the calibration of geothermal logging devices.
6. Provide research effort dedicated to the measurement of physical parameters, e.g., thermal conductivity, electrical resistivity, sonic velocity (P and S), etc., in the laboratory as a function of temperature, pressure, and salinity to reproduce the in-situ geothermal environment.
7. Gather and catalog data on the physical parameters obtained from geothermal wells.
8. Develop a logging capability to examine geothermal wells under production conditions.

* Chairman

PARAMETERS PANEL

Subpanel II Report

Subpanel Members

Jim Applegate	Boise State University
John Cromling	Big Chief Drilling Company
Tom Gould	Intercomp Research Development & Engineering, Inc.
Jack Howard	Lawrence Livermore Laboratory
Bill McDonald*	Maurer Engineering, Inc.
Sam Mitchell	Shell Oil
Bill Somerton	University of California, Berkeley

A part of this program plan is to list those parameters considered "useful" in connection with the exploitation of geothermal resources, and, furthermore, to prioritize them. What is "useful" depends in part on the objectives one has in mind when considering the possibility of measuring any of these parameters. These objectives can be grouped into three classes:

1. To assess the magnitude--both in situ and usefully recoverable -- of the resource.
2. To evaluate the impact of exploitation of the resource on the environment.
3. To help clarify legal and institutional considerations such as ownership of the resource, for example, where temperature distinguishes a geothermal resource from ordinary well water.

The usefulness of the measured parameters varies with these objectives as well as with the geothermal resource type being considered for exploitation, (i.e., vapor dominated, hot dry rock, etc.). Review of these parameters with respect to the classes of objectives and with respect to the type of resource suggests certain priorities for work. Some parameters are more important than others, and work to assure that they can be dependably obtained should, it would seem, receive higher priority in any program plan.

Some elaboration on the reasoning behind calling attention to the significance of the objectives listed above and of the resource types seems appropriate and perhaps can best be shown by the following illustration.

Everyone wants to know how much energy might be recovered from a geothermal reservoir. For liquid dominated reservoirs, temperature, porosity, and permeability are obviously important parameters. But is the stress state which might control the direction of hydraulic fracturing important? On the other hand, temperature, permeability, and stress state are of primary importance in considering exploitation of a hot dry rock resource.

* Chairman

Parameters to meet objectives (by resource type)

Liquid Dominated Systems

<u>Essential</u>		<u>Important</u>	
A	Temperature (t, d)	Hole Size	
	Formation Depth and Thickness	CD/ CV (= ratio of conductive to convective heat transport)	
	Porosity	Lithology and Mineralogy, including pore geometry and geochemistry	
	Permeability		
	Flow Rate (t, d)		
	Formation Fluid Pressure (t, d)	Relative permeability (of fluid and vapor)	
B	Thermal Conductivity		
	Fluid Composition		
	Fracture Distribution and Orientation		
C	Moduli and State of Stress		

Vapor Dominated Systems

A	Temperature (t, d)	Hole Size	
	Formation Depth and Thickness		
	Formation Fluid Pressure	CD/ CV	
	Permeability	Lithology and Mineralogy	
	Porosity		
	Flow Rate (t, d)	Fluid Composition	
	Fracture Distribution and Orientation	Thermal Conductivity	
B	Moduli and State of Stress		

Geopressured Systems

A	Temperature (t, d)	Thermal Conductivity	
	Formation Depth and Thickness	Hole Size	
	Permeability	CD/ CV	
	Porosity		
	Flow Rate (t, d)	Lithology and Mineralogy	
	Formation Fluid Pressure (t, d)	Relative permeability	
B	Fluid Composition		
C	Moduli and State of Stress		

Hot Dry Rock

Temperature (t, d)	Hole Size
Thermal Conductivity	Lithology and Mineralogy
Formation Depth and Thickness	CD/ CV
Porosity	
Permeability	
Moduli and State of Stress	
Flow Rate (t, d)	
Fracture Distribution and Orientation	

EssentialsImportantMagma (near Magma)

Temperature (t, d)
Thermal Conductivity
Formation Depth and
Thickness
Porosity
Permeability (of
natural or induced
fractures)
Moduli and State of
Stress
Flow Rate (t, d)
Fracture Distribution
and Orientation

Lithology and Mineralogy
CD/ CV

Hole Size

Note: The above are not limited to wireline measurements but include measurements that can be made on rock and fluid samples.

Letters A, B, and C denote relative development priority within the group of essential parameters.

Letters (t, d) denote time and depth reference.

Some specific program planning recommendations are:

1. Discuss in detail the reasons for the importance of certain parameters in attaining certain objectives and assessing resource types.
2. Determine deficiencies in the state of the art of determining parameters required to meet the stated objectives.
3. Perform cost/benefit analysis on correcting recognized deficiencies.
4. Formulate specific near and long term tasks; outlining methods for obtaining parameters and including the following elements:
 - a. Research
 - b. Development
 - c. Field work and testing
 - d. Collection of useful available data
 - e. Dissemination of results.

PARAMETERS PANEL

Subpanel III Report

Subpanel Members

Larry Ball	Energy Research and Development Administration
John Colp	Sandia Laboratories
Dick Dondanville	Union Oil
Terry Gerlach*	University of Arizona
Marty Kane	U. S. Geological Survey
Tien Lee	University of California, Riverside
Tom Moses	U. S. Geological Survey

This subgroup rated many of the initial list of parameters with respect to their "importance" in log investigations on a scale from 1 (most important) to 4 (least important). Qualifications and comments with regard to these ratings are outlined below.

Parameters Rated No. 1

We attempted to place those parameters of greatest importance to exploration, development, and modeling investigations in this category.

1. Temperature and pressure. We unanimously agreed that these parameters should be determined on a routine basis in geothermal wells during exploration and production. It was the opinion of this group that the necessary basic technology exists. Significant objectives for future research with regard to these parameters were concluded to be:
 - a. Improvement of the reliability of essentially existing techniques up to pressures of 0.5 kilobar and to temperatures of 400°C.
 - b. Development of equipment which would allow continuous reading and recording at the surface of downhole temperature and pressure.
 - c. Some research into development of equipment for extremely high temperatures (e.g., 1000°C) and high pressures (e.g., 5 kilobars) should be supported to permit ultimately the temperature and pressure logging of magmatic systems.

* Chairman

2. Fluid Sampling. The consensus of this subgroup was that a determined effort should be made to develop a fluid sampling system which would permit collection of uncontaminated hydrothermal fluids and their dissolved constituents. It was also suggested that the bottom hole pH of geothermal solutions should be measured because of the predominance of hydrolysis reactions occurring between these fluids and wall rocks in geothermal environments. These data would be fundamental to the prediction and solution of the following important problems:

- a. Environmental problems related to questions of disposal and reinjection procedures.
- b. The problem of compatibility between power plant equipment and working fluid.
- c. Geothermometer and modeling problems related to chemical thermodynamics of water-rock interactions.
- d. Feasibility studies of mineral recovery from spent geothermal fluids.
- e. Calculation of and laboratory measurements of parameters such as electrical conductivity, viscosity, heat capacities, etc., needed as input to computer models of the kinetics, chemical thermodynamics, and heat and mass transfer characteristics of geothermal systems.

Emphasis was repeatedly placed on the need to know the chemistry of these fluids in terms of all the major elements and certain isotopes (especially oxygen and hydrogen isotopes).

2. Porosity/Permeability, Especially With Regard to Through-Going Fractures. It was generally agreed that logging technology in geothermal systems must identify the locations (with respect to geologic formations), attitudes, spacings, and apertures of fractures. This information is critical in the exploration for conventional geothermal systems and in the stimulation of hot dry rock systems.

Parameters Rated No. 2

1. Flow Rates. Members of this subgroup frequently pointed out the need for flow rate data in both computer model studies and in the development stage of a geothermal resource. Development programs especially require this parameter from particular formations. It was frequently

mentioned that reliable data for this parameter required extremely accurate measurement of hole diameter.

2. Rock Samples and Mineralogy. This basic geological data are often needed to calculate other parameters (e.g., heat capacity, heat flow, etc.). It was emphasized that such data are considerably more important to geothermal problems than to petroleum problems. Some examples of the special need for mineralogic data in geothermal systems are:

- a. The search for highly fractured zones based on alteration mineralogy.
- b. Mineral alteration zoning studies as a means for predicting directions to and temperatures of heat sources ultimately responsible for the thermal energy.
- c. Interpretation of water chemistry data for clues to thermal history and mineralogy of rocks with which the fluid has interacted.
- d. The design and treatment of fluid to be employed in hot dry rock systems to inhibit water-rock reactions which could lead to fracture plugging by mineral deposition. This procedure is impossible without extensive knowledge of the mineralogy of the formations within which the working fluids will circulate.

Parameters Rated No. 3

1. State of Stress (From Sonic Velocity). The subgroup considered this to be an important variable in hot dry rock systems where the need for fracture stimulation requires knowledge of ambient stress conditions. While not generally of high importance, it was pointed out that it may become so in terms of legal ramifications due to possible seismic hazards induced by geothermal development.
2. Thermal Conductivity, Heat Capacity, Electrical Conductivity, Fluid Viscosity, and Fluid Density. The subgroup considered these parameters to be important but agreed that there was no need to measure them in every well. Many requirements can be satisfied by reliably calculating or measuring them in the laboratory. However, indirect determination of these parameters requires good information on rock type and mineralogy, rock lithology, and fluid composition, temperature, and pressure.

Parameters Rated No. 4

1. Natural Radioactivity, Magnetics. Measurement of these parameters were considered to be important only in special circumstances and not typically in need of measurement.

PARAMETERS PANEL

Subpanel IV Report

Subpanel Members

Paul Donaldson	Boise State University
Lee Dutcher,*	U. S. Geological Survey, WRD
Ali Daneshy	Halliburton Services Research
Lin Jaffe	Jet Propulsion Laboratory
Paul Kasameyer	Lawrence Livermore Laboratory
Marshal Reiter	New Mexico Bureau of Mines
Bob Rex	Republic Geothermal, Inc.

The first order of business was the determination of an objective for this subgroup to present to the Parameters Panel.

In general terms, this objective was to establish a research program to accomplish these two major objectives: (1) determination of the factors that affect the output of logging tools and that result in these outputs being peculiar to the geothermal environment; and (2) accurate determination of how to make the measurements in a geothermal environment by coordinating both laboratory and field experiments.

A. How do we achieve the objective?

1. We must collect data from existing wells, including core data, log data, and appropriate formation fluid data.
2. We must identify the dissimilarities observed in logs of "typical" geothermal terrains and "typical" petroleum researched terrains.
3. We must perform laboratory research leading to the ability to identify the causes of observed differences.
4. We must develop methods and techniques which will enable us to make valid measurements of both major and minor parameters listed by the workshop panel on parameters.

B. What ranges of pressure, temperature, and fluid characteristics do we need to examine to accomplish Items 1 through 4 above? Near-term temperatures to 260°C, pressure to 7000 psi, dissolved solids up to 25% by wt. and including dissolved gases such as hydrogen sulfide and CO₂; long-term temperatures to

* Chairman

400°C, pressure to 20,000 psi. Fluid characteristics the same as for the short range.

- C. We need to determine physical parameters using several techniques or methods other than logging, e. g. :
 - 1. A down-hole formation fluid sample.
 - 2. In situ permeability determinations through simulation in the laboratory, using in situ state formation fluids at in situ temperatures and pressures.
- D. We need to consider the use of long-spacing tools and multibore hole logging techniques in order to achieve greater formation penetration. It would be especially desirable to be able to detect fractures beyond the well bore.
- E. A handbook of significant parameters and their ranges for different geological environments would be of little use in extending the present state-of-the art; however, it would be extremely important to establish an information data bank that would be readily accessible to all researchers and operators.

It was the general consensus however, that a free exchange of information will not be possible except for release on a person-to-person basis because much information is considered proprietary and release will be on a person-to-person basis only.

PARAMETERS PANEL

Subpanel V Report

Subpanel Members

Glenn Greham	Core Laboratories, Inc.
Bill Harvey	EIC, Inc.
George Keller*	Colorado School of Mines
Tom McGetchin	Los Alamos Scientific Laboratory
L. G. Miller	Aerojet Nuclear Company
Frank Trailer	U. S. Geological Survey

We elected as a group to discuss needs for geophysical well logging in terms of drilling a wildcat or exploratory drillhole, rather than a production bore. This choice reflected the experience of the subgroup, and our concern with the fact that during the early stages of geothermal development, it will be necessary to get the greatest amount of information out of marginally successful test holes. We felt that the priorities to be assigned logging developments for this application are somewhat different than those for production bores. Three types of information appear to be of special concern.

1. Rock Typing. Many wildcats are drilled in unusual rock or geological settings. In a wildcat, to assist in developing the geological model for a geothermal reservoir, it will be especially important to identify the rocks penetrated by the borehole. This is particularly important if the bore has barely missed a production zone. Items of interest are such things as the identification of alteration halos which often accompany geothermal systems and the age-dating of such alteration.
2. Formation Temperature. There is a strong need for determining formation temperature without resorting to the procedure of waiting for the hole to stabilize. Attention should be given to devising a remote, instantaneous temperature logging system. Such a system might be based on detecting the energy of a thermal neutron flux, or on detecting some temperature dependent diagnostic electromagnetic effect in the rock. Lacking this, some serious thought should be given to determining temperature by keeping accurate records of mud temperature and flow with real-time computer simulation of the thermal history during drilling.

* Chairman

3. Fluid Samples. There is an urgent need to obtain formation fluid samples in a manner which will allow reliable tests for geochemical temperature indicators to be made.

The subgroup noted that nonlogging techniques are of considerable importance in testing wildcats. The importance of having cores and cuttings cannot be overstated. These are required to verify log responses and for use in lab studies to develop empirical correlations between log measurable parameters and parameters which are necessary in characterizing the rock. At present, commercial facilities for doing such tests at geothermal temperatures are not available. Priority should be given to the development of such equipment.

Development of mud logging to detect gases that indicate geothermal activity is warranted.

APPENDIX D
HIGH TEMPERATURE TECHNOLOGY PANEL REPORT

Cables, Connectors, and Seals Subpanel Report

Panel Members

C. Arnold, Jr.	Sandia Laboratories
Lawrence H. Axtell	Geothermal Services, Inc.
M. J. Davis	Sandia Laboratories
W. E. Garne *	Rochester Corporation
Sidney J. Green	Terratek
Don Grine	Systems Science and Software
Fred Sawin	Vector Cable Co.

The environmental exposure received by electrical cables, connectors, seals, metals, and other materials will be largely determined by the intended application. The three applications that were discussed and the environmental conditions associated with each application are listed below.

<u>Application</u>	<u>Depth (ft)</u>	<u>Temp. Range (°C)</u>	<u>Pressure (psi)</u>	<u>Other Conditions</u>
Exploratory	0-500	0-150	---	
Intermediate Source Evaluation	500-12,000	150-400 ^o	to 20,000	H ₂ O, H ₂ S, NaCl, others.
Reservoir Evaluation	> 12,000	> 400	> 20,000	H ₂ O, H ₂ S, NaCl, others.

For exploratory applications, the subpanel felt that commercially available "off the shelf" cables and seals were adequate. Problems were encountered, however, in the procurement of small connectors (3/8 inch OD) which would fit into the narrow casing pipes used in this application. This was considered to be a relatively minor problem. Such connectors could easily be fabricated using readily available state of the art materials.

There was a consensus that the materials listed below would be used in at least some of the intermediate source and reservoir type applications. Although the temperature capability of the ceramic type cables was quite high, some concern was expressed about the flexibility of these cables and their electrical resistance at elevated temperatures.

* Chairman

<u>Cables and Connectors</u>	<u>Temperature Limit (°C)</u>
Teflon (TFE)	310
Teflon (PFA)	285
Polyarylene	260
Teflon (FEP)	220
Ceramic (MgO, Al ₂ O ₃ , enamels)	600
<u>Seals</u>	
Viton A	200-250
Nitinol with composites	400+
<u>Armor</u>	
MP-35	400+
22-13-5 Stainless	400+
Inconel 625	400+

Seals were considered to be a major problem in geothermal logging applications. As can be seen from the list above, the temperature limit of the best material available (Viton A) is relatively low. Metal to metal seals are superior to organic O-rings, but they cannot always be used in geothermal tools because of certain electrical requirements as well as the need to seal to irregular surfaces.

Several new alloys such as MP-35 are available which are resistant to stress cracking. This particular alloy, however, is quite expensive.

It should be emphasized that the temperature limits cited above are not for continuous use at temperature. It was generally agreed that there was sufficient time to obtain logging data at these temperatures but that there was considerable uncertainty with regard to how long these materials could withstand these temperatures. Even more uncertainty existed with regard to the effect of hydrogen sulfide, steam, and alkali metal salts at elevated temperature and pressure on material performance.

In light of these limitations the subpanel on cables, connectors and seals agreed that ERDA should promote the following activities. These activities can be categorized as near term (0-5 years) and long term (5-10 years).

Near Term Recommendations

1. Procure cables, seals, and connectors made with the best available materials and techniques, and environmentally test these products both in the laboratory and in actual geothermal logging applications. Complete postmortem analyses should be carried out on all materials that fail. In all these tests, the effect of stress should be taken into account. In addition, this study should consider the effects of fabrication as well as materials composition on stress corrosion, hydrogen embrittlement, and general materials compatibility. The agency selected for this project should work closely with cable manufacturers on specific design and quantities.
2. Since seals and connectors were regarded as particularly knotty problems, it was recommended that an effort be initiated to develop novel seal configurations with state of the art materials.

Long Term Recommendations

Research should be sponsored to develop an elastomeric material that would be suitable for service at 350-400°C in a geothermal environment. Such an effort should be undertaken only under the following conditions.

1. After efforts to solve the seal problem by design innovations with state of the art materials have met with failure.
2. After it has been firmly established that such an elastomer does not already exist or is not under development by industry and/or government agencies, a similar research effort should be initiated to search for improved armor materials with qualifications similar to those just stated for elastomeric materials. In addition, consideration should be given to the development of electrical motors capable of operating at 400°C in a geothermal environment.

HIGH TEMPERATURE PANEL

Active and Passive Electronic Components Subpanel Report

Panel Members

Bob Baker	Sandia Laboratories
Asher Blum*	Lawrence Livermore Laboratory
Steve Depp	Los Alamos Scientific Laboratory
John Hauser	N. C. State University
Wade Johnson	Los Alamos Scientific Laboratory
Ron Kelly	Mechanics Research, Inc.
Bill Kerwin	University of Arizona
Bob Leiper	Raymond Engineering
Kelsey Martin	Well Reconnaissance, Inc.
Byron McCormick	Los Alamos Scientific Laboratory
John Prince	Clemson University

The various suggested technologies for providing high temperature devices have been divided into five categories based on the state of development.

Category I - Commercially available devices.

Category I contains the only commercially available high temperature device considered.

Category II - Direct extrapolation of highly developed technologies.

In the second category are devices which represent a direct extrapolation from mature technologies and in which the subpanel has a high degree of confidence in their realization.

Category III - Extrapolation from moderately developed existing technologies.

In category III are the devices which draw from an extensive technology base but require more development effort to attain successful performance.

Category IV - Relatively less developed technologies.

In category IV are grouped those devices which require substantial development effort with a correspondingly higher degree of risk.

* Chairman

Category V - Passive components.

The fifth category contains the passive elements.

No known work is presently being done in the electronics industry toward the extension of technology in any of the above categories, specifically for fabrication or operation of devices at a temperature above 200°C.

Work on items in Category II should first be directed toward the demonstration of device temperature capability. Work in device and circuit design should then be directed toward a specific logging tool circuit requirement. A systems study will be required to identify optimum device and circuit requirements for a cost effective logging tool. The study should address trade-offs in the following areas:

1. Tool reliability
2. Downhole communications systems, i.e., cables, microwave links, etc.
3. Electronic complexity vs. detector (transducer) complexity
4. Analog vs. digital data handling
5. Uphole electronics vs. downhole electronics
6. Tool compatibility and uniformity
7. High temperature operation vs. cooling or insulation

Work in Category III should be directed toward demonstration of satisfactory device design and demonstration of suitable fabrication technology. Work in this category does not depend on Categories I or II and may be started independently.

Work in silicon carbide in Category IV meets a long term goal and would be useful to many broad areas. Thus, it is felt that continued effort in this material should be supported.

Work in Category V parallels Category II.

Within ERDA, work is known to have been done in the following areas:

<u>Area</u>	<u>ERDA Facility</u>	
Silicon Technology	Sandia	Preliminary investigation of circuits and devices at elevated temperatures.
Integrated Thermionic Circuits	LASL	Extensive research in the integrated thermionic circuit technology
Gallium Phosphide and Silicon Carbide	LLL	A moderate amount of research has begun

Category I - Commercially Available Devices

Ceramic Tubes - No active device development required

- Commercially available ceramic tubes will meet the short and long term requirements immediately where high densities of components are not required.
- Ambient temperatures of $> 500^{\circ}\text{C}$.
- The upper temperature limit on the operation of circuits constructed from these devices is set by the performance of currently available, large value capacitors. In most instances, design techniques are available to avoid the use of such large values.
- A recommended option where circuit complexity is modest.

Category II - Direct Extrapolation of Highly Developed Technologies

Silicon Bipolar, Junction Field Effect Transistor, and Metal-Oxide-Semiconductor Technologies

- Junction limit 320°C
- Ambient 245°C - 320°C depending upon power dissipation.
- Intrinsic carrier concentration is the fundamental limit.
- Specialized device design, circuit design, and processing development will be required along specific identified lines.
- The MOS technologies generally have low power dissipation but are less easily applied to linear circuit functions.
- A recommended option to meet short term requirements.

Integrated Thermionic Circuits

- Ambient greater than 600°C
- Extrapolates from a broad base of existing technology, thus encouraging a high degree of confidence in ultimate productibility.
- Currents and voltages will be similar to existing vacuum tube devices (approximately 200 μA per device, 100 volts).
- Typical devices built on 50 mil centers. Resulting circuit component densities will be intermediate between discrete and integrated semiconductor densities. The number of devices per package is presently limited by the number of leads brought out from the package. The potential exists for total integration of active and passive devices.
- A recommended solution for both short and long term temperature requirements.

Category III - Extrapolation from Moderately Developed Existing Technologies

Gallium Arsenide - Metal Semiconductor Field Effect Transistor and Junction Field Effect Transistor Technologies

- Junction limit 500°C
- Ambient 450°C - 500°C depending upon power dissipation
- Intrinsic carrier concentration is the fundamental limit
- Calculated values of the gate current are adequately low for the Junction Field Effect Transistor. Additional work is needed to estimate gate currents in the Metal Semiconductor Field Effect Transistor.
- Metalization and isolation systems exist but require verification at elevated temperatures.
- Recommended as a promising developmental area for extending the operating temperature range of semiconductor devices. Most elements of the required technology have been demonstrated for room temperature operation. Data on material behavior at elevated temperatures are promising.

Gallium Phosphide Bipolar Devices

- Junction limit greater than 625°C .
- Estimated ambient temperature of 575°C - 625°C .
- Material properties are the fundamental limit.
- Estimates of current gain are satisfactory.
- Additional development is required to adopt existing technologies to the fabrication of bipolar devices.
- The metalization system, while similar to that of Gallium Arsenide, represents a more difficult problem.
- Recommended as a promising development area for extending the operating temperature range of semiconductors. Most elements of the required technology have been demonstrated for room temperature operation. Data on material behavior at elevated temperatures are promising. Gallium phosphide p-n-p-n switches have been operated at 500°C .

Silicon Depletion Mode Devices on Insulating Substrates

- Junction limit estimated at 425°C.
- Ambient 350°C - 425°C depending upon power dissipation.
- Intrinsic carrier concentration is the fundamental thermal limit.
- All fundamental parameters are well known.
- A recommended option following a theoretical feasibility study.

Category IV - Relatively Less Developed Technologies

Silicon Carbide

- Junction limit in excess of 600°C.
- The fundamental problem is materials preparation.
- Device fabrication technologies need to be developed.
- Its promise of exceptional durability and high temperature operation renders it an attractive but high risk option.
- A recommendation for developmental work in this material must be tempered by a clear recognition of the difficulties encountered in previous work.

Other Wide Band Gap Semiconductors

- There exist a number of other wide band gap semiconductors which show promise for high temperature application.
- Although these materials have been suggested on occasion for high temperature use, they represent a high risk due to the lack of supporting technology.

Category V - Passive Components

- Promising materials exist for resistors in both discrete and hybrid form for values up to 100 kΩ. Among the most promising systems are the cermet and metal-silicon or metal-carbon systems. Whereas additional verification of the properties of these materials at elevated temperatures is required, it is believed that they will not represent the thermal limit in any circuit including active devices. Development of the technology for fabrication of these resistor systems and verification of their high temperature properties are recommended.

- Boron nitride is a material of exceptional promise for capacitor dielectrics. Discrete devices have been demonstrated to 800°C. Additional development to establish fabrication techniques for hybrid circuits is recommended.
- Large value capacitors can frequently be eliminated from circuits by skilled circuits design. Where this is not presently possible, these are likely to be troublesome components.

HIGH TEMPERATURE PANEL

Components and Detectors Subpanel Report

Panel Members

Gerry Crawford	Birdwell, Div. of Seismograph Service Corp.
Bob Cross	Raytheon Company
Marvin Gearhart*	Gearhart-Owen Industries, Inc.
M. M. Hawthorne	SIE, Incorporated
Wade Johnson	Los Alamos Scientific Laboratory
Bob Mayer	Well Reconnaissance, Inc.
Stan Stroud	McCullough Services, R&D Baroid Division
Gerry Summers	Simplec Manufacturing Company, Inc.

The components subgroup attempted to determine the amount of effort necessary to provide the various logging tools recommended by the Log Interpretation Panel. The panel was comprised of representatives of service companies, instrument companies, and users. The recommendations, including probability of success, assume the cooperation of the companies active in this field. The results are summarized in Table D-I.

The availability and suitability of tools at 250°C is included in this table along with the cost to develop a 250°C capability and the chance of development success. It was felt that the cost of increasing the tool capability to 300°C would increase the 250°C development cost by a factor of 4. No attempt was made to predict the cost and probability of success of developing tools for operation at long term goal temperatures over 400°C.

It was the feeling of the committee that the efforts indicated in Table D-I represent that which is necessary to produce equipment with a reasonable operating life at 250°C or 300°C. Even though some tools are now available for use at temperatures in excess of 250°C, it was generally agreed that this represents a dash or one shot use capability. Special handling is required, and the tool generally requires rebuilding after use. A number of tools use a "Dewar Flask" to insulate temperature sensitive components. Because this limits operating time, it is desirable to design tools to operate without the need of insulation or heat sinks. In those cases where the extension of the technology to higher temperatures is a severe problem, the use of insulation or heat sinking may provide significant cost savings.

*Chairman

TABLE D-I
Logging Tool Development Review

Tools	Suitability at 250°C	Cost to Develop 250°C Capability (\$ x 10 ⁵)	Chances of Success (Percent)
Cables & Heads	R		
Temperature - Continuous & Intermittent	A	1.25	90
Flowmeter (Vane) Hi-Flow	R	2.2	70
Televiewer (Summers)	R	2.0	95
Sonic Velocity BHC (Dewar Flask)	R	2.0	80
YY (Bow Spring) (Dewar Flask)	R	1.8	80
YY Compressed x 4 Bow Spring Cost	R		
Neutron	R	1.0	
Borehole Gavimeter (Dewar Flask)	N	10.0	75
Nuclear Magnetic Resonance	N	10.0	50
Natural γ Spectrometer (Dewar Flask)	R	2.5	80
Neutron Generator	N	2.0	60
Resistivity - Conventional	R	1.0	90
Induction	R	4.5	90
Focused	R	2.9	90
Fluid Sampler (Borehole)	R/N	1.5	75
Microwave Tool (Dielectric)	N	6.0	75
Clocks (50 hr) - Mechanical	R	1.0	90
Electronic (Dewar Flask)	R	0.6	90
Pressure (± 0.1 psi)	N	3.0	80
Mechanical Caliper - Acoustic	R	2.0	90
3-arm	R	1.0	90
4-arm	R	2.0	90
Dipmeter - 3-arm	R	1.0	80
4-arm	N	2.5	80
Magnetometer & Magnetic Susceptibility (More specs needed)	N		?
Far Out Tools:			
Thermal Conductivity			?
Photo Electric - Gamma gamma			?
Separate Convection & Conduction Heat Flow			?

At 4 x estimated cost most tools could be raised to 300°C.

These figures also assume cooperation of companies active in the industry.

Letter Coding: N - not presently available

 R - needs reliability improvement

 A - available

Note: Listing order corresponds to that of Table I.

Comments on the High Temperature Technology Panel Sessions

Marvin Gearhart, in a subsequent meeting of the full panel, recommended that a set of performance standards, test standards, and a system of testing be established by the industry for the design and evaluation of logging tools. Each manufacturer could either submit his equipment to an independent laboratory or test it in his own laboratory in the presence of impartial experts. This would allow verification of published performance criteria for each tool or component. In event of a failure or if the test procedure required testing to destruction, the results of the postmortem could be made available to others in the industry without revealing proprietary information. Collection of these data would be extremely useful to the logging industry and should be supported by ERDA.

It became quite obvious by the end of the workshop that the electronic design, mechanical design, telemetry system selection, and the design of the cables and connectors are highly inter-related. A systems study to show the advantages in cost and reliability that could be achieved by optimizing the interrelated use of these elements in the logging system would certainly be worthwhile. This workshop was unable to achieve this type of systems analysis in the time allotted. A smaller group comprised of experts in the various aspects of geothermal logging should be assembled by ERDA to carry out this review. It is obvious that all types of logging tools cannot be developed in parallel. Some selection must be made in order to provide maximum benefit to the industry at minimum cost.

It was suggested that ERDA support research to characterize the behavior of current materials and components when exposed to the geothermal environment. This could reduce the number of unexpected failures in the field and provide information needed for design or material changes before large scale geothermal logging commences. It was also suggested that a central repository be established to store and disseminate information on component and material performance under various field conditions. There is at present a great lack of hard data on performance of various devices. Industrial practice generally consists of replacement of failed components without a thorough failure analysis. This procedure has been quite satisfactory in the past, but when moving into a new thermal and chemical threat regime, component development can be accelerated by careful failure analysis and prompt dissemination of the results to the industry. Again, it should be pointed out that with ERDA support, these detailed analyses can be made and proprietary information protected. The Government Information Data Exchange Program (GIDEP) could be used to implement information exchange covering materials and components.

ATTACHMENT
QUESTIONNAIRE

NAME _____
(Will aid Panel Chairmen to interpret results)

Please answer all of the following questions on which you have ideas or opinions. The results will be used by the Panel Chairman in promoting fruitful discussions. They will not be published, but may be used as background information for general summary statements. The completed questionnaire must be turned in at the time of registration to allow time for review by the panel chairmen.

1. What should be the near term temperature capability goal for downhole logging equipment?

2. What components most seriously limit the ability to build high temperature rated tools and what are the limitations?

3. What are alternatives to use of components with higher temperature capability and pros and cons of each?

Insulation _____

Equipment cooling - active and passive _____

Other _____

4. What are some alternatives to use of electrical logging cable for data transmission with pros and cons of each?

Downhole recording _____

Fiber optics data link _____

Sonic data link _____

Pressure pulse transmission _____

Other _____

5. What are some of the special problems of log interpretation related to geothermal formations (e.g., igneous, thermally altered sedimentary)?

6. What are tradeoffs relative to digital vs. analog data transmission in the geothermal environment?

7. What are the tradeoffs relative to multiconductor cable vs. single conductor cable?

8. What are some effects of temperature variation on logging operations (e.g., effect on tool calibration, cable resistivity and length)?

9. What are data bank requirements (e.g., log and core libraries, production information) to support log interpretation and reservoir engineering studies?

10. What suggestions can you make for shortening the normal development time for needed geothermal instrumentation and log interpretation techniques?

11. What are requirements for laboratories and field test facilities to support geothermal logging?

12. Please identify any technique other than standard logging methods for determining geothermal reservoir or well parameters (e.g., simultaneous multiple well measurements, hydraulic tests).

13. What areas do you believe will not receive adequate support without government funding and what government participation would you suggest?

14. What additional organized efforts of this type (workshop, etc.) are needed to support development of geothermal resources?

PARAMETER AND MEASUREMENT EVALUATION

The first attached sheet gives a listing of well parameters vs. geothermal well type. In the narrow column under each well type, please indicate your assessment of the importance of each parameter in evaluating that well type, using the following code:

1. Very useful
2. May be useful
3. Probably not useful
4. Do not know

At the top of the narrow column you may indicate your level of familiarity with each well type according to the following code:

1. Very familiar
2. Somewhat familiar
3. Not familiar

In the wider column, please indicate range of values of interest for each parameter where applicable.

The second sheet gives a listing of well parameters and a coded listing of measurement techniques. In the column provided please list the codes, in order of importance, of the measurement techniques which may be used to determine each parameter.

Parameters	Type of Well									
	Steam (Geysers)		Hot Liquid (Cerro Prieto)		Dry Rock (Jemez Mts.)		Geo-Pressurized (Gulf Coast)		Magma (Yellowstone)	
Level of Familiarity										
Lithography										
Porosity										
Permeability										
Mineral Component										
Natural Radioactivity										
Bedding Plane Strike & Dip										
Formation Depth & Thickness										
Mechanical Properties										
Magnetic Properties										
State of Stress										
Fractures										
Location										
Dip										
Strike										
Thermal Properties										
Formation Temperature										
Thermal Gradient										
Thermal Conductivity										
Pore Fluid Properties										
Salinity										
Density (Liquid and/or gas)										
Dissolved Gases										
Dissolved Minerals										
Depth of Invasion										
Fluid Flow										
Pore Pressure										
Formation Pressure										
Well Geometry and Construction										
Size and Shape										
Deviation										
Location of Liner, Cement, Perforations										

Application of Measurement Techniques

<u>Parameters</u>	<u>Use Codes</u>	<u>Measurement Techniques</u>
Lithology		<u>Electrical Techniques</u>
Porosity		E1 Induction
Permeability		E2 Laterolog
Mineral Component		E3 Electrical Survey
Natural Radioactivity		E4 Microlog
Bedding Plane Strike & Dip		E5 Microlaterolog
Formation Depth & Thickness		E6 Spontaneous Potential
Mechanical Properties		
Magnetic Properties		<u>Nuclear Techniques</u>
State of Stress		N1 Natural Gamma
		N2 Gamma-Gamma
Fractures		N3 Neutron Porosity
Location		N4 Neutron Capture σ
Dip		N5 Neutron Carbon/Oxygen
Strike		N6 Neutron Activation
		N7 Nuclear Magnetism
Thermal Properties		N8 Radioactive Tracers
Formation Temperature		
Thermal Gradient		<u>Acoustic Techniques</u>
Thermal Conductivity		A1 Acoustic Televiewer
		A2 Cement Bond Log
Pore Fluid Properties		A3 Sonic Velocities
Salinity		A4 Sonic Attenuation
Density (Liquid and/or gas)		A5 3D Sonic Logs
Dissolved Minerals		
Depth of Invasion		<u>Other Techniques</u>
Fluid Flow		01 Caliper
Pore Pressure		02 Dip Logs
Formation Pressure		03 Directional Survey
		04 Fluid Flow
Well Geometry and Construction		05 Temperature Log
Size and Shape		06 Pressure Meter
Deviation		07 Gravity Meter
Location of Liner, Cement, Perforations		08 Bottom Cores
		09 Sidewall Cores
		010 Fluid Samples
		011 Drill Stem Test
		012 Transient Well Test
		013 Formation Test

On the back of this page, please describe which you consider to be three major problems in geothermal well logging.

COMPONENTS LIST

Listed on attached sheets are materials and components which are or may be used in logging equipment. Please review the list and indicate next to items with which you are familiar the maximum temperature capability, if applicable. Please use the space provided to list additional items. If you are aware of special problems with particular components or materials relative to the geothermal environment (pressure, corrosion abrasion, etc.) please list these components and describe the problems in the space provided below, using additional sheets if needed.

COMPONENTS LIST - GEOTHERMAL WORKSHOP

<u>Materials</u>	<u>Mechanical, Electro-Chemical & Electro-Mechanical Components</u>
Seals	Connectors
O-rings	Electrical
Gaskets	Other
Lubricants	Cables
Ceramics	Electrical
	Other
Insulators	Relays
Electrical	
Thermal	Meters
Photographic Films	Valves
Packaging Materials	Pumps
Windows	Springs
Optic	Contacts
Acoustic	Switches
Electromagnetic	
Couplers	Batteries
Optical	Timers
Mechanical	Cameras
Fluid	
Heat Sinks	Gyroscopes
Electrical Conductors	Explosives
Other	Detonators
	Other
	Heat Powders
	Other

COMPONENTS LIST - GEOTHERMAL WORKSHOP (Continued)

Transducers

Radiation Detection

- Scintillation
- Chamber (incl. Geiger)
- Semiconductor
- Other

Radiation Sources

- Neutron Generators
- Other

Temperature

- Resistive
- Thermoelectric
- Photoconductive
- Semiconductor
- Other

Pressure

- Diaphragm or Capsule
- Strain Gage
- Capacitance
- Piezoresistance
- Variable Reductance
- Differential Transformer
- Manometer
- Other

Magnetic Field Strength

- Variable Permeability
- Hall Effect
- Flux Gate
- Magnetostrictive
- Other

Flow

- Δ Pressure
- Velocity
- Turbine
- Thermal
- Magnetic
- Momentum
- Other

Motion

- Acceleration
- Velocity
- Displacement
- Solenoids
- Hydraulic Actuators
- Other

Acoustic

- Magnetostrictive
- Crystal
- Variable Reluctance
- Piezoelectric
- Other

Force or Torque

Other

SPECIALIZED COMPONENTS

Please indicate specialized component usage for each tool (e.g., high-powered oscillator; scintillation spectrometer).

Type of Equipment

Specialized Components

Electrical Tools

Induction
Laterolog
Electrical Survey
Microlog
Microlaterolog
Spontaneous Potential

Nuclear Tools

Natural Gamma
Gamma-Gamma
Neutron Porosity
Neutron Capture
Cross Section
Neutron Carbon/Oxygen
Neutron Activation
Nuclear Magnetism

Acoustic Tools

Acoustic Televiwer
Cement Bond Log
Sonic Logs

Type of Equipment

Specialized Components

Other Tools

Caliper

Dipmeter

Directional Survey

Fluid Flow Meters

Temperature Tools

Gravity Meters

Other Equipment

Cables

Cable Heads

Coring Devices

Fluid Samplers

Packers

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