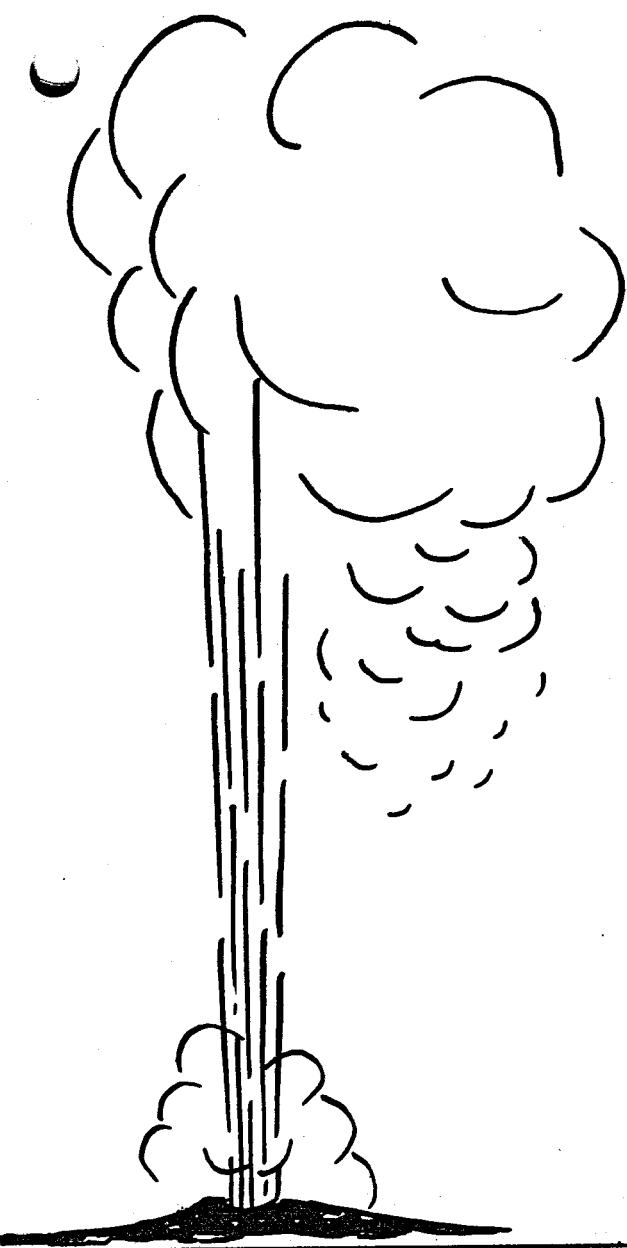


Ar. 367

SAN/1380-1



**RESEARCH AND DEVELOPMENT OF IMPROVED
GEOTHERMAL WELL LOGGING TECHNIQUES, TOOLS
AND COMPONENTS (CURRENT PROJECTS, GOALS
AND STATUS)**

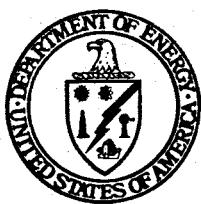
Final Report

By
Michael D. Lamers

January 1978

Work Performed Under Contract No. EG-77-G-03-1380

**Measurement Analysis Corporation
Palos Verdes Estates, California**



**U. S. DEPARTMENT OF ENERGY
Geothermal Energy**

MASTER

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$5.25
Microfiche \$3.00

RESEARCH AND DEVELOPMENT OF IMPROVED GEOTHERMAL
WELL LOGGING TECHNIQUES, TOOLS AND COMPONENTS
(CURRENT PROJECTS, GOALS AND STATUS)

MAC-TR-7047-1
FINAL REPORT

NOTICE

This report was prepared at an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

BY
MICHAEL D. LAMERS

JANUARY 1978

WORK PERFORMED UNDER CONTRACT NO. EG-77-G-03-1380
FOR
U.S. DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY

MEASUREMENT ANALYSIS CORPORATION

36 MALAGA COVE PLAZA / P. O. BOX 1056
PALOS VERDES ESTATES, CALIFORNIA 90274

eb
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

One of the key needs in the advancement of Geothermal Energy is availability of adequate subsurface measurements to aid the reservoir engineer in the development and operation of geothermal wells. This report describes some current projects being sponsored by the U. S. Department of Energy's Division of Geothermal Energy pertaining to the "development of improved well logging techniques, tools and components." The report attempts to show how these projects contribute to improvement of geothermal logging technology in forming key elements of the overall program goals.

TABLE OF CONTENTS

Abstract	iii
Table of Contents	iv
1.0 Introduction	1
2.0 Geothermal Well Logging Parameters	3
3.0 Design and Performance Requirements	7
3.1 Environmental Requirements	7
3.2 Measurement Requirements	9
3.3 Interface Requirement Standards	9
3.4 Reliability and Acceptance Test Requirements and Standards	11
4.0 Current Projects and Their Relation to Program Goals	13
4.1 Materials and Components	15
4.1.1 High Temperature Electronic Components, Circuits and Thermal Protection Devices	16
4.1.1.1 High Temperature Electronic Component and Circuit Development Projects	17
4.1.1.2 Thermal Protection Devices Development Projects	19
4.2 Well Logging Cable-Communications Systems	20
4.2.1 Electromechanical Cable Logging Systems	20
4.2.2 Mechanical Cable Logging Systems	22
4.2.3 Fiber Optic Cable Logging Systems	23
4.3 Cable Head Connector	24
4.4 New Measurement-Sensor Techniques	25
4.5 Improvement of Existing Logging Tools and Sensors	27
5.0 Conclusions	29
6.0 References	31
Appendix A - Detailed Scope and Status of Projects Monitored by MAC.	33
Appendix B - List of Some Commercially Available High Temperature Materials and Components.	53

The high temperature caustic hostile environment combined with the different geological formations and other reservoir parameters associated with geothermal wells has placed severe limitations on the use of existing petrophysical well logging techniques and tools for exploration, reservoir assessment and operation of geothermal energy systems. These limitations combined with the current high demand on the well logging industry by fossil energy development has resulted in a need for a federally sponsored program in improved geothermal well logging techniques, tools and components. The objective of the federal program is to stimulate commercial development of geothermal energy as an economic, reliable and environmentally acceptable energy source.

The specific logging technology needs for Geothermal Energy Development were addressed and itemized at the "Geophysical Measurements in Geothermal Wells Workshop" held in September of 1975 (Reference 1). This workshop resulted in specific programmatic recommendations to assure these needs were met and are summarized below:

- 1) Equipment Development - The development of new and improved logging tools and associated equipment to withstand the very hostile geothermal environment.
- 2) Test Facilities and Wells - The development of specialized facilities, simulation techniques and selection of a set of benchmark geothermal boreholes/wells to aid in the development and evaluation of new and existing tools and interpretation techniques.
- 3) Communication - The establishment of an industry based committee to provide guidance to and periodic assessment for the Department of Energy's Division of Geothermal Energy program management team responsible for this program. Also, improvement in communications with the multitude of different organizations involved directly and indirectly in the Geothermal Logging program.

- 4) Data Bank - The establishment of a data bank of cores, logs, production histories and other geothermal well and reservoir information. Also, data on logging equipment capabilities and limitations should be completed and maintained.
- 5) Logging - Logging of selected geothermal wells should be performed to obtain the data for petrophysical research as well as evaluate equipment capability.

Of the above listed areas, equipment development was given the highest priority. With the results of the workshop as a guideline, the Division of Geothermal Energy (DGE) instituted a program and solicited Industry for assistance to satisfy these needs (reference 2). While unable to tackle all possible logging equipment deficiencies, a selected group of key projects were started during 1976 and are now culminating or starting into a second phase. Measurement Analysis Corporation (MAC) was contracted during the initial phase to provide "Systems Engineering and Technical Assistance" to the Division of Geothermal Energy to assist them in coordinating and managing the various projects and interfacing the projects with the greater well logging and geothermal industry. The overall program management responsibility for this DGE sponsored effort has recently been assigned to one of DOE's laboratories, Sandia Laboratories. As a conclusion to MAC's current project, this final report attempts to present the current projects, their status and show how they all combine into a common program aimed at fulfilling the identified needs of the Geothermal Logging Industry.

GEOTHERMAL WELL LOGGING PARAMETERS⁽¹⁾

While many of the intrinsic parameters to be measured in a geothermal well are the same as those for an oil or gas well, the range of the parameters, their priority and the well environment differ significantly. Geothermal wells are typically much hotter and located in harder formations (i.e., igneous or metamorphic versus sedimentary for oil and gas). Permeability and reservoir size are key measurement parameter objectives for both geothermal and petroleum wells; however, the range of permeability (and associated fracture size) and parameters governing the reservoir size/potential vary significantly. Many of the existing petroleum well logging tools, though not optimum, could provide some useful data for the geothermal industry if they would operate at the higher geothermal temperatures. A very severe deep oil or gas well may reach bottom hole temperature of 260°C (500°F) while many geothermal wells have reported temperatures in excess of 275°C (527°F) with a few reported in excess of 350°C (662°F)(Ref 4). In recent years some development effort has been undertaken by the commercial well logging tool development and service organizations to "harden" some of their logging tools and equipment for operation at temperatures of 205°C (400°F) and upwards to 260°C for these deep oil and gas high temperatures (Reference 5). These tools, designed for the hostile environment deep oil and gas application, are primarily what have been and are being used in attempts to log the more moderate (<250°C) geothermal wells. Even with these moderately high temperature rated tools, most logging attempts in geothermal wells greater than 200°C have been unsuccessful. To overcome this tool deficiency, the wells are cooled using drilling mud or other fluid to perform the logging operation. Cooling of a geothermal well must be considered the lesser of two problems (no measurements versus distorted measurements). Also, in some wells this cooling operation can have a long term adverse effect on the well performance.

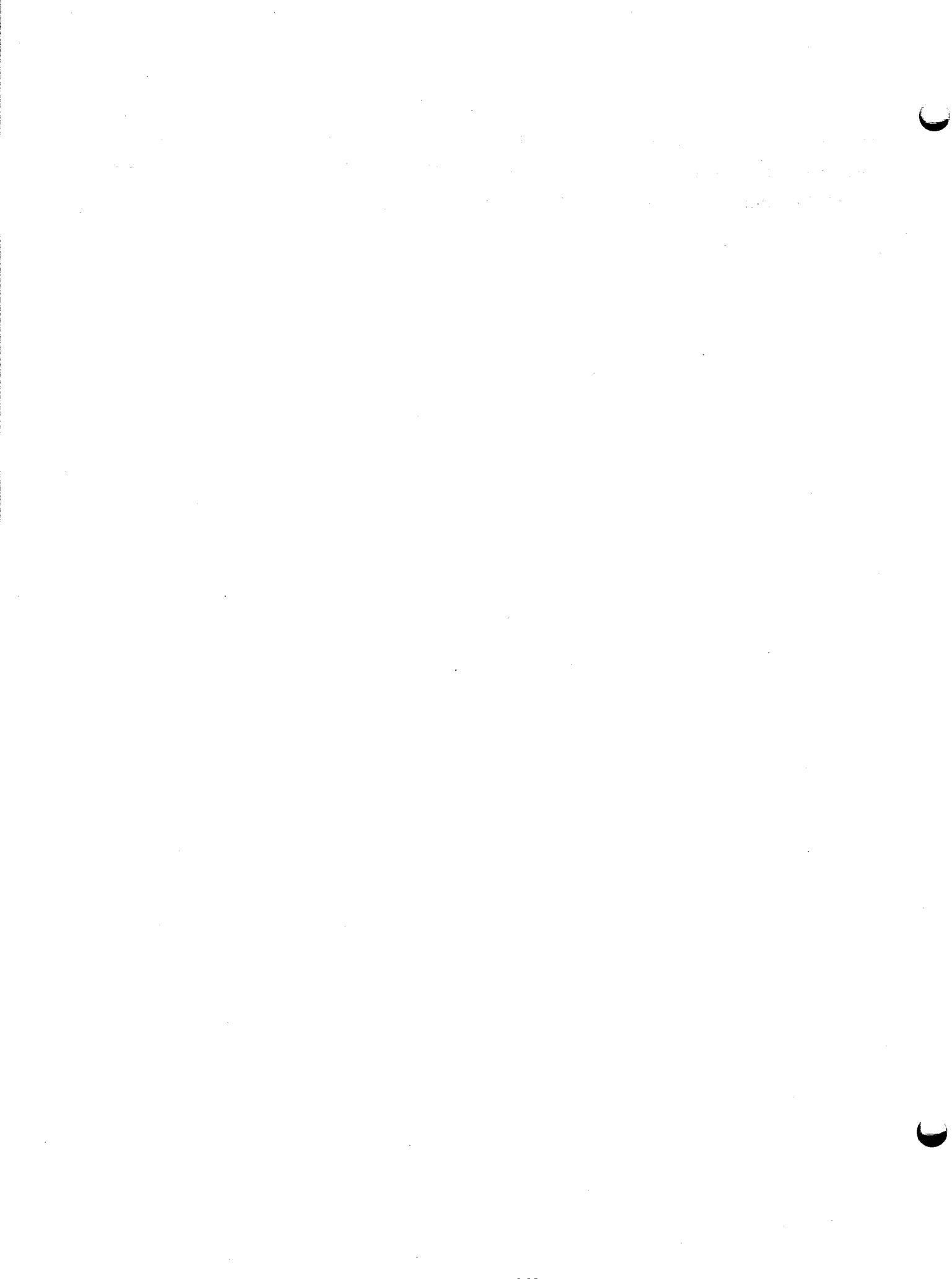
(1) The reader is referred to the Sandia assessment report (Reference 3) for a more detailed overview of Well-Logging Technology and Tools for Geothermal Applications.

The measurement parameters and associated equipment development needed for geothermal well logging, as identified at the 1975 Geothermal Measurements Workshop (Reference 1), were used as the framework for the current national program for improving logging techniques, tools and components. These needs have not changed based on recent interviews with Geothermal Energy Development and Operations organizations. The ordering of parameters is a general indication of ranking, however, the need and importance will vary depending on the specific geothermal reservoir properties and its stage of development (i.e., exploration, reservoir test and assessment or production control/operation). The following list presents these parameters/properties as currently interpreted by MAC's findings:

- 1) Temperature - both in situ formation and wellbore
- 2) Pressure - both in situ formation and wellbore
- 3) Wellbore Flow Rate (velocity), volume flow, mass flow) - for both high flow production and low flow mapping/test applications
- 4) Permeability - and its controlling parameters (e.g., fracture system, fluid viscosity, interconnected porosity, compressibility, etc.)
- 5) Hydrogeochemical Data - total dissolved and undissolved solids and gases, pH, fluid density, fluid chemical composition, fluid compressibility, etc.)
- 6) Well Casing Status - flaws due to corrosion, etc. on both external and internal surfaces
- 7) Porosity - isolated and interconnected
- 8) Geological Properties - formation thickness, orientation, mineral content, discontinuities, etc.)
- 9) Heat Flow and Thermal Conductivity

Many of the above parameters are derived by the measurement of one or more underlying variable parameters which can be related to the desired parameter. Therefore, the priority and need for these underlying variable parameters such as acoustic wave velocity or electrical resistivity will differ depending on the specific well logging measurement method utilized (i.e., electrical and electromagnetic vs radioactivity vs acoustic vs optical vs gravity vs mechanical vs other). The science and technology for relating

the underlying measured parameters to the desired geophysical parameters and properties usually falls under such headings as "Log Interpretation" and "Well Testing" (see References 6 - 12).



3.0 DESIGN AND PERFORMANCE REQUIREMENTS

A fundamental element for the geothermal logging tool and component improvement program is in establishing a set of baseline measurement performance and design criteria requirements. Besides the basic sensor measurement performance requirements such as range, accuracy and resolution, additional requirements are needed to cover environmental conditions, physical interface requirements (electrical and mechanical), reliability and qualification test requirements.

3.1 Environmental Requirements

The one most significant requirement that impacts the geothermal logging tool improvement program is the design operating temperature. Temperature, combined with the high pressure very corrosive geothermal fluid severely limits the design techniques and useable commercially available materials. The range of maximum well temperature varies from less than 200°C to above 350°C at depths less than 4000 meters. However, in the near future (-1985) the major commercial geothermal energy sources in the United States will be from convective (vapor dominated) and liquid dominated hydrothermal reservoirs having well temperatures greater than 240°C (464°F). Unfortunately, the availability of materials needed for improvement of existing well logging tools such as sensors, seals, electronics, wire insulation, fluids/lubricants, motors, solder, pottings, adhesives, etc., diminishes exponentially at temperatures above about 200°C. This is such that at temperatures above 325°C new materials and/or completely different logging techniques will be required. Fortunately, in the near future, very few producing geothermal reservoirs will have wells with bottom hole temperatures in excess of 325°C and the majority will be under 300°C. With this background, the Division of Geothermal Energy's logging tool improvement program set its design operating temperature requirement at 275°C and 7000 PSI with the stipulation that, where economically practical, to design and qualify the tools to 325°C (Ref 13). A far term design goal has not been established; however, a temperature of 400°C and pressure of 12,000 PSI might be realistic (The original PRDA specified 500°C and 20,000PSI). Therefore, with the above qualifying information, the recommended Environmental Design Requirements are:

Operating Downhole Environment (near term ~1985)

Temperature - 275°C (minimum near term goal)
 325°C (preferred near term goal)

Pressure - 7000 PSI maximum

Depth - Down to 4000 meters (~13,000 feet)

Minimum Borehole/Casing Diameter - 6 inches (except for "slim holes" used for shallow (<2000') exploration

Maximum Borehole/Casing Diameter - 14 inches (washouts are reported to 30")

Media - Highly corrosive geothermal vapor or fluid containing large amounts of dissolved salts (brine) and undissolved gases such as carbon dioxide (CO_2), hydrogen sulfide (H_2S) and methane.

Suggested Brine Composition (Reference 14)

NaCl	- 2.5%
H_2S	- 300 PPM
CO_2	- 1000 PPM
Ph	- 5-7

Synthetic Brine Recipe for Testing (Reference 14)

H_2O	- 990 grams/liter
NaCl	- 25.4 grams/liter
NaHCO_3	- 1.94 grams/liter
$\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$	- 2.15 grams/liter
HCl (1M)	- 17.9 ML/liter

Shock and Vibration - TBD

Thermal Shock - The tools should be capable of surviving a thermal shock of $\pm 150^{\circ}\text{C}$ (10°C to 160°C), which might be encountered during initial insertion and removal at the well head.

Thermal Cycling - The tools should be capable of surviving a thermal cycle between 90°C and 275°C and a rate of 80°C per hour.

3.2 Measurement Requirements

The required logging tool measurement performance requirements for determining the geothermal parameters of interest may vary depending on the specific application of the data. One example of a different performance requirement is the manometer (pressure sensor) for a production log application versus a pressure build-up well test application. The production pressure measurement application might be to verify wellbore fluid conditions requiring a sensor accuracy and resolution of about 50 PSI (~1% of full scale) which should be calibrated over the complete temperature range and survive the environment for less than 6 hours. However, the pressure sensor requirements for an interference test require about a 1 PSI accuracy (.01% of full scale) with a very high resolution (.001%) and stability over relatively long periods (months!) in a high but fairly constant temperature. It should be noted that in many applications, temperature data can be provided to correct for known temperature biases to improve the absolute accuracy.

Table 1 gives a list of key geothermal parameters and their measurement performance requirements. The quantitative measurement requirements have been obtained from many data sources, and in some cases a best estimate by the author using limited information. As such, the values should be treated as preliminary until further comment and data are received from the geothermal log interpretation industry.

3.3 Interface Requirements

Diameter - $\leq 3\frac{5}{8}$ inches unless otherwise specified (2 3/4" preferred)

Length - There is no limit on length, however, tools greater than about 12 feet (3.6 meters) should be segmented for handling and transportation.

Minimum ratio of borehole/casing diameter to tool diameter -
1.15 minimum (1.25 preferred)

Electrical Cable Head Interface - (TBD)

Communication Systems - TBD

TABLE 1
KEY GEOTHERMAL WELL SYSTEM PARAMETERS

Parameters			Measurement Requirements (1)	
#	Description		Well Head (2)	Down Hole (2)
a	Temperature - T °C	range - R accuracy - A resolution - Δ	80°C ≤ T ≤ 275°C ±1°C 0.5°C	80°C ≤ T ≤ 325°C (3) ±1°C 0.5°C (4)
b	Pressure - P PSI	R A Δ	P < 1000PSI 10 PSI 1 PSI	P < 7000PSI 1.0 PSI 0.1 to .01 PSI
c	Mass Flow Rate-W lbs/hr	R A Δ	W < 10 ⁶ lbs/hr	W < 10 ⁶ lbs/hr
d-1	Volume Flow Rate-Q _v Gallons per minute	R A Δ	10 < Q _v 2000GPM (4) ±1% of reading	10 < Q _v < 2000GPM (5) ±1% of reading
d-2	Velocity Flow Rate-v (3) ft/min	R A Δ	3.8 < v < 770 ft/min	3.8 < v < 770 ft/min (5)
e	Fluid Density - Y (Specific Gravity Units)	R A Δ	Liquid .7 to 1.2 SGU .01 Gas/steam	.7 to 1.2 SGU .01
f	Quality - X (Percent Vapor by Weight)	R A Δ	0 ≤ X ≤ 100% ±3%	0 ≤ X ≤ 100% (6) ±3%
g-1	Fluid Composition Dissolved Particu- late Parts per million)	R A	1K to 300K PPM	1K to 300K PPM (7)
g-2	Undissolved Parti- culate Particle size & %	Size R A	1μm to 800μm	1μm to 800μm (7)
g-3	Chemical Composi- tion H ₂ S,Na,Ca,Cl,etc	R		(7)
g-4	pH	R A		5 - 9 5% (7)
h	Borehole/Pipe size- D Diameter - inches	R A	5" ≤ D ≤ 11"	5" ≤ D ≤ 11" (8) 0.1"
i	Porosity (Percent voids)	R A		1 to 30% ±2%
j	Permeability - K (Darcys)	R		10 ⁻³ < K < 1
j-1	Intergranular vs Fracture Fracture size,spac- ing and orientation	size spacing orientation		.05" < δ < TBD
k	Compressibility	R A		±10%
l	Vertical Heat Flow Q _h = q/A = kb (μCal/sec cm ²) = HFU's	R A		.5 < Q _h < 20 nominal = 6 ±10% of reading
m	Thermal Conductiv- ity - k (Cal/(sec)(cm ²)(°C/cm))	R A		3(10) ⁻³ < k < 1(10) ⁻² ±10% of reading
n	Vertical Temp Grad- ient - b dt/dL (°C/km)	R A		40 < b < 1000 nominal = 100

1) The parameters and measurement requirements have been obtained, where possible, from technical representatives of organizations working in Geothermal Energy Development and Production. However, in some cases they were obtained as a best estimate by the author. As such, these parameters and requirements will be revised and improved as additional inputs are received.

2) Measurement in two phase flow will be required in many applications.

3) Estimate of maximum down hole hydrothermal temperatures are reported in excess of 370°C (700°F), however 325°C has been selected as desired near term design goal that will cover most hydrothermal wells and 275°C as the minimum acceptable near term goal.

4) A higher resolution may be desired as a technique to measure/detect the two phase transition zone.

5) Based on borehole diameter of 8 inches.

6) The determination of where the two phase region exists down hole is essential.

7) Samples must be obtained and held at operating T and P.

8) Shallow exploration boreholes can range down to 1 inch diameter.

3.4 Reliability and Acceptance Test Requirements

The reliability of a logging tool for use in extreme field environments has been reported to be a problem for the well logging service organizations. Though reported to be qualified in the laboratory for environment, the success rate for the tools in the real field hostile environment has been poor. The reason indicated is the high level of care and maintenance required for the tools to function.

While no reliability or acceptance test criteria or philosophy has been established to date for the logging tool improvement program, it would appear, based on the reported reliability problems, that specifying operating time between failures and qualification at higher than worst case expected environments would be appropriate to assure the tools would perform reliably in the field.

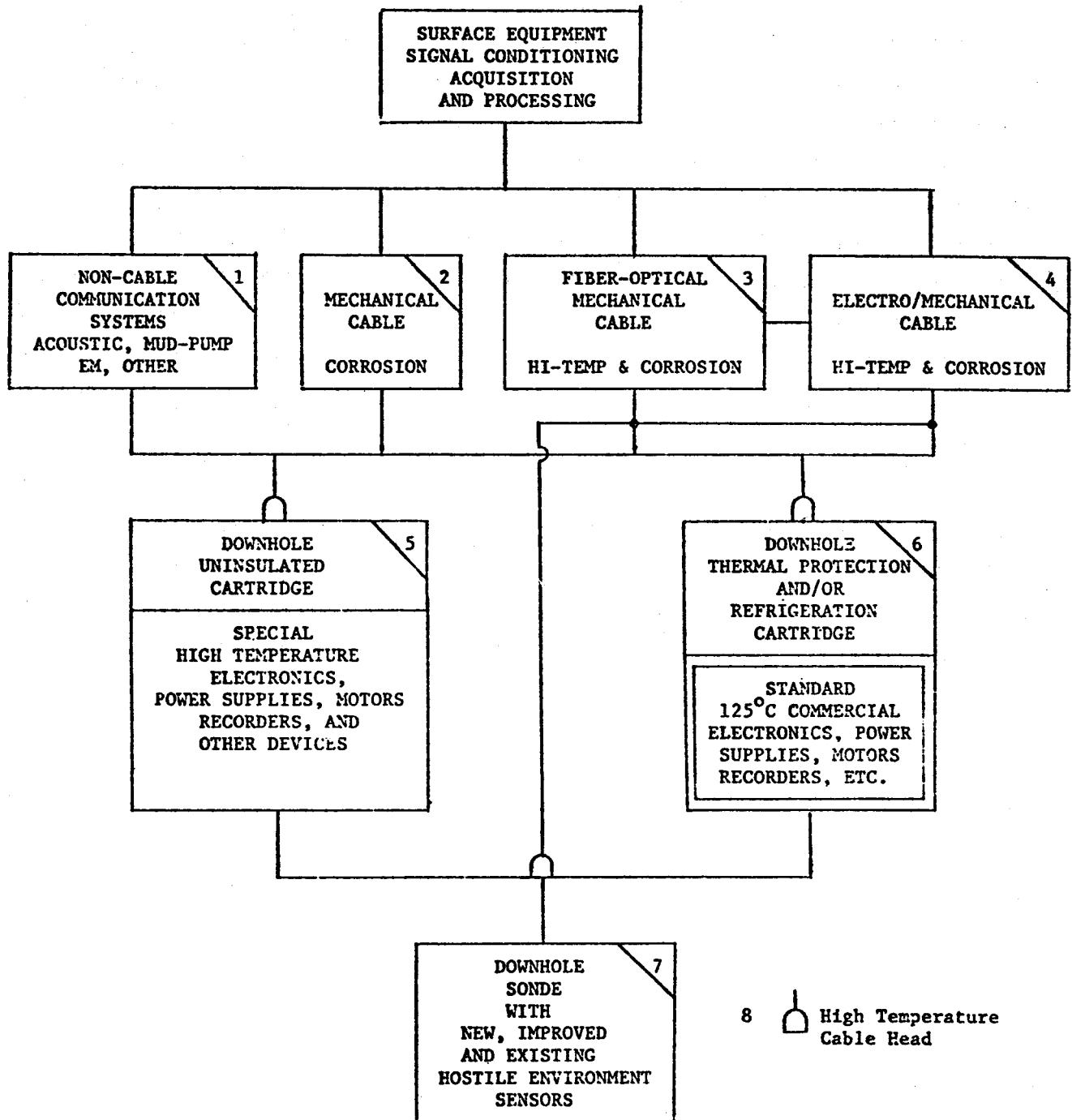


4.0

CURRENT PROJECTS AND THEIR RELATION TO PROGRAM GOALS

Figure 1 illustrates the various alternate configuration paths of Geothermal Well Logging Systems Implementation. Except for the non-cable communication systems (block #1), all other paths are currently being used with some limited degree of success in Hostile Environment Logging (HEL) for fossil energy applications and to a lesser extent of success in geothermal energy applications. Extensive efforts are currently being performed on the development of non-cable communication systems under both commercial and government (DOE) funding (See Ref 15 & 16); however, the majority of the work is aimed at the measurements while drilling application. The DOE-DGE's program for development of improved well logging techniques, tools and components is not involved in the non-cable communication system at this time; however, their program is supporting projects along all other paths.

The following subsection presents all the projects which are currently being sponsored by the Division of Geothermal Energy for the improvement of well logging technology, tools and components. A more comprehensive description and status of the nine projects for which MAC was a technical coordinator and reviewer are provided in Appendix A. The paths and associated technology blocks shown in Figure 1 that each project is attempting to solve are also given. These projects are not considered to be conclusive in solving the geothermal logging needs. They were selected as a starting point. Both new equipment R&D projects as well as follow-on to some of the projects are currently being formulated by DGE's Well Logging Program Management Staff to help solve the geothermal logging industry deficiencies. Besides these specific well logging tool, component and test facility R&D projects, DOE-DGE is currently sponsoring complementary geothermal R&D projects in Reservoir Engineering, Well Log Interpretation, Surface Exploration, Elastomeric Materials, Two-Phase Flow and other special facilities for test and evaluation of materials, components and equipment.



FLOW DIAGRAM OF ALTERNATE KEY CONFIGURATION PATHS FOR GEOTHERMAL WELL LOGGING SYSTEMS IMPLEMENTATION

FIGURE 1

4.1 Materials and Components

One common needed element to all blocks shown in Figure 1 is that of basic design material and components capable of withstanding the high temperatures and/or caustic fluids. These include such items as:

- a) Electronic components, circuit modules and thermal protective devices (passive and active devices, dewars and refrigeration) (blocks 5 through 7)
- b) Electrical-Electronic support materials and devices (substrates, bonding, insulated wire, insulation material and coatings, connectors and feedthroughs, switches and relays, etc.) (blocks 5 through 8)
- c) Elastomeric and resin materials (seals, gaskets, cable insulation packers, flexible tubing, etc.) (blocks 2 through 8)
- d) Structural materials for tool housings, exposed surfaces, cable armor, tubing, etc. (blocks 2 through 8)
- e) Fluids and coatings (for lubrication, hydraulic and heat transfer uses) (blocks 5 through 7)
- f) Motors and solenoids (blocks 5-7)
- g) Other (valves, metal "O" rings, paint, etc.) (blocks 5-8)

As mentioned in Section 3.1, the availability of most of these materials and components diminishes exponentially at temperatures above about 200°C such that at above 275°C to 325°C (527°F - 617°F), new materials and/or different logging systems design techniques will be required.

Except for categories a and c above, there are no known specific DGE projects working on the development of improved materials and components per se. However, there are many projects sponsored by the Division of Geothermal Energy involved in identifying and testing promising materials and components to meet their projects specific needs. Measurement Analysis Corporation, to aid in technical coordination in the projects assigned, has collected data on some of these materials and components that may be useful on the logging tool development projects. A partial list of some high temperature commercial materials

and components together with key performance data such as maximum useable temperature is included in Appendix B to indicate their availability and limits.

4.1.1 High Temperature Electronic Components, Circuit Modules and Thermal Protection Devices

The availability of high temperature electronic components for use in the development of new and improved logging tools is essential to the success of the overall program. While some tools for measuring basic borehole fluid properties such as pressure, temperature and flow have been and/or are being developed to operate in a downhole geothermal temperature environment, the amount of electronics within most existing downhole logging tools is extensive. This is especially true of most formation evaluation tools and high precision borehole parameter measurement tools which are required by the geothermal log analyst and reservoir engineer.

The design technique currently employed by most logging tool developers to "harden" their tools for high temperature applications is to package their electronic circuitry within a superinsulated cartridge (dewar). These dewars consist of metal vacuum barrier bottles that typically incorporate eutectic alloys integral with the electronic thermal packaging as heat sink material to maximize the internal thermal time constant. A major commercial supplier for these dewars is Vacuum Barrier Corporation. Using passive thermal protection techniques will typically provide a thermal protection against a 275°C environment for less than 6 hours; however, one recent dewar -eutectoid system developed for Los Alamos Scientific Laboratory is capable of maintaining a 15 watt internal heat load at under 85°C for 12 hours in a 275°C environment (Reference 17). While utilizing thermal protection techniques such as superinsulated dewars can eliminate and/or minimize the requirement for geothermal logging tool electronics to withstand very high temperatures, there are many tool applications where thermal protection is not readily adaptable or feasible. The reason for this is due to one or more of the following:

- a) Too high a temperature and/or exposure measurement time.
For a given dewar design, the thermal time constant is directly proportional to the outside temperature. This would approximately be equivalent to a one hour reduction for every 25°C increase in temperature. Also, the performance of the commercially available dewars developed for logging tools are limited to about 325°C .
- b) Exposed Sensor Electronics - Most sensors require some amount of electronics to be incorporated directly integral to exposed temperature sensors thereby eliminating the possibility of thermal protection. These electronic components can range from resistive strain gages and capacitative plate elements to preamplifiers, etc.
- c) Other design considerations such as fragility, space limitations, thermal sealing/feedthrough problems, serviceability and reliability.

Therefore, to meet this essential requirement for high temperature electronic components and/or thermal protection of same for geothermal logging tool needs, DOE-DGE is currently sponsoring several projects to meet near term requirements as well as several advanced development projects aimed at meeting long-term requirements.

4.1.1.1 High Temperature Electronic Component and Circuit Development Projects

Electronic components fit generally into two broad categories: active and passive. Active components are those capable of producing signal power gain and switching, such as vacuum tubes and transistors. Passive components are incapable of power gain such as resistors, capacitors and inductors. Typically, most electronic circuitry require both active and passive components. The following projects are currently being sponsored by DOE-DGE's logging tool and component development program.

Project #1 - Evaluation of commercially available and development of improved high temperature (up to 275°C to 300°C) electronic components for hybrid microcircuitry. Specific emphasis is on

thick film passive components and silicon junction field effect transistors (JFET's).

Contractor - Sandia Laboratory

Project #2 - Development and demonstration of high temperature (up to 275°C to 300°C) hybrid integrated circuit modules for geothermal logging tools. Specific emphasis is on circuit modules for temperature, pressure and flow-rate measurement logging tools.

Contractor - Sandia Laboratory

Project #3 - Evaluation of commercially available very high temperature (up to 400°C to 500°C) discrete electronic components and development/demonstration of circuit modules for geothermal logging tools. Specific emphasis is on the development of an amplifier module using wirewound and thickfilm passive discrete components and miniature ceramic vacuum tubes for active components.

Contractor - System Development Corporation

The primary objective of these first three projects is to utilize existing highly developed technologies to design, demonstrate and transfer to industry the means for building completely hardened electronic circuits for downhole geothermal logging sensor signal conditioning and processing.

The first two Sandia Laboratory projects are aimed at completely satisfying the near term high temperature requirements (up to 275°C to 300°C) while the third SDC project is a temporarily near term approach aimed at meeting the very high temperatures (up to 400°C to 500°C) requirements until other highly promising microelectronic technologies can be developed.

Project #4 - Development of thin film passive microelectronic components using chemical vapor deposition (CVD) techniques for very high temperature (up to 500°C) geothermal instrumentation applications.

Contractor - University of Arizona

Project #5 - Development of integrated thermionic components (ITC's) as active microelectronic devices for very high temperature (up to 500°C) geothermal instrumentation applications.

Contractor - Los Alamos Scientific Laboratory

Project #6 - Evaluation and development of promising very high temperature ($>300^{\circ}\text{C}$) microelectronic components. Work on both thin film and thick film passive components and gallium arsenide (GaAs) and Silicon MOSFET active components is being performed.

Contractor - Sandia Laboratory

The objective of these three latter projects is to develop micro-electronic technology for satisfying the long term very high temperature requirements (up to 400°C to 500°C) for geothermal logging tools.

As seen by the number of high temperature component and circuit development projects, DOE-DGE feels that much early emphasis is required in this area to assure their early availability to support the development of logging tools requiring "hardened" electronics. The first four projects listed above are scheduled for completion during FY78 while the latter two projects will continue into FY79.

4.1.1.2 Thermal Protection Device Development Projects

Due to the extensive amount of complex integrated circuitry incorporated within most logging tools, it would be prohibitive to "harden" all the circuitry by redesigning and fabricating special high temperature circuitry. The two alternative paths to using high temperature electronics are to 1) package the electronics in superinsulated dewar for thermal protection or 2) remove the electronics from the tool. As a way to improve thermal insulation capacity of superinsulated dewars, DOE-DGE is sponsoring a project for the development of a downhole mechanical refrigerator. The following is a brief description of this project.

Project #7 - Development of mechanical refrigerator for geothermal downhole well logging sonde electronics.

Contractor - Systems Development Corporation

The objective of this program is to develop a miniature downhole mechanical refrigerator to cool the electronic instrumentation contained in well logging sondes. The downhole refrigerator will provide a minimum of 50 watts of effective cooling in a high temperature (up to 275°C to 300°C) downhole environment. The compressor will be driven by a high temperature electric motor.

4.2 Well Logging Cable-Communication System

By far, the majority of existing commercial well logging tools utilize electromechanical (EM) cable-communication systems (path #4) while the remaining incorporate mechanical cables (wire rope) with tools containing downhole recording devices (path #2). Prototype non-cable communication systems are currently being evaluated (Reference 15) and DOE-DGE under this logging tool development program, is sponsoring a R&D feasibility study of fiber optic logging techniques. However, neither of these latter two techniques using paths 1 and 3 are currently considered ready for commercial field implementation, even in low temperature wells.

4.2.1 Electromechanical Cable Logging Systems

Most high temperature EM well logging cables used today are typically configured with one to seven insulated #20 AWG stranded nickel coated copper conductors that are bound together with a jacket material having a double contrahelical wound corrosion resistant metal armor braid over it. The single conductor and seven conductor are probably the two most common configurations. Due to cost and performance considerations involving multiple sensor tools, much emphasis in recent years has been on the development of logging tools that can operate with a monoconductor cable. Also, recent interest has been observed in the development of well logging cables containing individual shielded twisted pair conductors and/or on coaxial conductors to improve the noise shielding and bandwidth performance.

As a result of the 1975 workshop (Reference 1) it was pointed out that current limitations of EM well logging cables for geothermal application was not clearly identified. While even the best commercially available high temperature EM logging cable utilize elastomer and/or resin insulation materials that have continuous use temperature ratings not exceeding 260°C, it was not clear what the realistic geothermal combined hostile environments limits would be. Therefore, in an attempt to assess the current limits of electromechanical cable for geothermal use, DOE-DGE sponsored the following project:

Project #8 - Experimental evaluation of Geothermal Well Logging cables and development of test facilities for evaluation of electromechanical cables. (See Appendix A for details.)

Contractor - Systems, Science and Software (S³)

The primary objective of this project was to evaluate the performance of currently available EM well logging cables under combined high temperature, tension and flexure environmental conditions. Also included with this initial project was the design of a full environment autoclave for testing cables under combined tension, temperature and geothermal caustic fluid pressure. Construction of such a facility is still under consideration by DOE-DGE.

The results of this evaluation showed the following:

- 1) Available single (mono) conductor cables are capable of operation at temperatures to about 315°C (600°F) for short periods of time only.
- 2) Available multiconductor logging cable are capable of operation at temperatures up to about 260°C for short periods of time only.

Further, it should be noted that the cable tests did not include exposure to caustic geothermal fluids which could degrade their performance limits even more.

These findings on high temperature EM cable deficiencies indicate wire rope mechanical cable via path #2 is the only current approach for logging geothermal wells in excess of about 315°C and if long exposure measurement times (i.e., >4 to 6 hours) are required, the temperature limit is reduced even further. Also, the life of those cables is severely reduced above about 250°C due to extrusion and flow of the insulation.

Based on the test evaluations performed by this S³ project combined with information from the DOE-DGE elastomeric material development program, the "weak link" in current hostile environment EM well logging cables is the unavailability of a high temperature, mechanically and hydrolytically stable insulation material that can be employed in a cabling process.

While use of improved elastomers, resins and films may provide for the development of an EM cable capable of operation up to 325°C, the development of EM cables for use above 325°C will probably require radically different design configurations possibly employing such materials as ceramics or magnesium oxide and/or metal tubing/conduit.

4.2.2. Mechanical Cable Logging Systems

Very high temperature (500°C) corrosive resistant wire rope is currently available for logging systems employing tools with self-contained data recording systems using path #2. There is also currently commercially available pressure and temperature sensor well logging tools with an integral recorder capable of operation up to 370°C (700°F). Also turbine flow meters and fluid samplers rated at 315°C (600°F) operation are available. These tools supplied by firms such as Kuster Company and Geophysical Research Corporation, employ improved mechanical sensors and scribe recorder designs based on the 'Ameranda Gauge' logging tool that was developed many years ago.

Sperry-Sun Well Survey Company has developed a fluid coupled mechanical communication system for a down hole pressure sensor that appears suitable for very high temperature. The system employs a gas filled corrosive resistant small metal tubing for the mechanical cable wherein the gas column is used as the communication link.

The use of a tubing/conduit mechanical logging cable also appears attractive as an alternate technique to supply down hole fluid power to drive motors, generators and/or even direct cooling for a tool refrigeration system. Also, as mentioned in section 4.2.1, such tubing could serve as a protective jacket for electrical conductors.

The DOE-DGE program is not currently sponsoring any specific projects in this category/path, however the high temperature electronics and thermal protection devices could be useful in the development of new self-contained wire rope logging-recorder tools.

4.2.3 Fiber Optic Cable Logging System

As mentioned above, DOE-DGE is currently sponsoring a project pertaining to fiber optic cable logging which is briefly described below:

Project #9 - Feasibility investigation and design study of optical well logging methods for high temperature geothermal applications.

Contractor - Southwest Research Institute (SwRI)

The objective of this project is to explore the feasibility and applicability of fiber optic communication systems and optical sensors for use in geothermal well logging. One of the potentially attractive features of fiber optic cable systems for geothermal logging applications is the intrinsic immunity of the fiber optic conductor to very high temperature, electrical insulation, cross coupling and external noise pick up. However, mechanical buffer insulation is required to protect the fibers from corrosion and "microbends". "Microbends" is a term for local stress concentrations in the fibers which can severely increase the optical attenuation. Work to date on this project to develop a prototype piece of high temperature fiber optic cable has met with limited success.

4.3 Cable Head Connector

One of the key reliability factors in any hostile environment measurement application is the cable connector. The problem is compounded in a geothermal well logging application. Some of the cable head design performance requirements are:

- o Provide a reliable structural and signal connector-seal interface which can be connected and disconnected in the field in a reasonable time.
- o Provide a mechanical fuse or release mechanism which will activate (part) at a predetermined tension in the event a tool gets stuck. Also, both the tool and cable should be protected from the environment after parting.
- o Provide for recovery of the stuck tool by a fishing tool.

Design of well logging cable heads today is usually considered an art learned by trial and error design experience. With the limited high temperature material and components for geothermal applications, new cable head designs must be developed. DOE-DGE is sponsoring the following three projects which are addressing this problem:

Project #10- Design, development and evaluation of a high temperature (up to 275°C to 300°C) electromechanical cable head(s) for geothermal logging tools.

Contractors - Sandia Laboratory and
Gearhart-Owen Industries

Project #16A -Design and laboratory evaluation of a high temperature (up to 325°C) seven conductor electromechanical cable head for a geothermal logging tool.

Contractor - Systems Science and Software

Project #9A -Feasibility design and laboratory evaluation of high temperature electro-fiber optic cable head.

Contractor - Southwest Research Institute

4.4 New Measurement-Sensor Techniques

Using the desired geothermal well and reservoir measurement parameters defined in the 1975 geothermal measurements workshop (Reference 1) as a guide, requests for development of new measurement techniques were solicited from the industry. Upon receipt of various proposals, the following four projects were selected by the Division of Geothermal Energy.

Project #11 - Development of Thermochemical Temperature Indicator Devices for the measurement of geothermal formation temperatures while drilling.

Contractor - Spectro-Systems, Inc.

The engineering necessity of cooling the borehole during the drilling operation impacts the equilibrium temperature near the borehole which can take months after the drilling is stopped to be rebound. Many substantial economic benefits would accrue if a reasonable measurement of formation temperature could be achieved during the actual drilling operation. It is reasonable to believe that the drilling mud temperature in the vicinity of the drill bit approaches the actual formation temperature currently being penetrated. As a possible technique for obtaining this temperature measurement, Spectro-Systems is exploring the feasibility of using a group of materials which can be inserted into and retrieved from the drilling mud which will indicate their maximum exposed temperature.

Project #12 - Study of Neutron-Based, Nuclear Techniques for Measurement of Geothermal Well Parameters. Specific emphasis will center on use of a neutron gaging technique to measure formation temperature.

Contractor - IRT Corporation

As in Project #11 above, this IRT project is also attempting to develop a true formation temperature technique. This proposed technique would provide a measure of the formation about 6 to 10 inches out from the borehole wall. Using this temperature measurement and the temperature in the borehole could provide a means of extrapolating to the true undisturbed formation temperature.

Project #13 - The development of two new borehole logging measurement techniques: one for measuring *in situ* heat flux and one for measuring *in situ* thermal conductivity.

Contractor - Geoscience Ltd.

During initial geothermal reservoir exploration and assessment, a measure of the vertical heat flux is of paramount importance prior to drilling a deep well. To date, there is no direct technique developed to obtain a direct measure of heat flux. Typically what is done is a series of "slim holes" are drilled to a depth of 500 to 1500 feet and the vertical temperature gradient ($b = dt/dz$) is measured. Then, using estimates of *in situ* thermal conductivity, (k), obtained from core samples, etc., the vertical heat flux, $Q_h = kb$ is calculated. This current technique can be subject to significant error primarily due to poor thermal conductivity estimates.

These two new direct *in situ* measurement techniques being developed by Geoscience each present a possible solution for accurate measure of geothermal heat flux.

Project #9B - Feasibility investigation and design study of using passive optical sensors whose output can directly interface to a fiber optic cable. Specific emphasis is being placed on temperature sensors with some evaluation of pressure and thermal (slow) neutron sensors.

Contractor - Southwest Research Institute (SWRI)

This SWRI project is part of their overall project on the feasibility of fiber optic well logging techniques.

4.5 Improvement of Well Logging Tools

In order to meet the near term high temperature (up to 275°C to 325°C) geothermal logging tool requirements, several projects were sponsored by the Division of Geothermal Energy to improve key well parameter measurement tools. Use of existing commercially available high temperature materials, components and sensors is being used to assure a timely development. The three tool improvement projects being sponsored are each using one of the three implementation paths (5, 6, and 7) indicated in Figure 1.

Project #14 - Development and demonstration of improved downhole logging tools incorporating high temperature electronics.

Contractors - Sandia Laboratory and Gearhart-Owen Industries (GOI)

Specific logging tools being improved under this combined Sandia-GOI project are: temperature, flow, casing collar locator, mechanical caliper, pressure @ 1% accuracy, pressure @ .02% accuracy. This project is using the high temperature electronic circuits and cable heads presented in Section 4.1.1.1 and 4.3. To support the field test and demonstration of these tools, Sandia is also developing a complete logging truck/rig.

Project #15 - Upgrade of Acoustic Well Logging Tools for use in Geothermal Applications

Contractor - Westinghouse Electric Corporation

The primary objective of this Westinghouse project is to upgrade acoustic sensor technology such that existing acoustic well logging tools incorporating thermally protected (dewared) electronics will function in a high temperature (up to 275°C to 325°C) geothermal environment. To accomplish this, Westinghouse will develop and evaluate in a geothermal well high temperature acoustic sensors for a Borehole Televiwer (BHTV) tool and an Acoustic Velocity Log (AVL) tool.

Project #16 - Development and demonstration of a Geothermal Logging Tool for measuring temperature, pressure and pressure gradient using no downhole active electronics.

Contractor - Systems, Science and Software (S³)

The primary objective of this S³ project is to develop and determine the performance of a multisensor well logging tool wherein there are no active or passive electronics in the tool except for passive resistive temperature and strain sensitive elements integral with the sensors. High temperature commercially available sensor technology is to be employed.

5.0 CONCLUSIONS

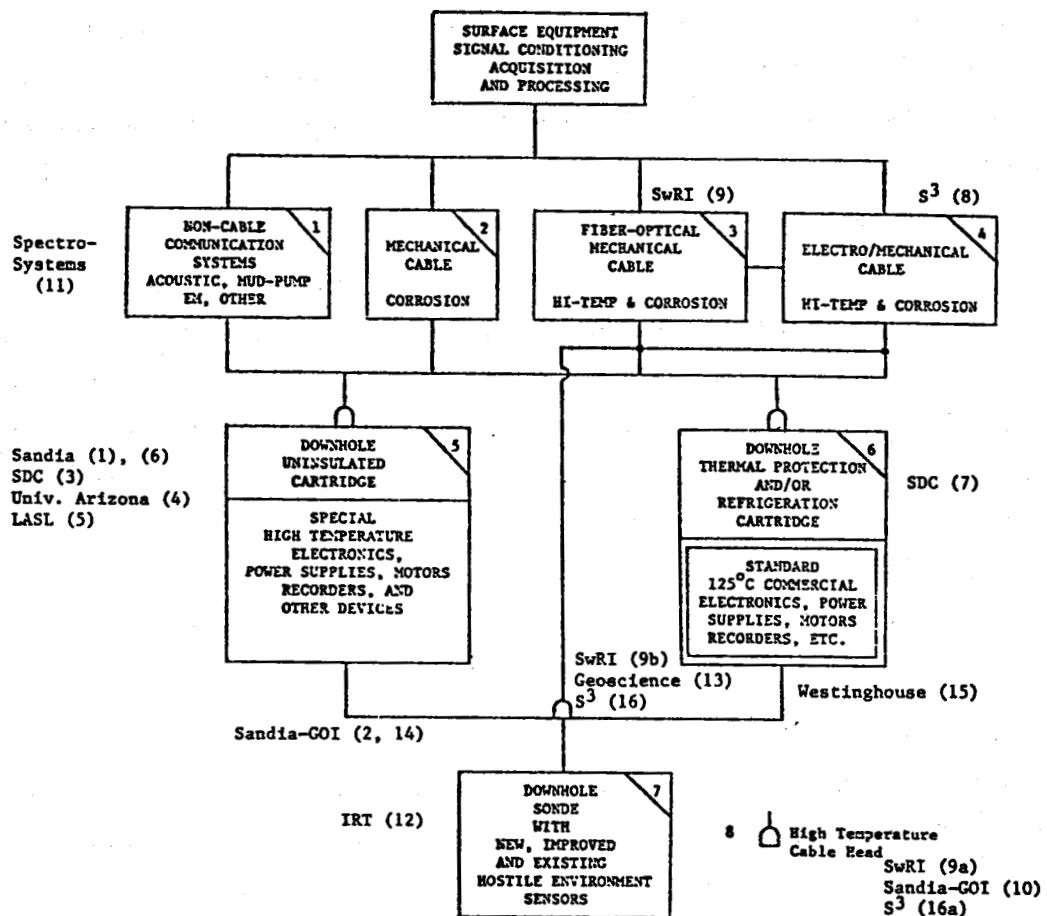
The current projects being sponsored by the U.S. Department of Energy, Division of Geothermal Energy's program for the development of new and improved well logging techniques, tools and components are aimed and organized at meeting both the immediate and far term requirements and needs of the Geothermal Energy Development and Production Industry. Though quite comprehensive from an initial starting point, additional projects and extensions of existing ones are being required to meet the Industry needs. Extensive progress has and is being made in meeting the immediate 'near term' needs. However, the path or paths to meeting the not too distant very high temperature ($>325^{\circ}\text{C}$) down hole measurement requirements will require major improvements and development of new key materials and devices and/or development of radically different logging techniques. Figure 1A below represents the logging system implementation flow diagram wherein the path and block approach for each project presented is indicated.

Major program emphasis to date has been placed on applying existing technology and commercially available materials and components to 'harden' existing logging tools and sensors to meet the near term high temperature minimum goal of 275°C . These federally sponsored projects in developing high temperature electronics, improved thermal protection devices, sensors and evaluation of materials to withstand the caustic geothermal fluid environment are complimentary to the observed commercial logging industry sponsored projects to 'harden' their existing tools by use of available thermal protection dewars.

Besides improvement of existing logging tools and sensors, projects are also being sponsored to develop new measurement systems for key geothermal parameters. This includes systems for measurement of in-situ formation temperature, heat flow and thermal conductivity, and formation temperature while drilling. Additional sensor development efforts are possibly required for measurement of two phase flow, casing inspection, fluid sampling/analysis and permeability/fracture zone detection and assessment.

Current effort to meet the higher temperature ($>325^{\circ}\text{C}$) requirements

are underway, however additional planning, analysis and Research and Development projects are required to meet this major technology void in current well logging systems. Additional improved very high temperature thermal protection devices and down hole data acquisition systems will be required. Also, special test facilities such as caustic high temperature autoclave to support these Research and Development efforts will be required.



FLOW DIAGRAM OF ALTERNATE KEY CONFIGURATION PATHS FOR GEOTHERMAL WELL LOGGING SYSTEMS IMPLEMENTATION SHOWING PATHS BEING FOLLOWED BY SPECIFIC PROJECTS.

FIGURE 1A

6.0 REFERENCES

1. Baker, L.E.; Baker, R.P.; Hughen, R.L.; "Report of the Geophysical Measurements in Geothermal Wells Workshop"; Sandia Laboratories Report #SAND 75-0608, December 1975.
2. Program Research and Development Announcement For Development of Improved Geothermal Well Logging Tools and Components, ERDA-DGE Document #PRDA-76-2.
3. Baker, L.E.; Campbell, A.B. and Hughen, R.L.; "Well Logging Technology and Geothermal Applications - A Survey and Assessment With Recommendations", Sandia Laboratories Report #SAND 75-0275, May 1975.
4. Overton, H.L. and Harold, R.J.; "Geothermal Reservoir Categorization and Stimulation Study"; Los Alamos Scientific Laboratory Informal Report #LA-6889-MS; July 1977.
5. Martin, C.A. and Rust, D.H.; "Hostile Environment Logging", The Log Analyst; March-April 1976.
6. Telford, W.M.; Goldart, L.P.; Sheriff, R.E. and Keyes, D.A.; Applied Geophysics; Cambridge University Press; 1976.
7. Schlumberger; Log Interpretation, Volume I - Principals; Schlumberger Limited, 1972.
8. Schlumberger; Log Interpretation, Volume II - Applications; Schlumberger Limited, 1974.
9. Schlumberger; Production Log Interpretation; Schlumberger Limited, 1973.
10. Well Logging Methods - Lesson 3 in "Lessons in Well Servicing and Workover", Petroleum Extension Service of the University of Texas, 1971.
11. Earlougher; Advances in Well Test Analysis ; Monograph - Vol 5, Society of Petroleum Engineers, AIME 1977.
12. Mathews, C.S. and Russell, D.G.; Pressure Build-up and Flow Tests in Wells ; Monograph - Vol I, Society of Petroleum Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers (SPE-AIME), 1967.
13. Summary and Minutes of the Second Geothermal Logging Steering Committee Meeting held June 28, 1977 at Sandia Laboratory.
14. Visual Aids for Second Technical Direction Meeting - Geothermal Elastomeric Material Program; January 19, 1977 prepared by L'Garde Inc.

15. McDonald, W.J.; "Borehole Measurements While Drilling - Systems and Activities", Maurer Engineering Incorporated Report #TR77-14, June 1977.
16. Geothermal Down-Well Instrumentation - Final Report; Sperry Research Center; Report #SCRC-CR-77-11, April 1977.
17. Information received from Mr. Bert Dennis of Los Alamos Scientific Laboratory (LASL). This passive thermal protection unit was developed for LASL by Systems Development Corporation (SDC). The unit incorporates a metal superinsulated dewar built by Vacuum Barrier Corp. for SDC who designed and developed the entectic heat sink and associated thermal packaging.

APPENDIX A

**DETAILED DESCRIPTION AND STATUS OF DOE-DGE PROJECTS ASSIGNED
TO MAC FOR REVIEW AND COORDINATION**

Project #3

"DEVELOPMENT OF AN ULTRA HIGH TEMPERATURE ELECTRONIC AMPLIFIER"

Contractor - System Development Corporation (SDC), formerly MRI
Santa Monica, California

Principal Investigator - Ron Kelly, phone 213-829-7511

Contract Duration - 15 months (9/76 thru 2/78)

Contract - #E(04-3)-1330

The objectives of this project are the following:

1. To identify, evaluate and report on existing commercially available active and passive discrete electronic components and support materials which will operate up to 500°C (932°F).
2. To design, develop and demonstrate an instrumentation amplifier module incorporating commercially available discrete components for use in very high temperature (up to 500°C) down hole geothermal measurement applications.

The instrumentation amplifier is considered the key electronic circuit module used in down hole logging tools. By successful development of this key module, DOE-DGE and SDC will demonstrate and provide logging tool designers the current technology and component sources required to develop complete signal condition circuitry to operate in ultra high temperature geothermal environments not previously considered readily available.

This program is complimentary to several DOE-DGE ultra high temperature microelectronic component development programs pertaining to advanced thin film passive networks (University of Arizona) and integrated thermonic circuits (LASL) and the moderate temperature (275°C) electronic components and systems demonstration program (Sandia).

This specific project is an extension of a previous ERDA (DOE) contract (#E-04-3-1184) with SDC (MRI) to develop an amplifier incorporating ceramic vacuum tubes for operation in a 250°C environment. The design performance specifications for the new amplifier module are shown in the accompanying table. The project is divided into the following major tasks:

1. Survey and evaluation of commercially available promising components to determine temperature coefficient, stability and reliability over the operating temperature range (0° to 500°C). This includes ceramic vacuum tubes, resistors, capacitors, inductors, lead and insulation material, electrical feedthroughs, lead bonding, etc.
2. Detailed design and analysis of promising amplifier circuits.
3. Development and breadboard testing of selected amplifier.
4. Packaging design, fabrication and evaluation of amplifier module.

The findings of all tasks will be documented in a final report.

Project Status

This program is currently completing task 4, having successfully completed all previous tasks. The current design incorporates miniature ceramic triode tubes, wirewound and thick film resistors. No capacitors are required. System testing to date has identified some component reliability, packaging interconnect and heat dissipation problems. Solutions to these problems are currently being implemented. Final evaluation will include testing with a 15,000 feet length of well logging cable while the amplifier is subjected to high temperature. To date, extensive information on ultra high temperature electronic components and support material, together with design and performance of amplifier circuits has been obtained.

PRELIMINARY SPECIFICATIONS FOR AN ULTRA HIGH TEMPERATURE AMPLIFIER

ELECTRICAL PERFORMANCE	
Input Characteristics	
Input connection	Differential or Single Ended
Allowable sources	
voltage	0 to 20 millivolts
resistance	120 to 1000 OHMS
capacitance	10 to 100 PF
inductance	10 to 100 MH
Output Characteristics	
Output connection	Single ended connected to circuit ground
Maximum linear output (1%)	5 volts
Line driving capability	15,000 feet of standard logging cable
Residual noise	5 millivolts
Transfer Characteristics	
Gain	40 DB
Gain accuracy	1%
Gain stability	Better than 1DB with temperature and time
Frequency response ($\pm 1DB$)	
max. cable load	0 to $> 1kHz$
no load	0 to $> 60 kHz$
Linearity	$\pm 1\%$ of best straight line
Power (at the amplifier)	
B+ and B-	20 MA at 200 volts
Filament	210 MA at 35 volts
PHYSICAL CONFIGURATION	
The amplifier is packaged in a cylindrical high pressure housing to protect the internal elements in the event of a downhole leak of the sonde.	
Diameter	- 2.95 inches
Length	- 7.7 inches (housing only) 9.5 inches (including connections)
Weight	- 7.5 lbs
Connectors	- welded lugs for input and outputs plus spare lugs for electrical through-cut.
OPERATIONAL ENVIRONMENT	
Operating pressure	10,000 PSI
Operating Temperature	0 to 500°C
Shock and Vibration	Perform in well logging environment

Project #4

DEVELOPMENT OF HIGH TEMPERATURE PASSIVE ELECTRONIC COMPONENTS FOR
INSTRUMENTATION OF IMPROVED GEOTHERMAL LOGGING TOOLS AND COMPONENTS.

Contractor - University of Arizona
Solid State Engineering Laboratory
Tucson, Arizona

Principal Investigator - Leonard Raymond, phone 602-884-1802
Contract Duration - 24 months (10/76 - 9/78)
Contract - EY-76-S-02-4081

The development of improved geothermal well logging tools and components requires electronic instrumentation circuits capable of functioning at temperatures as high as 500°C (932°F). Regardless of the type of active devices used in these circuits (integrated thermionic devices, semiconductor devices, ceramic vacuum tubes, etc.), passive devices such as resistors and capacitors will also be required.

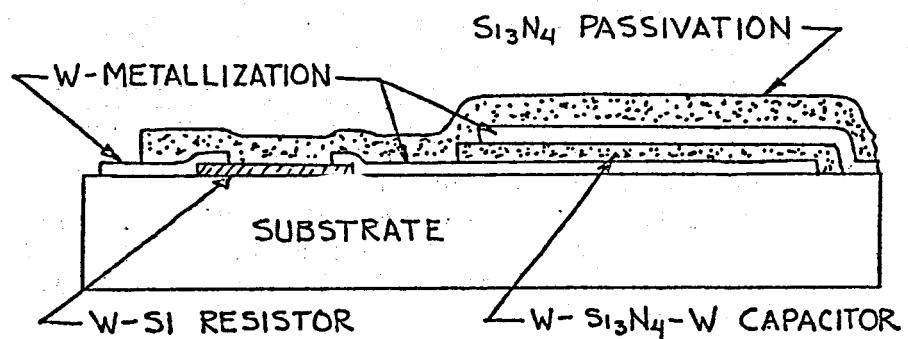
The investigators intend to develop resistors, capacitors, metallization and passivation capable of operation from 25°C to 500°C with thermal coefficients well below 100 parts per million per degree centigrade, and electrically and physically compatible with all active devices now under consideration. Chemical vapor deposition (CVD) techniques will be used because of the great flexibility of control they offer. Major emphasis will be on tungsten-silicon resistors and tungsten/silicon nitride capacitors. Both silicon and sapphire substrate materials will be evaluated. Also other promising dielectrics such as boron nitride will be evaluated. Tungsten-silicon resistors have already shown remarkable performance. The upper Figure on the accompanying page depicts the material configuration of a thin film microelectronic passive circuit.

The program is divided into the following tasks.

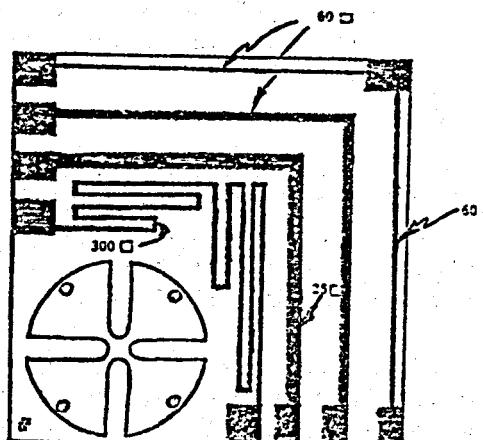
1. CVD Process Facility Modification
2. Materials Development and Analysis
3. Component Development and Testing
4. CVD Process Optimization

Status

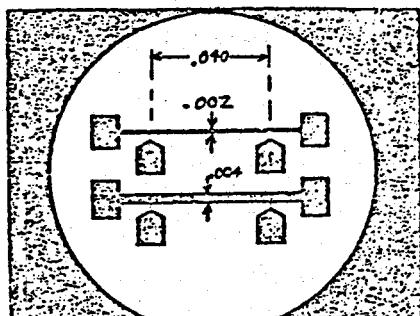
Task 1 is completed and tasks 2 and 3 are proceeding successfully. Both resistors and capacitors have been made and data to date indicates the design goals will be met. A third order butterworth low pass active filter R-C network has been selected for development and demonstration of interconnect and integration techniques. It is currently scheduled to sufficiently complete the characterization of the process, materials and resulting components and present a one day industry briefing on component performance and processing techniques in April of 1978. The lower 3 figures on the accompanying page show the thin film test patterns being utilized in the project.



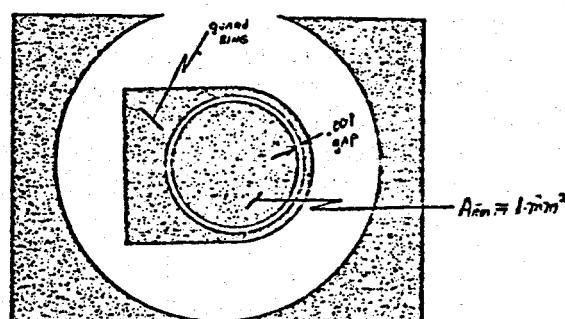
INTEGRATED PASSIVE COMPONENT SYSTEM



RESISTOR TEST PATTERN



CONDUCTIVITY TEST PATTERN



DIELECTRIC TEST PATTERN

Project #7

DEVELOPMENT OF A MECHANICAL REFRIGERATOR FOR GEOTHERMAL WELL LOGGING
SONDE ELECTRONICS.

Contractor - Systems Development Corporation (formerly MRI)
Santa Monica, California

Principal Investigator - Jun Fukazawa, phone 213-829-7511

Contract Duration - 9 months for Phase I (9/14/76 - 6/13/77)
12 months for Phase II (11/77 - 11/78)

Contract - #EY 76-C-03-1309

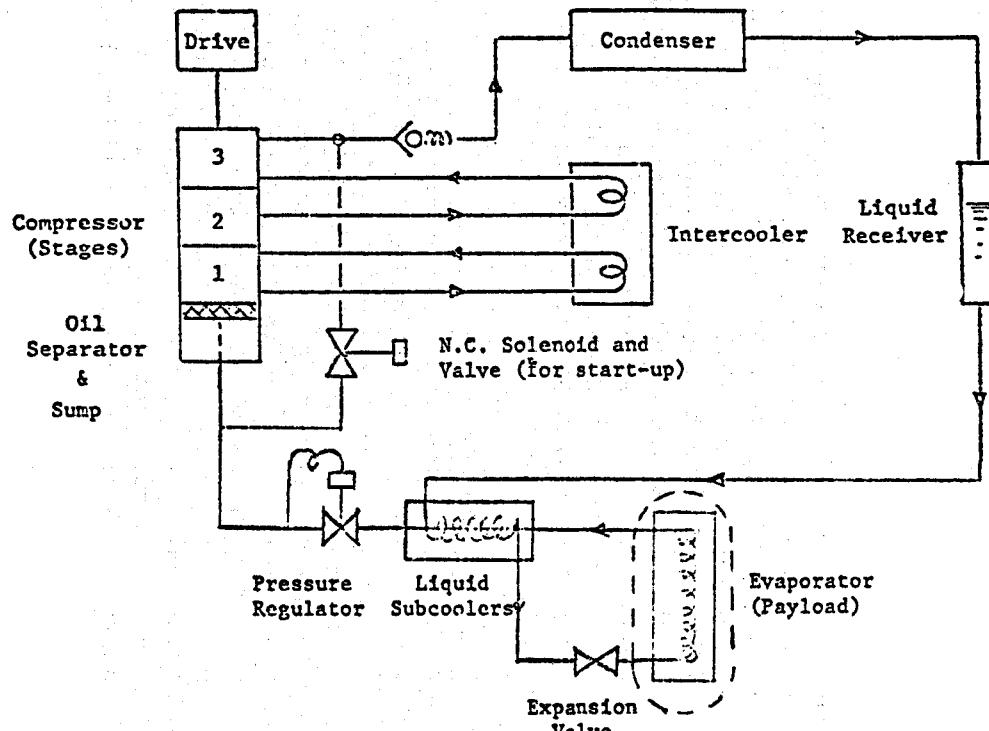
The objective of this program is to develop a mechanical refrigerator to cool the electronic instrumentation contained in well logging sondes used to measure the physical characteristics of geothermal wells. The program calls for the development of a water vapor refrigeration cycle reciprocating compressor. The refrigeration cycle is designed to provide a minimum of 50 watts effective cooling to an electronic package with a base plate temperature of 125°C. The compressor is driven by a 1/4 HP 3 phase induction motor.

The envelope dimension of the compressor section is 3 inch OD. This final diameter is to be under 3 5/8" and the length, including motor, less than 6 feet. The refrigerator system is to be designed for greater than 100 hours continuous operation. A preliminary refrigeration schematic and physical layout of the system are shown on the accompanying page.

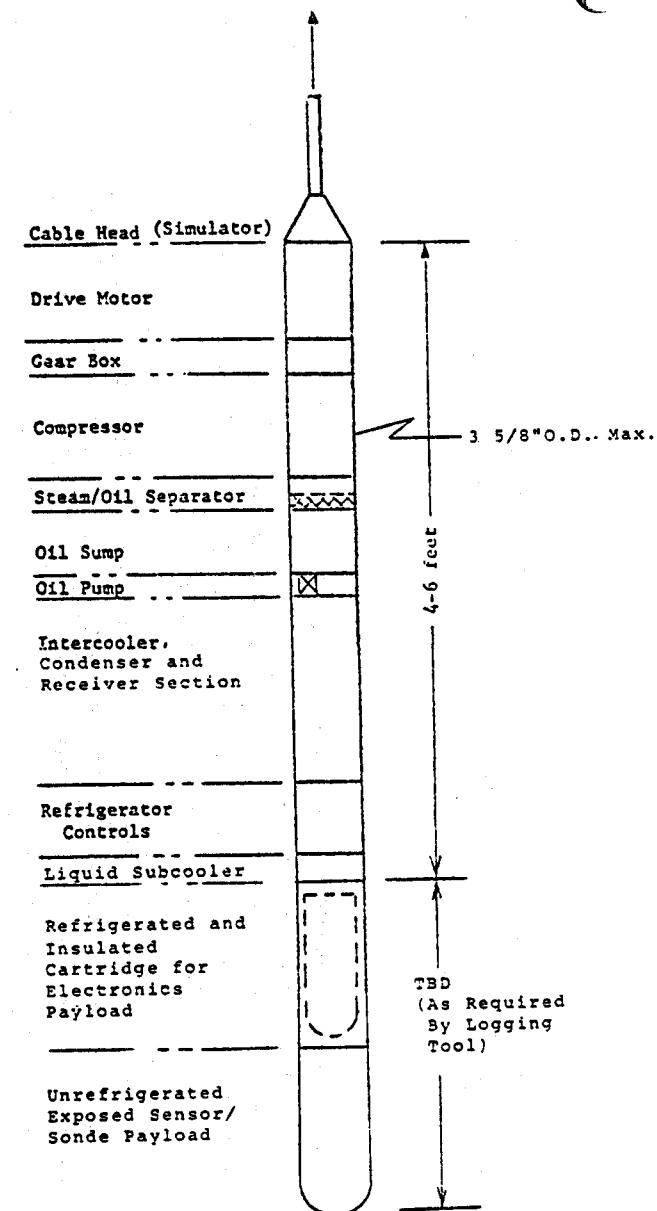
The first phase of this program for the feasibility development of the compressor was successfully completed in July of 1977. Phase II of the program for the complete development and autoclave testing of a down hole refrigeration system (drive system, compressor, condenser, evaporator, controls and insulated payload section) has just started.

The program for Phase II is broken down into the following 5 tasks:

1. System Design, Integration and Checkout
2. Additional Compressor Development
3. Refrigeration Control System Development
4. Drive System Development
5. Proof and Endurance Testing



REFRIGERATOR SYSTEM FLOW SCHEMATIC

PHYSICAL LAYOUT FOR DOWN HOLE LOGGING TOOL
MECHANICAL REFRIGERATOR

Project #8

Experimental Evaluation of Geothermal Well Logging Cables and Development of Environmental Test Facilities for Evaluation of Cables, Tools and Other Related Downhole Equipment.

Contractor - Systems, Science and Software (S³) Contract #E(04-3)-1208
San Diego, California

Principal Investigator - Ed Day, phone 714-453-0060

Contract Duration - Phase I, Approx. 14 months (1/23/76 thru 4/23/77)
Phase II, proposed 10 months

The objective of the Phase I contract was to evaluate the performance of currently available well logging electromechanical cables under combined high temperatures, tension and flexure environment conditions. Also included in Phase I was the design of a full environment autoclave to simulate geothermal hostile environment for use in test and evaluation of logging cables, tools and other related equipment and components. Phase II is for the construction and checkout of the geothermal full environment test autoclave.

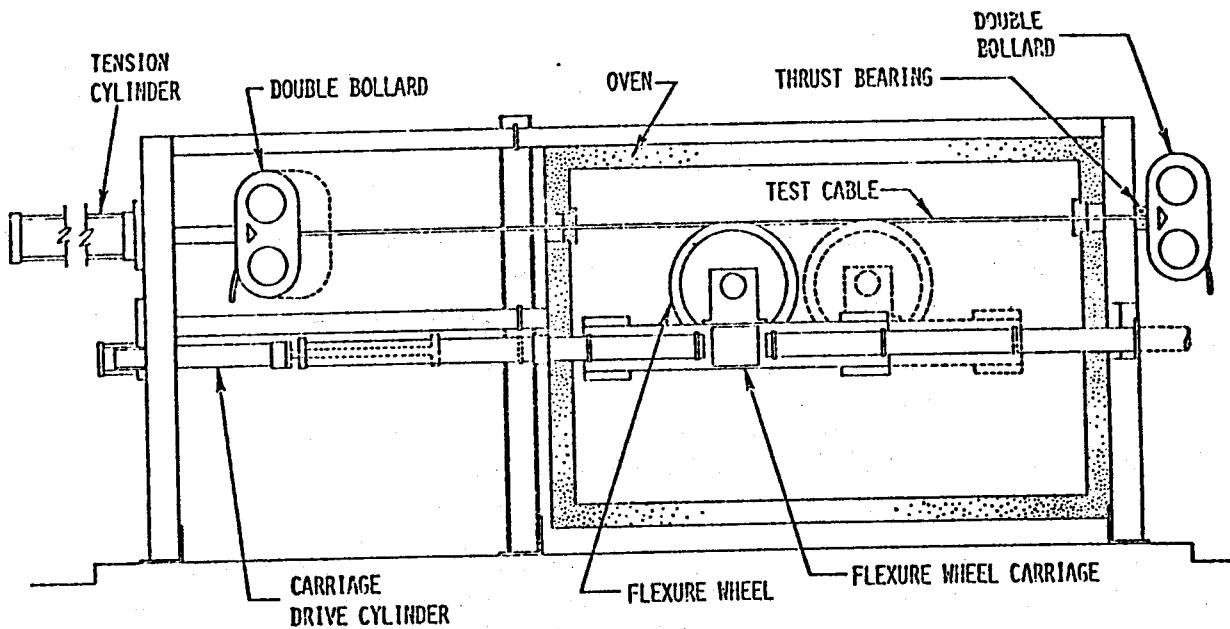
Current Status

Cable Tests

Under Phase I, S³ tested 10 electromechanical logging cables supplied by 3 manufacturers using a special atmospheric test stand they developed. The test results indicate that the single (mono) conductor cables are capable of operation up to 315 C, however even the high temperature insulations (TFE & PFA) start to extrude through the armor at temperatures greater than 250 C when tensioned to their rated working load. None of the seven conductor cables passed the combined tension-temperature test at 232 C. It should be noted that their cables were not exposed to corrosive geothermal fluids at high temperature and pressure which could further limit their performance.

Design of Full Environment Geothermal Test Facility

S³ has completed and submitted their specifications and designs to ERDA-DGE with cost estimates to construct and checkout the facility. The autoclave facility (8' long X 5" dia.) was designed to use corrosive fluids (brine with H₂S) at temperatures up to 350 C with facilities to tension a cable or tool while under combined pressure and temperature. ERDA-DGE is currently evaluating the specifications and design including reviewing them with potential users (cable manufacturers, well logging tool development and service companies) to obtain feedback on requirements, use rate, etc.) to access industry needs prior to funding construction. Indications received to date indicate such a facility could be useful to most groups within industry, however the chamber size (length) might require lengthening to approximately 24 feet to be useful to most.



Atmospheric pressure cable test stand - general arrangement.

Heated length = 68"

Tensioned length = 110" + circumference of flexure wheel

Max. temperature = 350°C

Max. tension = 20,000 lbs

ELECTROMECHANICAL WELL LOGGING CABLE SAMPLES TESTED

#	Manufacturer	Stock #	Insulation	ARMOR		No. of Conductors	Rated Temp (°C)	Max. Working Load Lbs (ends free)	Comments
				OD (in)	Material				
1	Rochester	10149	Polyarylene	.125	GIPS	1	>260	550	Passed @ 277 C
2	Rochester	10233	TFE (Teflon)	.186		1	>260	1250	Passed @ 277 C (Insulation extruded)
3	Rochester	10358	PFA (Teflon)	.220		1	260	1700	Passed
4	Rochester	10216	Tefzel	.220		1	260	1700	Passed
5	Rochester	70421	Tefzel	.421		7	260	5600	Electrically shorted
6	U.S. Steel (Amergraph)	1K18XD (AM-4)	(Teflon)	.182		1	285	1500	Passed
			TFE				315 (1)		(Insulation extruded) @ 260
7	U.S. Steel (Amergraph)	7J46RF	PFA (Teflon)	.469		7	232	6100	Electrically shorted (2)
8	Vector	A-10025-1	FEP (Teflon) + Tefzel Jacket	.464		1	232	2000	Passed (Insulation extruded when tested @ 275)
9	Vector	A-10104	TFE (Teflon)	.221		1	285	2200	Passed (Insulation extruded)
							315 (1)		
10	Vector	A-20007	FEP (Teflon) & Neoprene	.249	GIPS	7	232	7000	Electrically shorted

GIPS - Galvanized Improved Plow Steel - Manufacturers can also provide as special order with corrosion resistant steel.

¹⁾ Continuous use at 315°C not recommended.

²⁾ This may have resulted from improper handling by S³ of the antistatic coatings on conductor insulation.

Project #9

FEASABILITY INVESTIGATION AND DESIGN STUDY OF OPTICAL WELL LOGGING METHODS FOR HIGH TEMPERATURE GEOTHERMAL WELLS

Contractor - Southwest Research Institute (SwRI)
San Antonio, Texas

Principal Investigator - Bob Swanson phone 512-684-5111

Contract Duration - 15 months (10/76 thru 4/78)

Contract #E(40-1)-5268

The objective of this program is to explore the feasibility and applicability of optical sensors and fiber optic communication systems for use in geothermal well logging applications. The potential advantages of fiber optics for well logging include the following:

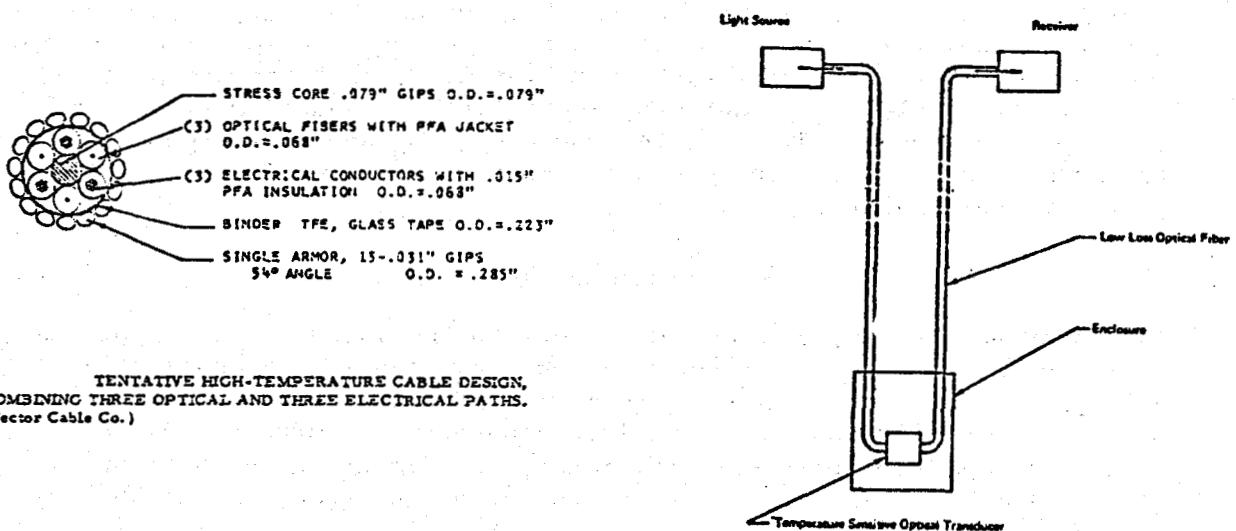
- Wide operating temperature range ($\gg 325^{\circ}\text{C}$)
- Complete electrical isolation/no short circuit possibilities
- RFI/EMI noise immunity
- No crosstalk
- Wide information carrying capacity (signal bandwidth)
- Low transmission loss (as low as 1 db/km)
- Very small lightweight conductors (individual fibers are about 100 to 200 microns)

However, development of complete fiber optic well logging cables with high temperature buffer material to protect the fiber from localized mechanical stress and corrosive fluids in contiguous long length (~ 4 km) cables, together with methods for sealing and coupling optical fibers in cable heads, and high temperature electro-optic signal converters to couple electrical sensor signals into the fiber cable require development. As a novel alternative to electro-optic signal converters, SwRI will examine the feasibility of using passive optic sensors whose output can directly interface to a fiber optic cable. This program is divided into the following tasks:

- 1) Work with optical fiber and cable manufacturers to develop/select cable materials, configuration and methods for manufacturing of fiber optic well logging cable(s). A 100 meter length of prototype cable will be manufactured and evaluated.
- 2) Evaluation of materials and design techniques for fiber optic cable head seals, connectors and terminations for the geothermal hostile environment.
- 3) Investigation of high temperature electro-optic signal converters.
- 4) Development and laboratory demonstration of a passive optical sensor for measuring geothermal borehole temperature by measuring the cut-off wavelength/absorption edge in a semiconductor material.
- 5) Investigation into passive optical sensors for measuring geothermal well parameters.

Status

- Task 1 - Vector Cable Company was selected for manufacturing a prototype cable incorporating a PFA teflon insulation which is rated for up to 260°C use. Delivery of the cable has been delayed due to difficulties in extruding the PFA buffer onto the quartz fibers. Vector's fiber supplier, Times Fiber Communications Inc., has recently agreed to supply the fibers with the 0.068" diameter PFA buffer and delivery to Vector is currently scheduled for early January. Evaluations of other higher temperature fiber coatings and buffer materials for operation up to 325°C have been performed including imide polymer (Polyimide) and silicones.
- Task 2 - A prototype cable head design is being evaluated together with a casagranian optical coupler design.
- Task 3 - Identification of a promising high temperature Light Emitting Diode (LED) made of gallium arsnide, together with several electro-optic modulators give promise to several alternate components for this key subsystem.
- Task 4 - Extensive analysis and experiments have been completed to assure feasibility of this passive temperature measurement technique using doped gallium arsnide.
- Task 5 - Besides the temperature sensor, SwRI has performed some laboratory investigation on a new slow (thermal) neutron optical scintillation sensor. Data obtained to date on this neutron detector concept are very encouraging. Also, information has been collected which indicates many types of passive optical sensors for acoustic, pressure and other tools are feasible.



Project #12

STUDY OF NEUTRON-BASED, NUCLEAR TECHNIQUES FOR MEASUREMENT OF GEOTHERMAL WELL PARAMETERS.

Contractor - IRT Corporation Contract #EY-76-03-0936, PA48
San Diego, California

Principal Investigator - Dr. Nicholas Vagelatos phone 714-565-7171
Contract duration - (17 months (10/76 thru 3/78)

The purpose of this program is to investigate the feasibility of using nuclear logging/measurement techniques for geothermal well logging in areas where conventional techniques have proved difficult to apply or do not provide the desired geophysical parameters. The nuclear techniques to be investigated will center on neutron gauging and neutron activation using Californium-252 as the neutron source. The parameters to be addressed are in-situ formation temperature and bore hole fluid flow rate with major emphasis on formation temperature. Other parameters such as fracture detection and orientation, dissolved mineral content, porosity and lithology will be briefly considered.

Status as of August 1977

The thermal neutron temperature, T_n , in a moderating medium (formation) has been shown to be related to the following three independent variables:

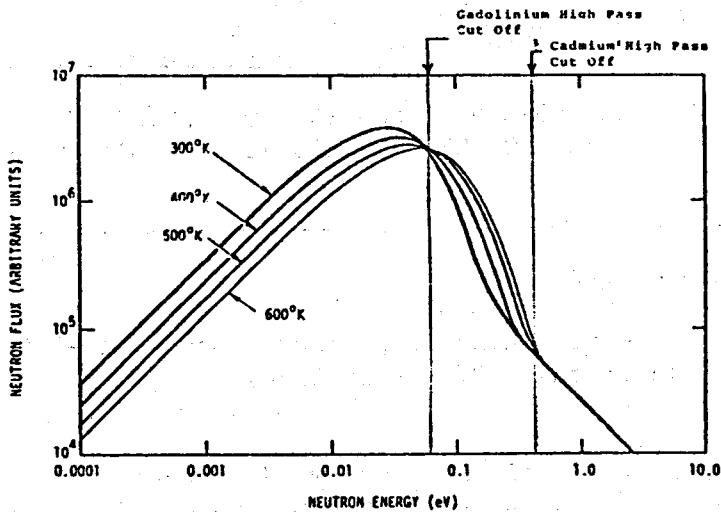
1) formation temperature, T ; 2) absorption cross section within medium, Σ_a ; 3) moderating power of medium, $\xi\Sigma_s$; where ξ is the average logarithmic energy loss per neutron collision, and Σ_s is the scattering cross section within medium.

$$T_n = F\{T, \Sigma_a, \xi\Sigma_s\} = F_1\{T\} \cdot F_2\{\Sigma_a\} \cdot F_3\{\xi\Sigma_s\}$$

For a point source configuration within a down hole logging tool, the explicit functional relationship for the neutron temperature is very complicated. However, the investigators have selected three different thermal neutron detectors (filters) with count rates, C , that are proportional to the three variables. One detector incorporates a gadolinium filter where $C_{Gd} \sim T_n$, one uses a cadmium filter where $C_{Cd} \sim \xi\Sigma_s$ and a bare detector is used for absorption, $C_B \sim \Sigma_a$. These counts can be used to empirically solve for the formation temperature:

$$T = G\{C_{Gd}, C_B, C_{Cd}\}$$

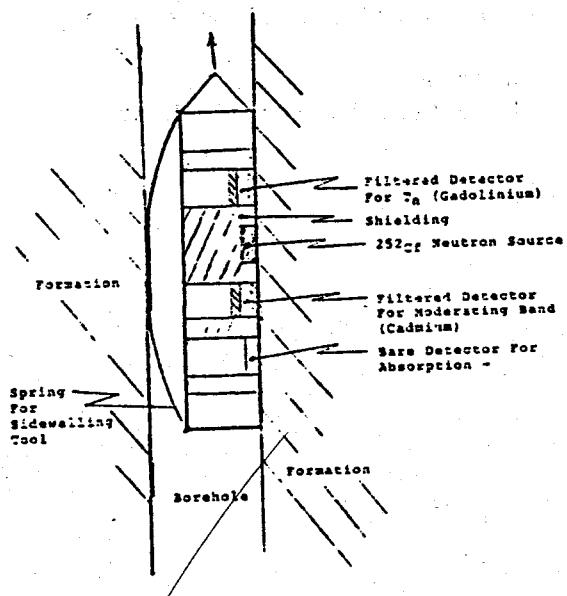
The count sensitivity of these detectors to the variables was experimentally evaluated and shown to represent a viable and feasible technique for values of $4\Sigma_a/\xi\Sigma_s \leq 1$. Measurement of formation saturated porosity will also be obtained by this technique. The investigators are currently designing a series of simulated bore hole laboratory experiments using a three detector tool mockup to optimize source/detectors configuration, establish basic measurement accuracies/sensitivities, neutron formation penetration and limitations.



Thermal neutron energy distributions for several neutron temperatures, T_n , displaying the spectral dependence on T_n which is a function of moderator (formation) temperatures, absorption cross section and moderation power.

$$T_n = F(T, T_a, \Sigma \Sigma_a)$$

Estimated performance specifications for the formation temperature sonde



FORMATION TEMPERATURE TOOL CONFIGURATION

1. Primary parameter measured

Additional information obtained

Formation temperature

Neutron absorption and moderation (saturated porosity).

2. Estimated technique accuracy

±3.5°C near room temperature
±2% at $T \geq 100^\circ\text{C}$

3. Neutron absorber concentration limit

Technique applicable in all known dominated hydrothermal systems; inapplicable when dissolved mineral content becomes 7-10 times that of Salton Sea KGRA. Technique inapplicable in completely dry formations with absorber concentrations resulting in cross-sections equivalent to that of 25% the Cl^- concentration of Salton Sea KGRA.

4. Temperature limitations

No inherent technique limitations.
The detectors can be designed to operate at $\geq 260^\circ\text{C}$.
Electronic component operating temperature range is presently the limiting factor.
High temperature multiconductor cable successfully tested at $\geq 260^\circ\text{C}$.

Continuous or step by step
25-50 ft/min continuous logging

20-70 ft/min step-by-step logging

50-150 μg ^{252}Cf

5-10 inches

Minimized by sidewall and neutron shielding design.

Project #13

THE DEVELOPMENT OF TWO NEW BORE HOLE LOGGING TOOLS/SENSORS - ONE FOR MEASURING IN-SITU HEAT FLUX AND ONE FOR MEASURING IN-SITU THERMAL CONDUCTIVITY

Contractor - Geoscience Ltd.

Solana Beach, California

Principal Investigator - Dr. Heinz Poppendiek, phone 714-755-9396

Contract Duration - 18 months (10/76 thru 3/78)

Contract - #E(04-3)-1318

This program supports the development of two different techniques to measure geothermal heat flux and earth thermal conductivity in bore holes. One technique, the heat flux transfer, requires only passive temperature measurements while the other technique, the thermal conductivity transducer, incorporates a heater for applying a constant known heat transfer. Under this current contract, Geoscience will develop the required supporting analysis methods, design and fabricate the transducer systems and experimentally evaluate their performance using a geothermal bore hole.

Specific technical details on the measurement/transducer concepts have been withheld until Geoscience can assess the patentability of their concepts.

Status

Development of Analysis Techniques and Tools - Geoscience has developed both closed form and numerical finite difference solutions for the two transducer design concepts. Using these analytical tools, sensitivity analyses have been performed to optimize the transducer design for the geothermal borehole configurations to be encountered.

Laboratory Feasibility Experiments - The basic feasibility of both tools in laboratory experiments using instrumented rods buried in dry sand (no borehole) yielded measurement accuracies from 6 to 20 percent.

Transducer Design - Detailed design of both transducers has been completed and the units are currently being fabricated and assembled. Current design calls for a 6 foot long section (both tools) with a ration of borehole diameter to tool diameter of 1.2.

Industry Application Survey and Borehole Selection - Meetings have been held with different Geothermal Energy Exploration and Development Organizations to explain the measurement concepts and obtain feedback on current borehole configurations and possible test sites. Based on this feedback, a target geothermal well test in northern California (Geysers area) belonging to Phillips Petroleum has been selected for experimental transducer evaluations. The well is a 2,000 feet deep X $6\frac{1}{4}$ " diameter 'observation well'.

UPGRADE OF ACOUSTIC SENSOR PERFORMANCE FOR USE IN GEOTHERMAL WELL LOGGING APPLICATIONS.

Contractor - Westinghouse Electric Corporation, Research Laboratory
Pittsburg, Pennsylvania

Principal Investigator - Jim Wonn, phone 412-256-3635

Contract Duration - 28 months (9/1/76 thru 12/31/78)

Contract - #E(11-1)-4082

The program objective is to upgrade acoustic sensor technology such that appropriate well logging instruments can be made to operate under the hostile environment conditions anticipated in geothermal resource exploration and evaluation. To accomplish this objective, Westinghouse will assess which type of acoustic logging tools would make the most effective use of a sensor development program based on the Geothermal Industry needs and present state-of-the-art feasibility/development risk. Tools being evaluated for consideration are: a) Borehole Televiewer, b) Acoustic Caliper, c) Borehole Acoustic Flowmeter (a new tool), d) Acoustic Velocity (Sonic Log), e) Acoustic Emission (Passive Listening), f) Cement Bond. Following the selection of the most appropriate acoustic tool, the specific sensor type will be developed/upgraded for operation in a downhole geothermal hostile environment (i.e. 275° to 325°C, 7000 PSI). The program is divided into the following three tasks:

- 1) Acoustic Well Logging Sensor Evaluation, Application Survey, and Developability Analysis.
- 2) Severe Environment Sensor Development and Optimization.
- 3) Fabrication and Demonstration of Related Sensor Embodiment Under Hostile Environment.

Status

Westinghouse is currently proceeding under task 2 to improve both an Acoustic Velocity Log (AVL) and Borehole Televiewer (BHTV) sensor. The survey to prioritize downhole acoustic tools based on the Geothermal Industry needs has indicated a high demand for a fracture zone measurement tool and a two phase flow measurement tool. This survey combined with assessment of the usefulness of the six tools listed above to meet the needs led to an extensive study of the BHTV and AVL to determine the overall tool developability (sensor, electronics, mechanical) led to current program plan. The BHTV incorporates a high frequency (1.5 megahertz) acoustic sensor to provide an acoustic image of the borehole wall wherein fractures in the wall can be directly identified. The AVL employs a low frequency (40 kilohertz) acoustic sensor to measure in-situ velocities, velocity ratios and velocity

variations which provide information on subsurface geology and wave propagation properties including fracture information. The BHTV, while ranking higher on the Geothermal Industry's potential usefulness to provide fracture information is a very complex tool which has other non-sensor components which require improvement whereas the AVL tool is a relatively simple design.

The U.S. Geological Survey Water Resources Division currently owns and operates AVL and BHTV logging tools manufactured by Simplec. Westinghouse will develop and install the acoustic sensors into USGS-WRD existing logging tools which have their electronics protected in superinsulated dewars. The USGS-WRD together with Westinghouse support will then evaluate the tools in one or more geothermal wells to assess the tool performance to survive the environment and provide useful fracture information. Further, it is felt that development of both a low frequency acoustic sensor (AVL) and a high frequency acoustic sensor (BHTV) will provide the necessary technology for tool manufacturers to improve acoustic sensors for the other tools listed above.

SUMMARY OF PRESENT AND NEAR TERM ACOUSTIC LOGGING TECHNIQUES

WHAT CAN BE MEASURED	WHAT ARE THE SPECIFIC PARAMETERS	INFORMATION OBTAINED	TOOL
ACOUSTIC PROPERTIES OF ROCKS	<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>VELOCITIES</p> <p>AMPLITUDE</p> <p>ELASTIC MODULII</p> </div> <div style="flex: 1;"> <p>LITHOLOGY CORRELATION</p> <p>LITHOLOGY IDENTIFICATION</p> <p>POROSITY</p> <p>FRACTURE ZONE</p> <p>ROCK "Q"</p> <p>GAS/WATER SATURATION</p> <p>YOUNG'S, SHEAR, BULK MODULII</p> <p>POISSON'S RATIO</p> </div> </div>		VELOCITY LOGGER
ACOUSTIC INTERFACES WITHIN INSONIFIED MEDIA	<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>REFLECTION/TRANSMISSION COEFFICIENTS</p> </div> <div style="flex: 1;"> <p>ROCK BOUNDARIES LOCATION</p> <p>WALL/ROCK FRACTURES</p> <p>WALL ROCK LOCATION</p> <p>MUD CAKE PARAMETERS</p> </div> </div>		VELOCITY LOGGER BHTV SEISMIC-CALIPER CEMENT BOND LOG
ACOUSTIC EMISSIONS FROM ROCKS	<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>AMPLITUDE</p> <p>FREQUENCY</p> <p>RATE</p> </div> <div style="flex: 1;"> <p>ACTIVE FRACTURING IN ROCK RESERVOIR "NOISES"</p> <p>MAN INDUCED FRACTURING</p> <p>FLUID FLOW BEHIND CASING</p> </div> </div>		PASSIVE LISTENING
FLOW	<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>FLUID FLOW PAST LOGGING TOOL</p> </div> <div style="flex: 1;"> <p>RATE OF INDUCED FLOW</p> <p>AMOUNT OF FLUID LOSS/GAIN</p> <p>AREAS OF FLUID LOSS/GAIN</p> </div> </div>		NEW FLOW METER
HOLE DIMENSIONS	<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>TRANSIT TIME TO AND FROM HOLE WALL</p> </div> <div style="flex: 1;"> <p>HOLE DIAMETER</p> <p>HOLE ECCENTRICITY</p> </div> </div>		SEISMIC-CALIPER
SUSPENDED SEDIMENT	<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>AMOUNT OF SOLID MATERIAL IN LIQUID OR GAS STREAM</p> </div> <div style="flex: 1;"> <p>PERCENT SOLIDS IN STEAM</p> <p>SEDIMENT TRANSPORT</p> <p>STREAM STRATIFICATION</p> </div> </div>		PASSIVE LISTENING

Project #16

DEVELOPMENT OF A GEOTHERMAL LOGGING TOOL FOR MEASURING TEMPERATURE, PRESSURE AND PRESSURE GRADIENT USING NO DOWNHOLE ACTIVE ELECTRONICS.

Contractor - Systems, Science and Software (S³)
San Diego, California

Principal Investigator - Howard Kratz phone 714-453-0060

Contract Duration - 21 months (9/76 thru 5/78)

Contract - #E(04-3)-1315

The objective of this program is to develop a multisensor geothermal well logging tool wherein there are no active electronics required in the tool. By removing the downhole electronics, the measurement degradation and limitations of high temperature electronics can be minimized. The developers are planning on using passive strain gauge type sensors for measuring pressure and pressure gradient which can operate continuously in a geothermal hostile environment at temperatures up to 325°C and pressures up to 10,000PSI. Temperature will be measured with a platinum resistance thermometer. The system design measurement performance requirements are:

	Range	Accuracy	Resolution
Temperature	0 - 325°C	±1°C	0.1°C
Pressure	0 - 10,000 PSI	10 PSI	2 PSI
Pressure Gradient	0 - 2 PSI	0.2 PSI	TBD

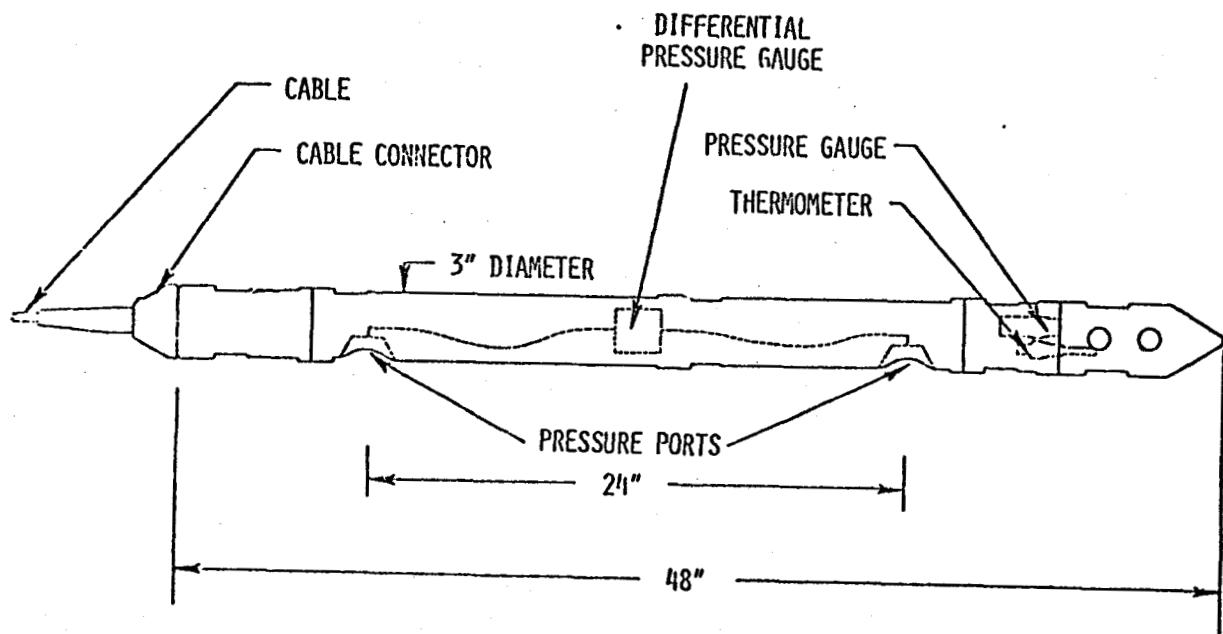
The tool will be designed for use with a standard 7 conductor logging cable. The pressure gradient sensor is to be used for measuring fluid density and detecting regions of two phase flow. Flowmeter and hole caliper sensors are proposed to be added later, if the concept proves out. A layout of the tool is shown on the accompanying page.

Project Status

Systems, Science and Software has selected a constant current excitation method and a voltage signal pickoff across each transducer to sense the change in resistance. The approach will utilize all seven conductors with the cable sheath (armor) as ground. No automatic electrical shunt calibration will be included, since the contractor did not want to include relays within the tool. However, the contractor is planning on developing/evaluating high temperature relays for possible later inclusion.

The contractor has selected a platinum resistance temperature device (RTD) manufactured by Celestec Industries for the temperature sensor, a strain gauge pressure transducer manufactured by Precise Sensors Inc. and has subcontracted for development of the differential pressure transducer system. The temperature transducer and absolute pressure transducers have been received. However, the subcontractor developing the differential pressure transducer has experienced much difficulty. As such, incorporation of a goniometer (differential pressure sensor) will not be incorporated within the tool during this development contract.

S³ has completed the sonde design, including development and testing of a high temperature cable head. Current plans call for testing the complete pressure-temperature tool in an autoclave and then performing an actual downhole test/evaluation in one of Los Alamos' geothermal wells at Fenton Hill, New Mexico.



AYOUT OF SONDE



APPENDIX B

A LIST OF SOME HIGH TEMPERATURE MATERIAL AND COMPONENTS*

*Other materials and components are available. No endorsement is implied by inclusion in these tables. The reader should contact the manufacturers for specific properties and carefully evaluate for use in his specific application. Blank property values were not obtained by the author.

TABLE B1
SOME HIGH TEMPERATURE ELASTOMERS AND STRUCTURAL DESIGN MATERIALS

Name	Material Description	Manufacturer	Recommended Upper Temperature-°C				Decomp or Melt temp °C	Caustic Fluid (Hydrolytic) Stability or Corrosion Resist	Thermo-Mechanical Stability	Comments
			Continuous Exposure 2000 Hrs	Up to 240 Hrs	Up to 24 Hrs					
Selastic 52U/82U	Silicone elastomer	Dow Corning	260	300	325	370	Poor			
Viton	Fluoroelastomer	Du Pont	250	288	315		Poor			
Kalrez	Perfluoroelastomer	Du Pont	288	300	315	340 (in air)	Good			Very expensive (\$2000/lb)
Aflas-150	Fluorinated elastomer	Ashi Glass			315		Fair to Good			\$13/lb
Teflon-PFA	Fluorcarbon resin	Du Pont	260	285	290	305				
Teflon-TFE	Fluorcarbon resin	Du Pont	260	300	310	327				
DC#8C5	Silicore resin coating	Dow Corning	530							
P55HD	Polymide coating	ElectroScience Lab	300			350				
	Ceramic coatings		500							
Kapton	Polimide film/tape	Du Pont	300		400	815				
DC#302	Silicore molding plastic	Dow Corning	410							
Duralco 700	Epoxy	Cotronics Corp.	350							Good dielectric
C3, C4	Ceramic cements	Dylon Ind.	1000							
TC	Heat conductive Compound	Dylon Ind.	760							
Grade AA & AE	Graphite release coating	Dylon Ind.	1000							
	Mica film/tape		450							
	Glass braid		450							
A-950	High aluminum ceramic parts	Alberox	500							
Mykroy 1100	Machinable ceramic		500							
Inconel 625	Nickel base metal alloy		500							
Hastelloy	Nickel base metal alloy		500							
Haynes 6B	Cobalt base metal alloy		500							
Admiralty Brass	Arsenic stabilized brass		500							

TABLE B2
SOME HIGH TEMPERATURE INSULATED WIRE

Insulation Type	Conductor	Gauges (AWG)	Temp Rating °C	Supplier(s) No. ⁽¹⁾
Mica-glass and asbestos with glass braid jacket	N, NCC	10 - 18	500°C	C(MAG)
Silicone impregnated asbestos with glass braid jacket	N	10 to 22	500	C(AGS)
Mica-glass with silicone impregnated glass braid jacket	N, NCC	2 to 22	500	C(MGS), T
Mica-glass with ceramic impregnated glass braid jacket	N, NCC	2 to 22	500	C(MGC)
Kapton tape	NCC	20 to 32		T(various)
Extruded TFE Teflon with Kapton tape jacket	NCC	up to 32	275	T(Tuffcote)
Ceramic coated	N, NCC	up to 26	500	P, CS
Aluminum oxide film	Al	10 - 46	1000	P
Magnesium oxide with stainless steel tubing jacket	N, NCC		1000	

1) Manufacturers - Continental Wire and Cable Co. (C); Tensolite Co. (T); Permaluster, Inc. (P); Coomer Sales (CS). It should be noted there are other suppliers for these types of insulated wires.
N = nickel, NCC = nickel and copper, Al = Aluminum

TABLE B3
SOME HIGH TEMPERATURE METAL SEALS*

Seal Type/Name	Manufacturer	Temperature-Pressure Rating
Conoseal	Aeroquip Corporation	900°C @ 20,000 PSI
'O', 'V', 'C' rings and corroseals	Advanced Products	900°C @ 20,000 PSI
'K' seals	Sierracin/Harrison	900°C @ 20,000 PSI
'O' and 'C' rings	United Aircraft Prod.	900°C @ 20,000 PSI

*The reliability of using metal seals for joints greater than 2" has been reported to be marginal due to critical alignment and maintenance of critical surface tolerances.

TABLE B4

SOME HIGH TEMPERATURE FLUIDS

Trade Name	Manufacturer	Type	Viscosity (Cst)				Flash Point °F	Auto Ignition Point °F	Pour Point °F	Boiling Point °F	Specific Gravity @ 100F	Temperature (Recommended Upper) in air °F Inert °F	Thermal Expansion Coefficient (cc/cc)/°F	Thermal Conductivity BTU/hr Ft °F	Dielectric Properties	Cost	
			100F	200F	400F	600F											
Therminol 66	Monsanto	Modified terphenyl	30	4.3	1.0	.5	352	705	-18	643	.99	650		3.9(10) ⁻⁴	5.5(10) ⁻²	Poor	\$1.15/lb
Therminol 88	Monsanto	Mixed terphenyls	-	-	.9	.4	375	1000	297	687	.99	750		4.7	7	Poor	
Coolanol 45	Monsanto	Silicate-ester	12		1.5	.8	370	700	-85		.9	700		9.5	9	Excellent	
Pydraul 35E	Monsanto	Phosphate-ester	32	4.8					-15	725	1.1			3.5	7.4		
Pydraul 115E	Monsanto	Phosphate-ester	122	9.1					+10	820	1.1			3.5	7.2		\$5.61/lb
Z10H	Dow Corning	Dimethyl polysiloxane	85	35	12	6.8	610		-50		.97	600		5.3			
550	Dow Corning	Phenyl-methyl silicone	75	24			575					600		4.4	8.5		
710	Dow Corning	Phenylmethyl polysiloxane	240	38	7			910				1.1	500		4.3		\$12/lb
1265	Dow Corning	Fluorsilicone	250	8000	5	80	500/600	720			1.25	400	550	5.3			\$54/lb
Versilube F-50	General Electric	Silicone oil	52	18	4.5	2.3	550	850	-100		1.04	450	600	5.0			
SF-1019	General Electric	Silicone oil										550	700				
SF-1147	General Electric	Silicone oil	31	9			500	800	-65		.9			4.0			
Santovac-5	Monsanto	Polyphenyl ether	363	16	2.1	.85	550	1135	+40		1.2	625	750		6.4		\$200/lb
Brayco 810-813	Bray Oil	Perfluoroalkyl poly-ether			5				0		1.9			5.5			\$110/lb
Brayco 815	Bray Oil	Perfluorinated poly-ether	129	44	11		570		-100		1.9	500		5.5			\$272/lb
Jet Gil II	Mobil Oil	Phosphate ester															
Brayco 899	Bray Oil	Phosphate ester	27	6	1.3		500	800	-75		.99	500					