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SEMI-ANNUAL REPORT ON THE PROJECT TO
DESIGN AND EXPERIMENTALLY TEST AN
IMPROVED GEOTHERMAL DRILL BIT

By
L. M. Barker
S. J. Green
W. C. Maurer

January 1976

Work Performed Under Contract No. EY-76-C-07-1546

Terra Tek, Inc.
Salt Lake City, Utah

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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SEMI-ANNUAL REPORT ON THE PROJECT
TO DESIGN AND EXPERIMENTALLY TEST AN
IMPROVED GEOTHERMAL DRILL BIT

[ERDA Contract No. E(10-1)1546]

By

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S. J. Green
W. C. Maurer

January 1976

Submitted to

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Division of Geothermal Energy
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TR 76-3

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FOREWARD

This report represents the semi-annual progress report for ERDA Contract No. E(10-1)-1546, "To Design and Experimentally Test an Improved Geothermal Drill Bit." The Phase I contract was for a one-year effort starting May 19, 1975. This report summarizes the progress to January 1, 1976.

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INTRODUCTION

Work was started on the effort to design and test an improved geothermal drill bit [ERDA Contract No. E(10-1)-1546] on May 19, 1975. Terra Tek, Inc., is the prime contractor, with Maurer Engineering as a subcontractor and Reed Tool Company providing informal industry participation. The major tasks of the Phase I effort which is covered in the contract, are:

Task 1. Failure Mechanisms of Existing Bits

Task 2. New Steels and New Bearing Design

Task 3. New Seals and Lubricants

The work has progressed well; we feel that we are on schedule, and it is anticipated that the statement of work will be completed by the end of the contract year. This report describes the progress made to January 1, 1976. Appendix A lists three topical reports which are also included (under separate cover) as attachments to this report. Program Discussion Meeting Reports on guidance meetings held in June, August, and December, 1975, are contained in Appendix B.

TABLE I Bar-Chart for Completion of Phase I

PROGRESS TO DATE

Current Geothermal Drill-Bit Problems

A survey was made of the current geothermal well drilling problems by visiting several drilling sites and talking to the engineers directly involved in drilling. Sites visited include the Geysers in Northern California, the Salton Sea area, the Cerro Prieto site in Mexico, Roosevelt Hot Springs site in Utah and the Baca Range site in New Mexico. The most critical problems with drill bit failures are experienced at the Geysers site, where more than half of the current geothermal well drilling is done, and where all of the current geothermal drilling for power production (as opposed to exploration) is being done. A number of worn-out drill bits were obtained from the Geysers and other geothermal drilling sites in order to study the failure mechanisms of the bits (see Figure 1).

Current bits, that have seals almost universally use elastomeric (rubber) rings of one type or another. The environmental conditions that a geothermal bit must face are not conducive to good rubber performance. These conditions include: 1) high-temperatures, 2) exposure to corrosive environments such as H_2S , SO_2 , SO_3 , brine, hot water, live steam, methane, etc., 3) solvents or swelling agents such as petroleum and its products, lubricants, etc., and 4) very abrasive constituents of the drilling mud and/or from the grinding "chips" or debris.

Figure 1. Used drill bit components from the Geysers geothermal area. The bit was disassembled for analysis of bearing wear conditions and causes of failure.

The drilling at the Geysers is done with compressed air rather than the usual drilling muds in order to prevent damage by the hardening of drilling mud in steam passageways. The temperature of the rock formation is 240°C (465°F), but peak drill-bit temperatures of more than 370°C (700°F) have been measured, presumably because of bearing friction and the limited cooling provided by compressed air drilling. Because current lubricant seals in conventional sealed drill bit designs cannot withstand the temperature environment, unsealed bits with unlubricated bearings are used. These bits are of conventional design for use in mining or oil well application. The high temperatures and the hard abrasive rock

formations at the Geysers cause slow drilling rates and a very short average bit life. The bit failure modes are both bearing wear and "gage" (hole diameter) wear, which is wear of the outside diameter of the bit such that the diameter of the drilled hole becomes under-sized. There are indications that the gage wear may be determined by the bearing wear, and that improving the bearing life may automatically improve the gage life as well.

The bearing life can be estimated with the following empirical formula of the Torrington Company (Anon., 1973):

$$\text{Bearing Life} = 500 H \left(\frac{33.3}{S} \right) \left(\frac{W_0}{W} \right)^{3.33} \text{ (hours)} \quad (1)$$

where:

H = Hardness Factor (See Table I)

S = Rotary Speed (RPM)

W = Bearing Load (lbs.)

W_0 = Bearing load which produces life of
1 million revolutions ($R_C = 58$).

Considering the reduced bearing loads used in drilling at the Geysers, Equation (1) indicates that Geysers drill bits wear out twenty times faster than would be expected from mining and oil well experience! Examination and testing of worn drill bits has shown that a major part of the problem can be attributed to the decrease in hardness of the bearing surfaces as a result of annealing in the high temperature environment (see Equation 1, and the hardness factor in Table I).

TABLE I
HARDNESS FACTOR TABLE

<u>R_c</u>	<u>H</u>	<u>R_c</u>	<u>H</u>
58	1.00	40	0.0064
56	0.88	38	0.0036
54	0.69	36	0.0020
52	0.44	34	0.0011
50	0.21	32	0.0006
48	0.10	30	0.0004
46	0.05	28	0.0002
44	0.023	26	0.00014
42	0.012	24	0.00008

Unsealed Drill Bits of High-Temperature Steels

In view of the problem of the annealing of the bearing surfaces, it seems clear that a significant gain in drill bit performance can be made by re-optimizing the current unsealed drill bit designs (Figure 2) for operation at temperatures to about 426° C (800° F) through the use of high-temperature steels in place of the current steels. Since currently used steels have low drawing temperatures (about 200° C), and since steels with a wide range of higher drawing temperatures are available, this method of improving drill bit life seems assured of some degree of success. Therefore, two unsealed drill bits of high-temperature steels specified by Terra Tek, Inc. are being fabricated by Reed Tool Co., and a pressure-temperature vessel for simulating the geothermal drilling environment is being constructed at Terra Tek for drill bit testing (Figure 3). Two additional bits of conventional steels, but otherwise

Figure 2. Unsealed drill-bit design.

Figure 3. Schematic of the pressure-temperature vessel being fabricated for testing full-scale drill bits under simulated geothermal well drilling environments .

of the same design, are also being procured from Reed Tool Co. These will be used as controls in the testing program to help evaluate the progress made as a result of using the high-temperature steels in the new geothermal drill bits. It is anticipated that test results will be available on these four bits by the end of the present Phase I contract.

In addition to the testing of full-scale bits, information on several base-line material properties is being collected at temperatures to 426° C for the high-temperature steels and the currently-used drill-bit steels. These properties include hardness, yield strength, elongation, fracture toughness and thermal expansion. Together with the full-scale drill bit test results, these properties should enable one to choose wisely in further optimizing the steels used in high-temperature drill bits.

High-Temperature Drill-Bit Seals

Drill bits can be further improved by the development of sealing methods to allow the bits to operate at high temperatures with lubricated bearings. Oil-well experience indicates that bits with sealed and lubricated bearings (Figure 4) last about ten times longer than unsealed bits; thus, the solution of the seal problem is extremely important. Experts agree that the lubricant itself represents only a minor problem since high-temperature lubricants are already available.

During Phase I the following work was done on the seal problem. An extensive study was completed of the past and current state of the art. The major result of this study was the report (TR 75-55, provided to ERDA)

Figure 4. An elastomer-sealed drill-bit design.

"Patent Search and Review on Roller-Bit Bearings Seals and Lubrication Systems" (Maurer, 1975). We feel that this along with the search of the open literature, discussions with representatives of rubber, seal and bit manufacturers has given us a good overview of what the state of the art is, what has been proposed in the past and what the potentials are for various seal materials and configurations under geothermal conditions.

We have had rather extensive discussions with manufacturers of new high-temperature and anti-corrosive elastomers that might be used in future seals. This includes discussions with officials in the research and development laboratories of 1) Firestone Tire and Rubber Co., Akron, Ohio; 2) B.F. Goodrich Tire and Rubber Co., Avon Lake, Ohio; 3) PRC Co., Gainesville, Florida; 4) Horizons Res. Corp, Cleveland, Ohio; 5) Union Carbide Corp., Bound Brook, N.J.; 6) Dow Corning Corp., Midland, Michigan; 7) DuPont, Wilmington, Delaware; 8) Hercules Chemical Co., Wilmington, Delaware. Discussions were also held with university and government researchers who were known to be active in this field.

The conclusions resulting from these contacts are that a number of high-temperature elastomers warrant testing, but that at the present state of the art, elastomeric seals will not be of much use above about 230° C (450° F).

Since drill bits are needed for much higher temperature environments, particularly for deep geothermal sources where cooling by the drilling fluid is less effective, (W. J. McDonald, 1975) new seal designs are being considered which will use only non-elastomer, high temperature materials.

A seal tester is being designed and built to simulate the known aspects of the geothermal drill-bit environment. The tester will provide for temperatures to 426°C (800° F), pressures up to 14MPa (2000 psi), axial and excentric motion of the rotating shaft through the seal, and pressure fluctuations of ± 0.7 MPa (± 100 psi) across the seal in drill mud environments. The seal tester will be completed during the current Phase I contract year.

SUMMARY

Considerable progress has been made in understanding the causes of premature drill-bit failure in the geothermal well drilling environment. As a result, there appears to be a high probability that very significant gains in drill-bit life can be achieved by optimizing the drill-bit materials and the design for operation at higher temperatures.

Drill-bits of high-temperature steels are being fabricated, as well as a test chamber to simulate the geothermal environment. In addition, several basic properties of the candidate steels and of the conventional drill-bit steels have been gathered from the literature, and provisions have been made for completing the material property picture through a materials testing program at Terra Tek. Considerable background material has been gathered on the drill-bit seal problem and on candidate seal materials. Some seal materials have been selected for further testing, and a seal tester is being designed to provide a very good simulation of the environment experienced by seals in geothermal well drill-bits.

The work on the contract is proceeding on schedule, and it appears that the statement of work will be completed by the end of the contract year.

APPENDIX A

Three topical reports have been written in support of various aspects of the effort to develop an improved geothermal drill-bit. The reports are included as attachments (under separate cover) to the present report. The three topical reports are:

W. C. Maurer, "Patent Search and Review on Roller-Bit Bearings, Seals and Lubrication Systems," Report No. TR 75-55, Maurer Engineering, Inc., Houston, Texas (October, 1975).

W. J. McDonald, "Temperature Distribution in Circulating Mud Columns," Report No. TR 75-67, Maurer Engineering, Inc., Houston, Texas (December 11, 1975).

H. R. Pratt and E. R. Simonson, "Geological Studies of Geothermal Reservoirs," TR 76-2, Terra Tek, Inc., Salt Lake City, Utah (January 1976).

APPENDIX B

Major guidance meetings on the project to develop an improved geothermal drill-bit were held on June 10-11, August 13, and December 10-11. This Appendix includes the reports of these meetings.

TERRA TEK CONTRACT E(10-1)-1546

"DEVELOPMENT OF AN IMPROVED
GEOTHERMAL DRILL BIT"

First Program Discussion Meeting

(at Maurer Engineering and
Reed Tool Co. June 10-11, 1975)

Signed: _____

Sidney J. Green

TR 75-35
June, 1975

FOREWORD

The first planning meeting was held in Houston at Maurer Engineering and Reed Tool Company, June 10 and 11, 1975. The objective was to help Terra Tek formulate an updated program plan, to effectively inform and seek the support of those who will be involved, and to define an effective means of project control. These were all accomplished and the program is currently well underway. Reed Tool Company not only provided a forum for program discussion in Houston, but provided top staff and engineers to attend and participate in the program planning.

PROGRAM PLAN

The Program plan below was developed to meet the contract requirements. It should be noted that this plan is subject to change and reemphasis depending upon research findings, and it is fully expected that the plan will be changed as this research program progresses.

PROJECT CONTROL

1. Approximately monthly status and planning meetings will be held between staff and engineers involved in the program. The Contracting Office Representative (COR), Morris Skalka, will be notified of significant meetings and is automatically invited to any he may be able to attend. The next meeting is planned at Terra Tek in early July.
2. Monthly (approximately) bar-chart plan and progress reports will be provided by each engineer working on a given task. Along with these should be brief writeups of each item (maybe one sentence) indicating status and immediate plans. These will be discussed at the monthly meeting and incorporated in future reports. Individuals as shown on the following page should prepare their bar-charts and attached writeup immediately.
3. Periodically more formal meetings will be held to brief a larger audience, including outside consultants and particularly the COR. The first such meeting is planned for early October, either in Washington, D.C., Salt Lake City or Houston.
4. Terra Tek will maintain monthly Engineering Accounting Summary sheets to show amounts spent, amounts committed, and amounts remaining. All contract expenditures, labor and/or materials, should be pre-authorized by S. J. Green or A. H. Jones at Terra Tek. This will usually be done at the monthly meeting, as was done at the first planning meeting.

ACTION ITEMS

1. Task 1.1.1. will be started by Bill Maurer and work will begin immediately.
2. Task 1.1.2. will be handled by Howdy Pratt and work will start immediately.
3. Task 1.2.1. will be started by Bill Maurer with help from Reed to obtain worn bits. Once a task plan has been formulated, Carel Otte (or his staff) at Union Oil should be contacted to seek Union Oil support at obtaining worn bits; Sidney Green will contact Union Oil. LASL should be contacted to obtain worn bits as possible; Bill Maurer will contact. Idaho-ERDA should be contacted to obtain their worn bits; Arfon Jones will contact. Utah Power and Light should be contacted to locate worn bits; Sidney Green will contact. Phillips (Utah operation) should be contacted to obtain worn bits; Howdy Pratt will contact.
4. Task 1.3. will be handled by Arfon Jones. Reed has provided considerable help here, and Arfon will need to coordinate with Chad Wiley regarding final arrangements.
5. Task 2.1.1. will be started by Bill Maurer with help from Reed. Professor William Leslie, University of Michigan, (formerly head of U.S. Steel Edgar Bain Research Laboratory) has been retained as consultant to work on this task. First discussion will be held with him on June 24, in Salt Lake City.
6. Task 3.1.1. will be started by Bill Maurer with help from Reed. Professor Larry DeVries, University of Utah, will be used as consultant

on this task. He will be briefed, and asked to begin work immediately; his role will be to search for "new-candidate" materials for the high temperatures.

7. Task 3.2.1. will be started by Bill Maurer with help from Reed.

TERRA TEK CONTRACT E(10-1)-1546

"DEVELOPMENT OF AN IMPROVED
GEOTHERMAL DRILL BIT"

Second Program Discussion Meeting for
the Geothermal Drill Bit Program

August 13, 1975

Signed: _____

Sidney Green

Sidney J. Green

TR 75-44
August 1975

FOREWARD

The Second Planning Meeting was held at Terra Tek on August 13, 1975. The objective was to present the research performed since the last Planning Meeting and to update the planned research for the next time period. The meeting was attended by Maurer Engineering, Reed Tool Company, Terra Tek staff and special consultants on the program. The next Program Planning Meeting is scheduled for sometime in September with the location as yet undecided.

OVERVIEW AND SUB-OBJECTIVES

The program is well under way and the following sub-objectives are being pursued. The comments below are made by S. Green after reviewing the overall program. Individual Task reports are included following the summary overview.

1. Heat Flow Analysis

An attempt is being made to determine the average bulk temperature of the drill bit as a function of time, for tripping in and out of the hole, for normal drilling, and for failure conditions (such as pump failure or pipe failure). Although this seems straight forward, design engineers do not have readily available the average time-temperature that the drill bit will see (even without adding heat energy due to bearing friction).

Additionally, the local temperatures within the drill bit versus time, particularly in the vicinity of the bearing and seals and in the vicinity of the inserts, would be desirable. This would require a much more complicated analysis, however.

The theoretical solution for this heat flow problem involves heat and mass flow as well as a moving boundary condition. The material properties, particularly thermal conduction coefficients for rock and drilling mud, and the heat transfer coefficient between drill bit and mud, and the mud and rock are not well known.

Heat flow calculations would not only be valuable for design of drill bits, but would be valuable for many other applications including: reservoir modeling, drill-pipe design and analysis, well casing loading, and other problem areas.

2. Geotechnical Analysis

An estimate is being made of the geology of the areas that are being drilled and that are most likely to be drilled in the next decade. More specifically, the rock type including strength, abrasiveness, and plasticity are desired for design engineers who will design the drill bits that will be used in the next decade.

An estimate of current formation temperatures and of expected temperatures is to be formulated, as well as details of the environments (particularly corrosiveness). It is intended that an approximate-number-of-feet drilled versus temperature will be plotted. This will provide designers with temperature requirements, and indicate the relative merits of improvements in a given high temperature capability.

3. Bit Failure Analysis

An organized systematic approach is being made to identify and understand as much as possible bit failures while drilling geothermal wells. To some extent this may have been done by individual companies, but whatever data are available are being kept proprietary. Visual observation will be made, expert opinion will be obtained and sectioning and analysis may be performed on selected drill bits.

Gathering of worn drill bits, including details of the drilling history - i. e., the bit record and well temperature, should provide a valuable assistance to industry in their efforts for improved design of geothermal drill bits.

4. New Steels

Candidate steels that will stand up for a "600 - 650° F" bit and an "800-900° F" bit are being determined. Some fundamental material property tests will be performed on these candidate steels as well as limited drill-bit tests, to add credibility to their candidacy. It is realized that not enough tests and analysis will be performed to fully develop new drill bits in this program, but information and tests are to be provided to help industry through the development stage as much as possible.

Generally, these high temperature steels are available. The problems in using them are in connection with adequate toughness to prevent cracking and adequate corrosion resistance characteristics.

5. Component Test Fixtures

A bearing and seal test facility is to be provided for use on this program. The large Drilling Research Laboratory test rig is to be modified slightly, and a high temperature chamber provided. This will give a versatile, servo-controlled test stand, with pressure and temperature capability. Bearing and seals can then be tested in this rig, and the rig can subsequently be used for cutting-structure evaluation if desired (particularly for retention-of-insert experiments).

Other tasks are being pursued which will lead to meeting the overall objective of the program. These tasks will be emphasized more as the program proceeds while the sub-objectives discussed above will be completed. Individuals working on different tasks are encouraged to be sensitive to the sub-objectives and the overall objectives of the program.

The following are separate sections on the various tasks with the information included as provided by each individual responsible for that task.

TASK 1.1.1 AND TASK 1.1.3

**William McDonald
Maurer Engineering**

DESIGN OF AN IMPROVED GEOTHERMAL BIT

TASK 1: Analysis of Heat Flow

1.1.1 Literature Search (McDonald)

1.1.3 Simple Bounding Calculations (McDonald)

Summary

An extensive literature search is being made to locate technical publications and computer programs relating to temperatures in geothermal wells. Several publications have been obtained which contain calculations of circulating temperatures in wells. Examples in these publications confirm the need for calculations of transient and steady state circulating temperatures in the design of geothermal bids. Attempts to locate and obtain a computer program to make these transient and steady state borehole temperature calculations have been unsuccessful; however, August 31 is a decision date to determine the direction of additional work and September 30 is a goal date to have completed the heat flow analysis. These target dates are discussed later in the paragraph on Plans.

Studies of Circulating Temperatures

The design of bits for drilling in very hot geothermal environments and the prediction and control of downhole drilling fluid properties depends on knowing circulating temperatures in the wellbore. A limited number of publications pertinent to this problem have been located. They are listed in the attached references. The problem is basically as follows:

Circulation of the drilling fluid during drilling operations is represented schematically in Figure 1.

Fig. 1- Schematic of Circulating Fluid System (Raymond, 1969)

This circulation has three distinct parts: 1) fluid enters the drill pipe at the surface and passes down through the drill pipe; 2) fluid exits the pipe through the bit nozzles cooling the bit and cleaning the cutters and entering the annulus at the bottom; 3) fluid returns up the annulus and exits the annulus at the surface. An accurate simulation of the thermal behavior of the fluid in this system must treat all three phases of the circulation including heat gain from the formation, transfer of heat between inside and outside of the drill pipe and heat generated by the bit.

In phase one, the fluid enters the drill pipe at a known temperature, and flow rate. As the drilling fluid flows down the pipe, temperature is determined by the rate of flow (forced convection) down the pipe, the rate of heat exchange between the drill pipe and the annulus, and time. Heat gain due to friction should be added but this is very difficult to estimate.

In phase two, the drilling fluid exists the bit and enters the annulus. Heat generated by the bit is added to the fluid at this point. Also at this point the boundary condition is imposed that the temperature is the same inside and outside of the drill pipe.

In phase three the fluid flows up the annulus. Its temperature is determined by the flow rate (forced convection) up the annulus, the rate of heat exchange between the adjacent formation and the fluid in the annulus, and time.

In order to properly account for the heat exchange between the formation and the fluid in the annulus, the computer model should include the capability of accounting for the effects of additional casing strings and cement or fluid behind the casing. Geometry for such a model is shown in Figure 2.

Figure 2.

Geometry for
Wellbore Temperature
Model.

The boundary conditions for such a model are usually 1) mud inlet temperature and circulation rate are known; 2) the inlet and outlet flow rate are the same; 3) the initial distribution of fluid temperature in the drill pipe and annulus is given by the geothermal gradient; 4) the formation is an infinite heat sink.

When circulation begins, temperatures along the length of the borehole change very rapidly. The bottom hole temperature becomes considerably cooler and temperatures near the surface become somewhat warmer than at equilibrium. Fig. 3 shows this time dependence of bottom hole and outlet temperatures for 20,000 ft. well. As may be seen from the figure, the initial

Fig. 3 - Time Dependence of Temperature after Initiating Circulation for a Simulated Well. (Raymond, 1969)

temperature of the formation is 400°F at the bottom but, under equilibrium circulating condition, the bottom hole fluid temperature (and hence the temperature the bit will see) is about 260°.

Fig. 4, which shows circulation being initiated and then stopped after 16 hours and the time dependence of borehole temperatures during these periods, illustrates two very important elements in the design of an improved geothermal bit. First, by adequately cooling the hole, including

Fig. 4 - Temperatures in a Simulated Well for Starting and Stopping Circulation. (Raymond, 1969).

breaking circulation as the bit is run into the hole, it may not be necessary to design geothermal bits to take the maximum temperatures of formations penetrated by the bit. Second, there is a time dependence such that if circulation is not maintained while the bit is in the hole (for example, there is a pump failure) then there is some period of time to reestablish circulation before damage will occur to the bit.

Figures 5-8 show details of the transient analysis for the particular case of a 20,000 foot well with 18 ppg, oil base mud. (Raymond, 1969)

Fig. 5 Temperature as function of depth at 2 hours of circulation time for a simulated well.

Fig. 6 Drill pipe temperature vs depth as a function of time for a simulated well.

Fig. 7 Annulus temperature vs depth as a function of time for a simulated well.

Fig. 8 Borehole wall temperature vs depth as a function of time for a simulated well.

Figure 5 shows temperature as a function of depth after two hours of circulation. Note that the formation between the surface and 12,000 feet has been heated and the formation between 12,000 and 20,000 feet has been cooled. Also, there is a reversal in temperature differential between the annular fluid and borehole wall at 10,000 feet so that the formation above 10,000 feet is being heated and the formation below 10,000 is being cooled at this particular circulation time.

Maximum fluid temperature occurs at 17,000 feet. This point will tend to move up the hole as circulation time increases. Raymond's studies indicated that the maximum temperature usually stabilized about one-fourth to one-third of the way up the annulus from the bottom of the hole. Of course, location of the maximum temperature point is dependent on parameters such as circulating velocity, mud weight, etc.

Figures 6 - 8 give additional temperature profiles for the fluid in the drill pipe, fluid in the annulus and for the borehole wall. In the cases studied by Raymond, the time to approach steady state was approximately 16 hours. This seems to be true for both cases tripping into and tripping out of the hole.

In tripping out of the hole there is no forced convection during the trip. Therefore, the important modes of heat transfer are heat exchange with the formation and conduction in the fluid. In general, conduction in the fluid was found to be negligible and the temperature during the trip was found to be well approximated by heat exchange with the formation assuming that the fluid temperature is equal to the formation temperature at the borehole wall.

It should be recognized that drilling fluid properties will be strongly influenced by temperatures to which the fluid is exposed. Fig. 9 shows a plot of the percent of fluid above a given temperature versus temperature. For geothermal system this type of calculation may become important in assessing degradation of borehole fluids.

Figure 9 - Percent of Fluid above a given temperature. (Raymond, 1969)

Raymond's model was used to generate type curves for a number of situations; these are shown in Figs. 10-13. While these curves could be used to determine steady state circulating bottom hole temperatures, the conditions under which the curves were developed will likely not apply in geothermal situations. In addition these are basically steady state conditions and the model proposed by Holmes and Swift (which has not been discussed) allows a simple calculation of this steady state temperature.

The validity of calculations such as those by Raymond (1969) and by Keller, Couch and Berry (1973) have been questioned by Sump and Williams (1973). In their study, Sump and Williams were able to use field data to determine heat transfer coefficients by regression analysis. Comparing results with these heat transfer coefficients with those used by others

Fig. 10 Difference between bottom-hole fluid and outlet fluid temperatures for 10 lb/gal oil based mud.

Fig. 11 Difference between bottom-hole fluid and outlet fluid temperatures for 18 lb/gal oil-base mud.

Fig. 12 Difference between bottom-hole fluid and outlet fluid temperatures for 10 lb/gal water-base mud.

Fig. 13 Difference between bottom-hole fluid and outlet fluid temperature for 18 lb/gal water-base mud.

led to differences in bottom hole temperatures as great as 60° F. In comparison, outlet mud temperature did not prove to be sufficient test of correct bottom hole temperature calculation.

The results of Sump and Williams indicate that while a good borehole circulating temperature model will be extremely useful in the design of geothermal bits, the calculation will be very sensitive to input parameters and to assumptions such as the linearity of the geothermal gradient. Their work also demonstrates that there will be a need to obtain field measurements of circulating temperatures in order to calibrate the model if it is to be used on a continuing basis in the design of bits and in the design of proper operating procedures for geothermal drilling.

Computer Models

Several organizations known or believed to have computer models for calculating borehole temperatures were contacted to try to obtain a model for use in design of an improved geothermal bit. These organizations were Exxon, Sun Oil, Halliburton, and Mobil. The request to Mobil is still open; other requests were met with a generally negative response.

In addition, Control Data Corporation and University Computing were contacted about the use of network simulators or contracting with them to develop a borehole temperature model. CDC submitted a proposal to adapt the MIDAS structural analysis package to this problem. The proposal is not acceptable because of the awkwardness to adapt a network analyzer to the circulating fluid problems, because the expense of using this powerful model would prohibit detailed parametric studies and because of the cost of their proposal (\$11,000).

We remain optimistic that an agreement can be reached with Mobil to use their model.

Plans

Plans for this work are to complete the search for publications and computer programs by 31 August. We will by that date have obtained a suitable computer model or defined an alternative procedure. If we have been successful in obtaining the needed model, the next step will be to identify the required parameters such as geothermal temperature gradient and borehole sizes needed to run the program. By 30 September, tentatively, a set of bounding calculations should be complete.

Should it be established by 31 August that a computer model is not available to us, than an alternative procedure will have to be established. Alternatives to be considered are:

- 1) develop a model to calculate both steady state and transient circulating temperatures in the borehole;
- 2) develop a simple model to calculate steady state circulating temperatures in the borehole;
- 3) defer further borehole temperature studies until preliminary bit designs indicate effective temperature constraints due to materials.

Alternative 3) should include recommendations as to later development of a borehole temperature computer model as well as detailing the consequences not pursuing model development at this time. Alternative 2) should detail the consequences of accepting the steady state solution, and alternative 1) should be explicit about the application of such a model and the availability of accurate input data for such a program.

REFERENCES

- Annis, M.R.: "High-Temperature Flow Properties of Water-Base Drilling Fluids", J. Pet. Tech. (Aug., 1967)
- API RP-10B, Recommended Standards for Testing Oil Well Cements.
- Couch, E.J., Keller, H.H., and Watts, J.W., "Permafrost Thawing Around Producing Oil Wells, " Canadian Journal of Pet. Tech. (April 1970).
- Edwardson, M.J., Girner, H.M., Parkison, H.R., Williams, C.D., and Matthews, C.S., "Calculations of Formation Temperature Disturbances Caused by Mud Circulation," Journal of Pet. Tech. April 1962, pp. 416-426.
- Farris, R.F., "A Practical Evaluation of Cements for Oil Wells, " Drill. and Prod. Prac., API, 1941, p.283.
- Holmes, C.S. and Swift, S.C., "Calculations of Circulating Mud Temperatures," Journal of Pet. Tech., June 1970, pp 670-674.
- Howell, E.P., and Perkins, T.K., "Temperature Calculations for Wells Which Are Completed Through Permafrost," S.P.E. Paper 3969 (1972).
- Keller, H.H., Couch, E.J., Berry, P.M., "Temperature Distribution in Circulating Mud Columns," Soc. Pet. Engr. Journal, Feb. 1973, pp. 23-30.
- Lea, J.F., " The Application of a Thermal Network Analyzes Program to Pipe and Wellbore-Heat Transfer," SPE 5548, to be presented at the 50th Annual Fall Meeting of SPE of AIME, Sept. 28-Oct.1, 1975, Dallas, TEXAS.
- Polyakov, G.G.: "The Effect of Flushing on the Temperature in a Borehole During Drilling:, Izv. Vyssh, uncheb. zavedenii Neft' i gaz (1965) No.9,31.
- Ramey, H.J., "Wellbore Heat Transmission," J. Pet. Tech. (April 1962) pp. 427-435.
- Raymond, L.R., "Temperature Distribution in a Circulating Drilling Fluid," Journal of Pet. Tech., Mar. 1969, pp. 333-342.
- Shell, F., and Tragesser, A.F., "API Is Seeking More Accurate Bottom-Hole Temperatures, : The Oil and Gas Journal, July 10, 1972, pp. 72-79.
- Sump, L.D. and Williams B.B., "Prediction of Wellbore Temperatures During Mud Circulating and Cementing Operation", ASME paper N. 73-Pet-6, presented at the Petroleum Conference, Los Angeles, Calif., Sept. 16-20, 1973.
- Tragesser, A.F., Crawford, P.B., and Crawford, H.R., "A Method for Calculating Circulating Temperatures, : Journal of Pet. Tech., Nov. 1969, pp. 1507-1912.

Tragesser, A.F., and Parker, P.N., "Using Improved Technology to Obtain Better Cement Jobs on Deep, Hot Lines, : Journal of Pet. Tech., Nov. 1973, pp. 1307-1313.

Wheeler, J.A., "Analytical Calculations for Heat Transfer from Fractures", SPE 2494, presented at the Annual Fall Meeting of SPE of AIME, 1969.

TASK 1.1.2

GEOTECHNICAL ANALYSIS

Howard Pratt
Terra Tek, Inc.

Task 1.1.2 Geotechnical Studies

The objectives of this task are (1) to delineate the important factors in the geothermal environment that will affect drilling; (2) to compile a detailed description of the geologic environment of producing and potential geothermal areas.

The nature of the geothermal resources that will be explored and developed over the next decade will be the following types:

1. Vapor dominated hydrothermal systems
2. Liquid dominated hydrothermal systems
3. Geopressured sedimentary basins
4. Hot dry rock formations.

The depths of primary interest for current geothermal resources range between two and about 12,000 feet, although the hot dry rock reservoirs could be considerably deeper. We will not consider the magma source as potential geothermal resource in this study. Important factors to be considered that will affect drilling are the rock type, geologic structure, temperature, pressure and fluid chemistry. All of these factors will have an important bearing on the rates of penetration, bit life and the mud chemistry of the drilling fluids to be used in the geothermal environment. The data base for this information will come primarily from drill holes in producing and potential geothermal areas. In addition, data such as regional heat flow, regional geologic studies and geophysical surveys can be used to make inferences about the geothermal environment. Geological environment of a typical geothermal reservoir is shown in Figure 1 and consists of the following parts:

1. An impermeable cap which, in effect, seals the geothermal reservoir from the surface.

2. A reservoir rock which is usually highly fractured and which serves as the aquifer system.
3. A conduit structure in the form of faults or shear zones along which the geothermal fluids can migrate from below, and
4. The heat source.

The parts of the geothermal system are shown for the Cerro Prieto field in Mexico. Figure 2 shows the areas in the western U. S. where geothermal data is available. Figure 3 shows the known geothermal resource areas (KGRAs) in the western U. S. (Ref. 1). These areas will form the basis of the study of potential geothermal areas. The predominant areas that will be investigated are shown in Table 1, and will form the basis for this study.

A typical example of the types of information to be gleaned from a potential geothermal resource is exemplified by the Salton Sea area (Figure 4). Geothermal anomalies include the Dunes, East mesa, Brawley, Nyland and Salton Sea areas. Drill hole locations are shown in Figure 5; wells have been drilled to depths of approximately 7000 feet. Figures 6 and 7 show plots of temperature versus depth and concentration of total dissolved solids versus depth for the wells in the previous figure. A cross section of the Cerro Prieto field (Figure 1), just south of the Salton Sea, which has the same geologic environment, shows the lithology and geologic structure of the area with the impermeable clay cap, underlain by permeable sandstone and shales and the highly fractured aquifer zone. The heat source is shown diagrammatically (Ref. 2).

Tentative rocks that must be considered in drilling the geothermal environment include all three rock types: sedimentary, igneous and metamorphic.

Specific rock types that are expected to be encountered are included in Table 2.

Future Work

1. Several geothermal drilling sites will be visited where geologic and geophysical logs will be examined.
2. The geologic and geophysical logs will be correlated with drilling and bit performance records.

Figure 1. Geologic Structure and Stratigraphy of the Cerro Prieto Geothermal Resource (Reference 1)

Figure 2. Areas in Western United States with Geothermal Well Data (Reference 2)

Figure 3. Areas Classified as Known Geothermal Resource Areas in Western United States (Reference 2)

Figure 5. Well Location Map of Salton Sea Geothermal Area (Reference 3)

Figure 6. Temperature as a Function of Depth for Salton Sea Geothermal Wells (Reference 3)

Figure 7. Concentration of Total Dissolved Solids as a Function of Depth for Salton Sea Geothermal Wells

TABLE 1

UNITED STATES

Producing

- Geysers, Ca.

Development Drilling

- Imperial Valley, Ca.
- Valle Grande, N. M.

Exploratory Drilling

- Milford, Utah
- Raft River, Idaho
- Chandler, Arizona
- Beowawe, Nevada
- Hawaii, Hawaii
- Marysville, Montana
- Long Valley, Ca.
- Jemez Caldera, N. M.*

* Hot dry rock

TABLE 2

ROCK TYPES

Cap Rock

- Igneous

Rhyolite

Basalt

- Metamorphic

Greenstone

Metarhyolite

- Sedimentary

Mudstone and Shale

Sandstone

Limestone

Reservoir Rock

- Igneous

Tuff

Rhyolite

Basalt

Granite

- Sedimentary

Sandstone (low porosity)

- Metamorphic

Equivalents of the reservoir rocks mentioned above.

REFERENCES

Jet Propulsion Laboratory, "Status Report Geothermal Program Definition Project Part II: Geothermal Energy Development Status," Technical Report 1200-205, April 1975.

Mercado, S., "High Activity Hydrothermal Zone Detected by Na/K, Cerro Prieto, Mexico," *Proceedings of the United Nations Symposium on the Development and Utilization of Geothermal Resources*, Pisa, October 1970, Vol. 2 Part 2, p. 1367-1376.

Helgeson, H. C., "Geologic and Thermodynamic Characteristics of the Salton Sea Geothermal System," *Am. Jour. Sci.*, Vol. 266, March 1968, p. 129-166.

TASKS 1.2.1 and 1.2.2

Arfon Jones

and

Howard Pratt

Terra Tek, Inc.

POTENTIAL BIT SOURCES

1. Vapor dominated systems

Geysers

Union

Shell

Curma

2. Liquid dominated systems

High temperature - high salinity

Salton Sea

Republic Geothermal

Phillips

Moderate to high temperature - salinity (?)

Roosevelt Area, Utah

Phillips

Valle Grande, N. M.

Union

Low to moderate temperature - low salinity

Raft River, Idaho

INEL

Marysville, Montana

Battelle

SMU

3. Hot dry rock

Jemez Caldera, N. M.

Los Alamos

RAFT RIVER GEOTHERMAL PROJECT
(Bottom Hole Temperature 290 - 300° F)

BIT	FORMATION	DEPTH DRILLED* (FEET)	TIME (HOURS)	DRILLING FLUID	LOAD (1000 lbs)	RPM
Smith Tool Company 12½" DGHJ bit	Tuffaceous Siltstone & Sandstone	2470 thru 3054	20½	Mud ⁺	10-15	90
Smith Tool Company 12½" 9JS bit	Extremely hard Quartzite	5335 thru 5523	32	Water	40	45

* Ground level 4845 ft. elevation

+ Input mud temperature 160° F
Return mud temperature 180° F

TERRA TEK INC.

MEMO

To SID

From HOWDY

Subject Geothermal Drill Bit Discussions Date August 5, 1975
Aug. 1, 1975 with Dr. Pat Muffler (USGS)

re: USGS drill holes. Dr. Muffler said that they did not have any deep drill holes but that most of his were for heat flow or hydrologic data. He felt that the only possibility was Yellowstone which was drilled 7 or 8 years ago, and he had no idea where the bits might be and doubted if they could be found. Sprague and Henwood of SLC did the drilling, so I will try to contact them. He suggested that we contact two other people: One, Mike O'Donnell of Geothermal Kinetics. He said he saw some bits from the Chandler, Arizona wells and they looked pretty chewed up. Whether this was due to temperatures or the caustic nature of the fluids, he didn't know. Sid, have you contacted him? He also suggested I contact Dr. Bob Rex of Republic Geothermal in Whittier, California (213) 698-2255, home phone (213) 691-6843 for a possibility of getting some geothermal drill bits.

I also talked with Jim Kuwada of Rogers Engineering who is in charge of the Marysville, Montana program under Battelle. He indicated that they might have some drill bits available. Subsequent to this, one of his engineers, Wynn Bott, said that he was up on the rig and that there were a couple of 12 1/4 inch bits in a storage shack in Helena and this has been turned over to Battelle and to contact Bill McSpadden (509) 946-2367. He also said that Dave Blackwell and some of his graduate students had some of the smaller bits (7 7/8 inch) and that the Mayor of Marysville, Montana had taken some 7 7/8 and 12 1/4 bits for souvenirs for the town. Bott said they were just publishing a report on bit performance and he would send that along to me. He indicated over the phone that they used mostly Security bits, the H100's and that these were the best but that inserts dropped out at surprisingly low temperatures. He had a bag of these inserts. He also said that one Hughes bit with a journal bearing was a very good performer.

I also talked with Blain Martinsen of Smith Tool in Vernal, Utah who supplied Phillips with bits in the Milford area and he indicated that they did not have any of the bits. I subsequently recalled Bill Berge and he indicated that he would contact his field man and that they would cooperate in terms of getting bits; and he would get back to me in terms of how to go about it.

I will contact both McSpadden and Rex on Monday.

Charles W. Berge
Phillips Petroleum Company
11526 Sorrento Valley Road
San Diego, California 92121

July 9, 1975

Dear Bill,

This letter is intended to confirm the conversation that you and Howard Pratt had regarding obtaining worn drill bits from your geothermal program. We have a contract from ERDA to "develop an improved geothermal drill bit", Contract E-(10-1)-1546. This contract calls for gathering worn geothermal drill bits and assessing failure mechanisms as is possible. We intend to inspect these worn drill bits, and in some cases, section and do metallurgical investigation on the metals.

Along with each worn bit we request as much information as possible about the location of the drill hole, the geology, the interval drilled, the bit record, and the temperature at that depth. We are most interested in the bits that are drilled at the highest temperatures, and we will keep your data as confidential as might be required. We realize that much of the requested data will be proprietary to Phillips and that you will only be able to release certain information. We are interested in bits from the Imperial Valley, the Geysers area, and from Utah if possible.

Viewing of the worn drill bits and information from the detailed inspections of some of the bits will certainly be available to you. Additionally, we will provide proper credit to you and to Phillips. We can pay for shipping of the bits, and if you desire, they can be sent collect. We are interested mainly in tri-cone roller bits and to a lesser extent, roller coring bits. Because of the expense of diamond bits, we do not envision inspecting any diamond bits.

Thank you for your help. We appreciate the support given by Phillips Petroleum Company.

Very truly,

Sidney J. Green
President

SJG/va

cc: Morris Skalka
W. C. Maurer
Howard Pratt

Bert McCormack
President
Geo-Drilling
P. O. Box 736
Gilbert, Arizona 85234

July 10, 1975

Dear Bert,

This letter is intended to confirm our telephone conversation regarding obtaining worn drill bits from your geothermal program. We have a contract from ERDA to "develop an improved geothermal drill bit", Contract E-(10-1)-1546. This contract calls for gathering worn geothermal drill bits and assessing failure mechanisms as is possible. We intend to inspect these worn drill bits, and in some cases, section and do metallurgical investigation on the metals.

Along with each worn bit we request as much information as possible about the location of the drill hole, the geology, the interval drilled, the bit record, and the temperature at that depth. We are most interested in the bits that are drilled at the highest temperatures, and we will keep your data as confidential as might be required. We realize that much of the requested data will be proprietary to Geo-Drilling and that you will only be able to release certain information. We are interested in bits from the Imperial Valley, the Geysers area, and from Utah if possible.

Viewing of the worn drill bits and information from the detailed inspections of some of the bits will certainly be available to you. Additionally, we will provide proper credit to you and to Geo-Drilling. We can pay for shipping of the bits, and if you desire, they can be sent collect. We are interested mainly in tri-cone roller bits and to a lesser extent, roller coring bits. Because of the expense of diamond bits, we do not envision inspecting any diamond bits.

Thank you for your help. We appreciate the support given by Geo-Drilling.

Very truly,

Sidney J. Green
President

SJG/va

cc: Dr. Val Finlayson
Dr. W. C. Maurer
Mr. Mike O'Donnell
Mr. Morris Skalka

July 3, 1975

Mr. Don Ash
Union Oil Company
P. O. Box 6854
Santa Rosa, California 95401

Dear Don:

This letter is intended to confirm our conversation regarding obtaining worn drill bits from your geothermal program. We have a contract from ERDA to "develop an improved geothermal drill bit," contract E-(10-1)-1546. This contract calls for gathering worn geothermal drill bits and assessing failure mechanics as is possible. We intend to inspect these worn drill bits, and in some cases, section and do metallurgical investigation on the metals.

Along with each worn bit we request as much information as possible about the location of the drill hole, the geology, and the interval drilled, the bit record and the temperature at that depth. We are most interested in the bits that have drilled at the highest temperature, and we will keep the data as confidential as might be required. We realize that much of your data will be proprietary to Union Oil Company and that you will only be able to release certain information. We are interested in bits from the Imperial Valley area, the Geysers area, and from New Mexico, and hope that some bits might be available from all three areas.

Viewing of the worn drill bits and information from the detailed inspections of some of the bits will certainly be available to you. Additionally, we will provide proper credit to you and to Union Oil Company. We can pay for shipping of the bits and if you desire, they can be sent collect. We are interested mainly in tricone roller bits and to a lesser extent, roller-cone coring bits. Because of the expense of diamond bits, we do not envision inspecting and sectioning any diamond bits.

Thank you for your help; we appreciate the support Union Oil Company is giving.

Very truly,

Sidney J. Green,
President

cc: Don Outmans
Morris Skalka
W. C. Maurer

July 2, 1975

Dr. John C. Rowley
Los Alamos Scientific Laboratory (MS 570)
P.O. Box 1663
Los Alamos, New Mexico 87544

Dear John:

This letter is intended to confirm our conversations regarding obtaining worn drill bits from your geothermal research program. We have a contract from ERDA to "develop an improved geothermal drill bit", contract E(10-1)-1546. This contract calls for gathering and assessing as is possible selected worn geothermal drill bits. We intend to inspect these bits and in some cases section and do metallurgical investigations on the metals.

Along with each worn bit we request as much information as possible about the location of the drill hole, the geology, the interval drilled, the bit record, and the temperature at that depth. We are most interested in the bits that have drilled at the highest temperatures, and we will keep the data as 'confidential' as might be required by the dictates of your program.

Viewing of the worn drill bits and information from the detailed inspections of some of the bits will certainly be available to you. Additionally, we will provide proper credit to you and your program. We can pay for shipping of the bits, and if you desire they can be sent collect. We are interested in both tricone roller bits and roller coring bits. Because of the expense of diamond bits, we do not envision inspecting and sectioning any diamond bits.

Thank you very much for your help--we appreciate the support you are giving.

Very truly,

Sidney J. Green
President

SJG/as

cc: D. Simms
M. Skalka
B. Maurer

TASK 2. 1. 1
NEW STEELS

Material Choices for Geothermal Drill Bits
to Operate at a Maximum Temperature of 600° F

William Leslie
University of Michigan
(Consultant to Terra Tek)

Typical Materials Used in Current Rolling Cutter Bits*

Cones

AISI 4815, forged, machined, carburized to 0.07-0.13 in. deep, quenched and tempered

Bit Bodies

AISI 5220, forged and machined. Bearing pin carburized in ball and roller bearing races. Nose bearing and thrust surfaces hard faced and ground.

Nose Bushing

AISI Type 430 stainless, press fit into cone, carburized on inner surface.

Nose Buttons

AISI M2 tool steel, air quenched and double tempered.

Balls and Rollers

AISI 52 tool steel, oil quenched and tempered.

Hard Facings

Group 4 A (Co base)

* K. W. Coffman and J. Connors, "Rolling Cutter Bit Development and Application in the Mining Industry", Symposium on Materials for the Mining Industry, Climax Molybdenum Co., June 1974, p. 111

PROPOSED MATERIALS

Cones

H11, Medium Alloy, High-Strength Steel Several Producers

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>
.35	.30	1.00	5.20	1.50	.40

Processing

Forge, 2000°-1650°F, slow cool
Anneal 1600F, slow cool
Machine to shape
Pack carburize, 1800°F
Air cool
Temper 1050°F, 2+2 hours

Properties (Room Temperature, core only)

.2% offset yield strength	230,000
UTS	270,000
RA	47%
Elong	13%
Hardness	53RC

600°F

.2% offset yield strength	217,000
UTS	266,000
RA	38%
Elong	13.0%
Hardness	53RC

Notes

H11 may amount to "overkill" when used at 600°F. However, there is a good chance that this steel would also be a good candidate for use at 800°F.

The principal problem with H11 is probably cost.

Cones (2nd Choice)

M50 tool steel
any supplier

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>
.80	.30	.20	4.10	4.25	1.00

Processing

Forge between 2000 and 1700°F
Anneal 1525-1550, slow cool
Austenitize 2000-2100F
Oil Quench
Temper 1000°F, 2+2 hours

Properties (Room Temperature)

0.2% offset yield strength	338 ksi
UTS	410 ksi
RA	1.7%
Elongation	1.6%
Hardness (Rc)	64

at 800°F

0.2% offset yield strength	262 ksi
UTS	345 ksi
RA	12%
Elongation	6%
Hardness (Rc)	57

Coefficient of thermal expansion 70-800°F $7.05 \times 10^{-6}/^{\circ}\text{F}$

Bit Bodies

Crucible Hy Tuf
Crucible Steel Division, Colt Industries

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Cr</u>	<u>Ni</u>	<u>Mo</u>
.25	1.30	1.50	0.35	1.80	0.40

Processing

Forge, 2200F-1650F
Anneal, 15-20 hours 1200F
Machine
Carburize, 1600°F, oil quench
Temper, 700°F, 2 hours
Welding: Use low-H₂, Hy-Tuf rods

Properties (Room Temperature, core only)

0.2% offset yield strength	193 Ksi
UTS	230 Ksi
RA	53%
Elong	14%
Hardness	45RC

Properties - 600°F

Not available

Notes

The high silicon content of this steel allows an increased tempering temperature, with high strength. On the other hand, the high silicon content decreases the depth of a carburized case. Cost is only slightly higher than AISI 4815.

The principal problem with this grade will be availability.

Bit bodies (2nd Choice)

Thermold J Hot Work Tool Steel
Universal Cyclops

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Cr</u>	<u>V</u>	<u>Mo</u>	<u>Ni</u>
.50	.40	1.00	5.00	1.00	1.40	1.50

Processing

Forge 2000-1605°F
Anneal 1550-1600°F
Austenitize 1800-1850°F
Quench in still air
Temper 975°F, 2 + 2 hours

Properties (Room Temperature)

0.2% offset yield strength	259 ksi
UTS	310 ksi
PA	15%
Elongation	5%
Hardness (Rc)	57

at 800°F

0.2% offset yield strength	190 ksi
UTS	218 ksi
RA	40%
Elongation	10%
Hardness (Rc)	not available

Less weldable than H13.

Balls and Rollers

M 50 High-Temperature Bearing Steel
Any Supplier

See previously listed properties in "Material Choices for
Geothermal Drill Bits" August 13, 1975.

NEW BEARINGS AND SEALS

William Maurer
Charles Ward

Maurer Engineering

2.1.1 Literature Search: Bearings

3.2.1 Literature Search: Seals

A literature search has been conducted in order to evaluate the present state-of-the-art, thus providing a basis for development of improved roller bit bearings and seals for high temperature geothermal drilling. The Tulsa University Petroleum Abstracts, Rice University Library, Reed Tool Company files and other private and industry literature and patent files have been examined.

More than 130 published articles on the general subject of geothermal energy have been identified through the search. Five articles and reports relating to geothermal drilling and drilling problems were found, although none of these are concerned specifically with bits and/or bit problems. However, copies of these articles are being obtained to determine if any useful information concerning bit failure or problems is mentioned.

More than 300 U.S. patents (as well as a number of foreign patents) on roller bit bearings, seals and lubrication systems have been identified. Copies of these patents have been ordered and to-date approximately 225 have been received. A sequential listing by patent number with subject categorization has been started and is expected to be completed during the next two month period. In addition, specific patents thought to have significance to the development of seals and bearings in bits for geothermal drilling will be abstracted for ready reference and study.

In an attempt to eliminate unnecessary duplication of effort and at the same time reduce the chance of overlooking potentially good ideas, a pictorial and descriptive history of the developments in roller bits from their inception in about 1909 to the present is being assembled (Table 1). Patents, manufacturers' literature and other technical publications are being used to obtain the necessary background. This historical review should also be completed within the next two month period.

The initial literature search and review tasks for both the new bearing design and the new seal design tasks (2.1.1 and 3.2.1) should

be completed by the next project review meeting in mid-October. Consideration of possible new bearing and seal designs bases on state-of-the-art information will already have been started. Selection of several promising candidates for manufacture and testing should be accomplished before the end of December.

TABLE I
HISTORY OF ROLLER BIT DEVELOPMENT
(TENTATIVE - INCOMPLETE)

<u>YEAR</u>	<u>COMPANY</u>	<u>DEVELOPMENT OR FEATURE INTRODUCED</u>
1909	Hughes	Roller cutter bits
1916	Reed	Company founded
1917	Reed	Licensed Humason cross-roller bit (friction bearings)
1921	Reed	Mud lubricated friction bearings
1925	Hughes	Self-cleaning cones
1926	Reed	Roller bearing bits
1933	Hughes	Tricone bits with interfitting teeth on rollers
1939	Reed	Forged lug, welded body bits
1940's	Reed	Jet cleaning of cutters
1950	Reed	Twin jets
1951	Hughes	Insert cutter bits
1952	Reed	Insert cutter bits
1953	Hughes	Integral jet nozzles
1960	Reed	Sealed bearing, insert bit with replaceable nozzles
1967	Reed	Sealed bearing with long inserts and skewed cones
1968	Reed	Sealed friction bearings
1970	Hughes	Silver inlay journal bearing bits
1972	Reed	Floating bushing friction bearings(Beryllium copper)

ASSOCIATED TASKS

2.1.1 Literature Search: Bearings

3.1.1 Literature Search: Seals

A literature search has been conducted in order to provide a basis for development of improved roller bit bearings and seals for high temperature geothermal drilling. The Tulsa of University Petroleum Abstracts, Rice University Library, Reed Tool Company files and other private and industry literature and patent files have been examined.

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In an attempt to eliminate unnecessary duplication of effort and at the same time reduce the chance of overlooking potentially good ideas, a pictorial and descriptive history of the developments in roller bits from their inception in about 1909 to the present is being assembled. Patents, manufacturers literature and other technical publications are being used to obtain the necessary background. This historical review should also be completed within the next two-month period.

COMPONENTS OF ROLLER BEARING

COMPONENTS OF SEALED FRICTION BEARING

TERRA TEK CONTRACT E(10-1)-1546

"DEVELOPMENT OF AN IMPROVED
GEOTHERMAL DRILL BIT"

Third Program Discussion Meeting for
the Geothermal Drill Bit Program

December 10 and 11, 1975

Signed:

Sidney J. Green

TR 75-66
December 1975

Third Program Discussion Meeting for the Geothermal Drill Bit Program

ATTENDEES:

Terra Tek

Sidney Green
Arfon Jones
Howdy Pratt
Lynn Barker
Alan Black
William Leslie, Consultant (University of Michigan)

Maurer Engineering

Bill Maurer, Houston
Bill McDonald, Houston

Reed Tool Company

Dewey Thiessen, Houston
Bill Schumacher, Houston
Bob Truman, Houston

ERDA/INEL

Robert Doyle, Idaho Falls

ERDA/LASL

Darrell Sims, Los Alamos

FOREWORD

The Third Program Discussion Meeting was held in Salt Lake City at Terra Tek the afternoon of December 10 and December 11, 1975. The discussion of current geothermal drilling activities and of geothermal drill bit life and characteristics occurred on December 10th, while December 11th consisted primarily of program planning for the remainder of the contract.

TOPICS COVERED

1. Discussion of Los Alamos Geothermal Drilling Program

Darrell Sims from LASL gave a detailed presentation for their drilling program including drilling characteristics and much valuable information about real-world drilling problems.

2. Discussion of Current Geothermal Drilling Activities

Howdy Pratt presented a review of his recent visits and contacts with companies actively drilling. The presentation included considerable discussion of drilling techniques and drilling characteristics, as well as the types of formations that are being drilled. The report of this part of the drill bit program is being prepared and will be available in early 1976.

3. Discussion of Worn Drill Bits

Lynn Barker presented information on drill bits inspected including detailed data on worn drill bits. These data will all be presented in the final report for the program.

4. Heat Flow Calculations

Bill McDonald presented the results of their steady state calculations as well as discussed the calculations to be made by Exxon using their thermal simulator. The details of these calculations will be presented in the topical report including the drill bit temperature analysis.

Bill McDonald and Howdy Pratt are to meet to insure that we have used the most representative and best estimate of the in situ conduction/convection coefficient for the thermal calculations.

5. Patent Search Briefing

Bill Maurer presented a briefing on his patent search. The results of this patent search analysis are included in a topical report which has been previously published.

6. Geotechnical Data

Howdy Pratt presented rock mechanics data for geothermal reservoirs. He presented an estimate of the kind of rock and some comparison to other rocks that exist for reservoirs that are now being drilled and might be drilled in the near future. The results of this study will be presented in a report (the report mentioned above in Item 2).

7. Future Test Program

Lynn Barker presented the proposed tests to include obtaining base-line data, full-scale tests, and new seal materials research to be performed on the remainder of the contract. In general, the program is on schedule. The current contract is expected to be completed by May 1, 1976. No major problems affecting the schedule or the funding of the contract were foreseen by Lynn Barker.