2
SAND79-7125
Unlimited Release
Category UC-66c

PROGRAM FOR THE IMPROVEMENT OF DOWNHOLE DRILLING-
MOTOR BEARINGS AND SEALS, PHASE III, PART 2:
FINAL REPORT

MASTER

Terra Tek
Salt Lake City, Utah 84108

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of
Energy under Contract DE-AC04-76DP00789

March 1980

Work performed under Sandia Contract No. 07-7298
for the Geothermal Drilling and Completion
Technology Program for the Department of Energy,
Division of Geothermal Energy

Sandia Laboratories

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.

Issued by Sandia National Laboratories, operated
for the United States Department of Energy by
Sandia Corporation

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the 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.

Printed in the United States of America
Available from:
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$5.50; Microfiche \$3.00

SAND79-7125
Unlimited Release

Category UC-66c

PROGRAM FOR THE IMPROVEMENT OF
DOWNHOLE DRILLING-MOTOR BEARINGS AND SEALS*

PHASE III, PART 2: FINAL REPORT

Terra Tek
Salt Lake City, Utah 84108

ABSTRACT

This report documents 6 months of activity in a program to improve downhole drilling-motor bearings and seals for geothermal applications.

DISCLAIMER

This book 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.

*Work performed under Sandia Contract No. 07-7298; sponsored by U.S. Department of Energy, Division of Geothermal Energy.

fy

2. C

C

FOREWORD

This report summarizes the work performed for the second six month period of Phase III - Part 2 of the DOE/DGE Contract Number 07-7298, "Program for the Improvement of Downhole Drilling Motor Bearings and Seals".

This reporting period saw three main areas of development for the project:

1. Completion of test BSP-01, the first test in the Bearing-Seal Package Test Facility
2. Further testing of candidate non-elastomer seals and the testing of the first generation elastomer Canted Seal
3. Lubricant tests on modified Pacer PLX-014 samples with EP additives and testing of Pacer PLX-014 for degradation with water

This report will have four major sections: Seal Testing and Evaluation, Bearing-Seal Package Testing and Evaluation, Lubricant Testing and Evaluation, and Program Status, Plans and Schedule. It will cover progress on the contract from May 1, 1979 through October 31, 1979.

TABLE OF CONTENTS

	<u>Page</u>
List of Illustrations.	8
Acknowledgements	11
Introduction	13
Summary	19
Seal Testing and Evaluation	27
I. Seals	29
II. Seal Test Results.	41
III. Conclusions.	50
IV. Future Work.	51
Bearing-Seal Package Testing and Evaluation.	55
I. Bearing-Seal Package Test Results.	57
II. Bearing-Seal Package Test Facility	61
III. Conclusions.	67
IV. Future Work.	68
Lubricant Testing and Evaluation	73
I. Lubricant Test Results	75
Program Status, Plans and Schedule	79
Bibliography	85
Appendix A - Seal Test Results	91

LIST OF ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
1	<i>Grafoil</i> ^R - Brass Seal Cross Section	29
2	Canted Seal Package	30
3	Graphite-Metal Matrix Seal Ring	31
4	Modified Bearing-Seal Package Bearing Make Up Sub Containing Redundant Seals	33
5	Porous Filter Assembly	35
6	Piston Assembly	36
7	Back Up System I - SAE 660 Bearing Bronze with "O" Ring	38
8	Back Up System II - TFE and Bronze	39
9	Back Up System III - Flexing Leaves	40
10	Formation of <i>Grafoil</i> ^R Seal on Mandrel	43
11	Cross Section of <i>Grafoil</i> ^R Seal After Formation	44
12	Cross Section of <i>Grafoil</i> ^R Seal with Ribbons Separated	44
13	Thermal Conductivities of <i>Grafoil</i> ^R Ribbon	45
14	DMT-032 Test Seal Pack	47
15	DMT-032 Test Seal Pack	47
16	Upper Seal Pack After DMT-033	49
17	Lower Seal Pack After DMT-033	49
18	Shaft Seal Sleeve	59
19	Detail of Upper Seal Area on Shaft Seal Sleeve	59
20	Detail of Upper Seal Pack	60
21	Bearing-Seal Package Test Facility Systems	63
22	Wear Block from Test Number 162	75
23	Wear Block from Test Number 163	76

TABLE

I	Major Milestones	17
II	Seal Test Results	42
III	Tests on Candidate <i>Grafoil</i> ^R and Graphite- Metal Matrix Seals	52
IV	Tests on New <i>Grafoil</i> ^R Seals	53
V	Tests on II Canted Seals with High Temperature Elastomers	53
VI	Tests on New Candidate Seals	54
VII	Bearing-Seal Package Tests with <i>Grafoil</i> ^R Seals	68
VIII	Bearing-Seal Package Tests with Redundant Seals	69
IX	Bearing-Seal Package Tests with Cooling Modifications	70

TABLETITLEPAGE

X	Bearing-Seal Package Tests with Different Shaft Coatings	70
XI	Full-Scale Motor Testing	71
XII	Phase IV Schedule	84

ACKNOWLEDGMENTS

Terra Tek would like to thank the following individuals and companies for their valuable technical support and interest in this program:

1. Hank Miser, Fred Pippert and Ray Snow of Utex Industries, Inc., for their help with seals
2. Don Twomey of Pacer Lubricants, Inc., for his help with lubricants and for supplying candidate lubricant samples for testing
3. Christensen Diamond Products for supplying candidate lubricant samples for testing
4. Kurt Trzeciak, John Tschirky and Bela Geczy of Dyna Drill for assisting in the design of the interconnecting parts for the Bearing-Seal Package and recommending candidate lubricants for testing
5. Jim Estep of Eastman Whipstock for assisting in the design of the interconnecting parts for the Bearing-Seal Package
6. A.E. Goldman of Union Carbide Corporation for his help with *Grafoil*^R

INTRODUCTION

INTRODUCTION

This report deals with the work completed during the second six months of the third year effort on the DOE/DGE Contract Number 07-7298, "Program for the Improvement of Downhole Drilling Motor Bearings and Seals".

Increased drilling rates are characteristic of downhole turbines and motors and can reduce drilling costs for wells of all types. In geothermal wells, where drilling costs are generally two to three times greater than oil and gas wells, the potential cost savings become very significant.

In addition to reducing drilling costs by increasing drilling rates, downhole motors have many advantages over conventional rotary drilling, including, (1) the reduction of drill pipe and tool joint wear, (2) reduction of vibration and fatigue failures and (3) reduction of casing wear and borehole instability.

The main problem that limits the widespread use of downhole motors is their relatively short drilling life which is on the order of 20 to 40 hours. The primary cause of the short drilling life of downhole motors is premature bearing failure. In general, bearings are damaged when the lubricant seals fail and allow abrasive mud to contact the bearings.

The key to longer and economically significant downhole motor life is the development of a successful Bearing-Seal Package that can better withstand conditions under which downhole motors are exposed. The purpose of this program is to develop a significantly improved Bearing-Seal Package that can be used by industry.

The specific objectives of this program are as follows:

- (1) Develop a lubricated Bearing-Seal Package with a life of over 200 hours

- (2) Develop an improved rotary seal which allows bit pressure drops over 1,000 psi
- (3) Develop a Bearing-Seal Package to operate at 250⁰F circulating bottomhole temperature.

The major accomplishments of the program to date have been:

- (1) Design and fabrication of a Downhole Motor (DHM) Seal Test Machine
- (2) Screening tests on elastomer and non-elastomer seals in the DHM Seal Test Machine
- (3) Development of "zero clearance" back up systems for *Grafoil*^R and Graphite-Metal Matrix seals
- (4) Screening tests on lubricants in the Terra Tek High Temperature Lubricant Tester, and selection of candidate lubricants for testing in the Bearing-Seal Package
- (5) Design and fabrication of a Bearing-Seal Package
- (6) Design and fabrication of a Bearing-Seal Package Test Facility
- (7) Completion of the first test (BSP-01) in the Bearing-Seal Package Test Facility

The major milestones of the program are shown on the following page.

MAJOR MILESTONES

1976

1977

1978

1979

1980

D, J

D, J

D, J

D, J

MILESTONES	Mar	Sept	Oct	Sept	Oct	Sept	Oct	Sept	Oct	Sept
	FY'76		FY'77		FY'78		FY'79		FY'80	
Survey New Drilling Motor Concepts	▼									
Selection of Candidate Seals and Bearings		▼								
Complete Design of Seal Bearing Assembly			▼							
Complete Design of Seal Tester			▼							
Seal Tester Operational			▼							
Complete Testing of Seal Packs							▼			
Complete Design of Seal-Bearing Assembly Test Stand					▼					
Laboratory Evaluation of First Seal-Bearing Assembly							▼			
Full-Scale Laboratory Tests								▼		
Test Final Bearing-Seal Pack Configuration with Improved Cooling									▼	
Laboratory Evaluation of Full-Scale Shaft Surfaces									▼	
Final Laboratory Evaluation of Redundant Seal Systems										▼
Laboratory Evaluation of Dynamic Response of Bearing-Seal Package with and without Shock Tools										▼
First Laboratory Evaluation of Motor Interfacing Members										▼
Field Evaluation										▼

Table I
Major Milestones

SUMMARY

SUMMARY

In the Phase III - Part 2 Semi-Annual Report (TR79-38), a summary of the major accomplishments of each phase of the program was given. In this report, the summaries of Phase I, Phase II and Phase III - Part 1 will be reproduced, and a summary of Phase III - Part 2 will be added. The updating of the summary section will be added to all subsequent reports for this program. This will allow the reader to have the overall scope of the program summarized in one section of each report.

Phase I - Major Accomplishments

- (1) Gathered background information to determine current needs of industry and established a range of conditions needed to simulate geothermal conditions -
 - A meeting was conducted with downhole motor experts at Rice University.
 - Jeddy Nixon of Maurer Engineering presented his experiences in downhole motor development at a review meeting at Terra Tek, Inc.
 - John Jeter, consultant, was consulted on the Bearing-Seal Package design and the DHM Seal Test Machine.
 - Industry contacts and correspondence were established.
 - Information from the Geothermal Bit Program, performed by Terra Tek, such as downhole geothermal temperatures, rock formations, and drilling problems were used to establish design limits of the seal and bearing test equipment.
- (2) Determined the state-of-the-art in motor development and the feasibility of new motor concepts.
 - Maurer Engineering conducted a patent search on downhole motors and reported the results in the Semi-Annual (TR76-59) and Final (TR77-29) reports.

- Maurer Engineering presented a review of the economic incentives for geothermal downhole motor development.
- (3) Performed the preliminary design of the Bearing-Seal Package -
 - The Bearing-Seal Package design was described in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
- (4) Candidate high temperature seals were identified -
 - A description of the candidate seals was presented in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
 - Bearing application was presented in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
- (5) Design and fabrication of the DHM Seal Test Machine was completed -
 - Preliminary concepts and evolution of the final design were presented in the Semi-Annual (TR76-59) report.
 - John Jeter was consulted on the design of the DHM Seal Test Machine.
 - Detailed design and fabrication of the DHM Seal Test Machine was completed.
- (6) Conceptual design of the Bearing-Seal Package Test Facility was completed.

Phase II - Major Accomplishments

- (1) Seal Testing and Evaluation -
 - Debugging tests on the DHM Seal Test Machine were completed.
 - The first evaluation tests on the baseline seals were completed.
 - Contacts were established with major seal manufacturers.
 - Candidate seals for future testing were obtained.

(2) Bearing-Seal Package Testing and Evaluation -

- Preliminary design of the Bearing-Seal Package Test Facility was completed.
- Fabrication of the Bearing-Seal Package was completed.

(3) Lubricant Testing and Evaluation -

- The Terra Tek High Temperature Lubricant Tester was made operational.

Phase III - Part 1 Major Accomplishments

(1) Seal Testing and Evaluation -

- Baseline tests on a standard industry seal were completed.
- Several of the new candidate seal types were tested.
- Additional high temperature candidate seal types were tested.
- The DHM Seal Test Machine underwent several modifications to improve ease of handling and to increase reliable operation.

(2) Bearing-Seal Package Testing and Evaluation -

- A design to solve the fluid erosion problem was completed and successfully tested.
- Final design of the Bearing-Seal Package Test Facility was completed. Fabrication of parts was started.
- Machining of the Grayloc connections in the pressure vessel tubes was completed.
- Design and fabrication of the pressure vessel holding fixture was completed.
- The Dynamic Actuator was received and modifications for the Bearing-Seal Package Test Facility were started.
- The 100-HP hydraulic power supply to drive the dynamic actuator and Bearing-Seal Package was designed and purchased.

(3) Lubricant Testing and Evaluation -

- Wear rings and blocks for the Terra Tek High Temperature Lubricant Tester were obtained.
- A survey of downhole manufacturers was made to obtain lubricant recommendations. The candidate lubricant matrix was revised.

Phase III - Part 2 Major Accomplishments

(1) Seal Testing and Evaluation

- Second and third generation *Grafoil*^R and Graphite-Metal Matrix seals were obtained and tested.
- New flexing leaf seal back up system designs were completed and manufactured.
- A new main shaft for the DHM Seal Test Machine was manufactured, and several minor modifications were made to the machine for easier operation, better reliability and to replace worn parts.
- The DHM Seal Test Machine seal sleeve was modified to improve installation of the seals.
- The first generation elastomer Canted Seals were tested.
- An observation was made concerning the manufacture of *Grafoil*^R seals that may improve the life of the seal and improve the heat transfer by modifying the manufacturing procedure of the seal.
- Computer analyses were completed on the following:
 - One Dimensional Heat Transfer Model of Rotary Seals in Downhole Motors (TR78-29);
 - Deflections in Rotary Seal Back Up Rings (TR78-34); and
 - Factors Affecting Seal Life in Downhole Motors (TR79-5).

(2) Bearing-Seal Package Testing and Evaluation

- Initial assembly of Bearing-Seal Package Test Facility was completed.

- BSP-01 was completed in the Bearing-Seal Package Test Facility.
- The hot water system was operated. New heaters for the geothermal vessel were purchased to improve the operation of the system.
- Designs were completed for interconnecting parts between the Bearing-Seal Package and the Dyna Drill and Eastman Whipstock motors. Quotations were obtained for manufacture of the parts.
- Designs have been completed to modify the Bearing-Seal Package so that drilling fluid can be diverted to flow behind the seal sleeve to cool the seals.
- A computer analysis was completed on the Bending Stress and Frequency Calculations for the Bearing-Pack Shaft (TR79-26).
- First generation Redundant Seal design was completed for the Bearing-Seal Package.

(3) Lubricant Testing and Evaluation -

- Screening of candidate high temperature lubricants was completed in the Terra Tek High Temperature Lubricant Tester.
- The candidate lubricant was selected for testing in the Bearing-Seal Package.
- The candidate lubricant was tested up to a temperature of 600°F and was also tested for degradation when mixed with water.

SEAL TESTING AND EVALUATION

SEALS

Three different seals were tested for the first time during this reporting period. In addition, redundant seals were designed and several back up systems tested.

1. *Grafoil*^R - Brass Seals

The *Grafoil*^R - Brass seals were tested for the first time during this reporting period. This seal differs from the previously tested *Grafoil*^R - BeCu seals in that the 0.005 inch beryllium-copper preformed ring has been replaced with a .030 inch preformed ring of yellow brass. The yellow brass was used in place of BeCu because it is softer and will not score the shaft sleeve. A cross sectional photograph of this seal is shown in Figure 1.

Figure 1
Grafoil^R - Brass Seal Cross Section

2. Canted Seals

The Canted Seal package, shown in Figure 2, consists of two elastomer canted seals held in place by a three-piece back up system made of 9C aluminum bronze. The three sections of the back up system are held in place by pins.

Figure 2
Canted Seal Package

Two different types of elastomer seals were tested in the Canted Seal package:

1. 31A - This material consists of Buna-N compound with cotton duck reinforcing. This is the same material used in Baseline Chevron seals (Utex Style 701).
2. 42DR - This material consists of Buna-N compound impregnated with graphite with cotton duck reinforcing. The graphite is used for friction reduction.

3. Graphite-Metal Matrix Seals

Graphite-Metal Matrix seals were first tested in Phase III - Part 2 of the program. Four generations of this seal type have been tested: the first three generations were tested and reported in the Phase III - Part 2 Semi-Annual Report (TR79-38); and the fourth generation, RD-199, was tested during this reporting period and the results are presented in this report.

The graphite-metal matrix seals are formed from powdered graphite which is cold pressed into a woven metal core and held together in a Chevron cross section with an adhesive binder. Each generation utilizes a different adhesive binder. The assembly is heat cured and is relatively hard and brittle. It has a high gloss surface, and the pattern of the metal mesh is visible on the surface. The free ends of the metal mesh protrude slightly from the surface, as shown in the photograph in Figure 3.

Figure 3
Graphite-Metal Matrix Seal Ring

4. Redundant Seals

Extensive work has been done on the design of redundant seals for the Bearing-Seal Package. The redundant seal will be tested during Phase IV, and will only be tested in the Bearing-Seal Package. The reason for testing this seal only in the Bearing-Seal Package is that the redundant seal is a system concept. The DHM Seal Test Machine was designed to test seal types, not systems. This seal type involves a set of primary seals to provide initial sealing a set of spare or redundant seals which are activated when the primary seals fail.

Figure 4 shows the redundant seals incorporated into the modified Bearing Make Up Sub on the Bearing-Seal Package. The upper primary seals provide the initial seal and the lower redundant seals provide back up sealing. This modification will be made so several redundant seal concepts can be tested by inserting different components into the modified Bearing Make Up Sub.

Figure 4
Modified Bearing-Seal Package Bearing Make Up Sub
Containing Redundant Seals

Oil leaking past the primary seal flows down the passageway and through the two-way check valve. When the primary seal fails, the leakage flow becomes excessive and causes the check valve to close and seal the passageway. This allows pressure to build and activate the redundant seal. The check valve remains closed and drilling continues until either the bit run is completed or the redundant seals fail, at which time the motor is tripped out of the well. The pressure drop across these seals approximately equals the pressure drop across the bit. No commercial check valve with suitable properties for this application has been located, so a special check valve is being designed. The characteristics of a check valve design are good reliability, simple concept and minimum maintenance, all of which are important to industry.

Figure 5 shows an alternate design where a filter is placed above the check valve. In this case, the one-way check valve prevents drilling mud from leaking upward into the filter passageway. When excessive oil leakage occurs past the primary seal, *Grafoil*^R particles will plug and seal the filter. This allows pressure to build on the filter and thereby activates the redundant seal.

Figure 5
Porous Filter Assembly

The characteristics of the porous filter design are similar to those of the check valve design. It may be possible to activate the redundant seals sooner with the porous filter design because high leakage rates are not required.

Figure 6 shows a third design which utilizes a piston to activate the redundant seal. At low leakage rates, fluid leaking past the primary seal flows through holes in the piston and through the one-way check valve. When the leakage rate exceeds a threshold value, the pressure drop across the holes in the piston exceeds a critical value causing the shear pin to fail. This allows the piston to move downward and close the flow port, thereby activating the redundant seal.

Figure 6
Piston Assembly

Designs of all three of these assemblies are being completed. The best of these three systems will be manufactured and tested during Phase IV. The drawings have been completed for a manually activated redundant seal while the design is being completed for the check valve.

5. Zero Clearance Back Up Systems

In the Phase III - Part 2 Semi-Annual Report (TR 79-38), three different zero clearance back up systems for *Grafoil*^R and Graphite-Metal Matrix seals were presented. The zero clearance systems reduce the clearance between the rotating shaft sleeve and back up ring effectively to zero to contain the seal material in the seal cavity. The three back up systems are numbered and a brief description of each is presented.

a. Back Up System I

Back Up System I consists of an SAE 660 bearing bronze seal ring and an O-ring as shown in Figure 7. The lip on the inside diameter of the bronze ring is undercut to minimize the contact area with the rotating shaft and to introduce a weak area into the ring that will allow it to flex under pressure, effectively reducing the clearance to zero between the back up ring and the rotating shaft.

Figure 7

Back Up System I - SAE 660 Bearing Bronze with "O" Ring

b. Back Up System II

Back Up System II consists of a TFE ring and an SAE 660 bearing bronze ring as shown in Figure 8. The TFE ring is soft and will flex under pressure, forcing to zero the clearance between the bronze ring and the rotating shaft.

Figure 8
Back Up System II - TFE and Bronze

c. Back Up System III

Back Up System III consists of an SAE 660 bearing bronze back up ring with 1/64 inch to 1/32 inch thick phosphor-bronze support rings that flex under pressure as shown in Figure 9 . The phosphor-bronze flexing leaves are designed so that there will be approximately 0.005 inches interference with the shaft when the seals are subjected to a 1,500 psi differential pressure.

Figure 9
Back Up System III - Flexing Leaves

SEAL TEST RESULTS

Three different types of seals were tested for the first time during this reporting period. A total of six tests were completed. The seal types tested were:

1. Generation II *Grafoil*^R
2. Generation IV RD-199 Graphite-Metal Matrix
3. Canted Seals

The following is a description of the results from these seal tests. A summary of the test results is shown in Table II, and the individual test plots are found in Appendix A.

1. II *Grafoil*^R - Brass

The generation II *Grafoil*^R - Brass seals were tested in DMT-028 and DMT-029, and each test was run with Back Up System I. DMT-028 was the first test run in the DHM Seal Tester following a major overhaul of the tester. The purpose of the overhaul was to make the DHM Seal Test Machine operation more reliable. The overhaul included modifications to the machine to incorporate tapered roller bearings on both ends of the main shaft to decrease radial runout and axial motion of the main shaft so that controlled runout can be more easily introduced in future testing. It also included installation of new thermocouples and installation of new oil lines to ease the changing of test seals.

During DMT-028, the main shaft was removed and reinstalled several times to complete all adjustments to the DHM Seal Test Machine.

Test ID	Ending Date	Seal Type	No. of Pressure Rings	Back Up Rings	ΔP (psi)	RPM	Duration (hrs.)	Chrome Shaft Coating Finish (rms)	Diametral Clearance: Shaft to Back Up Rings
028	9-20-79	II. Grafoil ^R -Brass	3	Back Up System I	1500	412	2.92	4 - 8 μ	.001
029	10-01-79	II. Grafoil ^R -Brass	3	Back Up System I	1500	412	3.17 (Aborted)	4 - 8 μ	.001
030	10-12-79	Canted-31A Material	2	9C Aluminum Bronze	1500	412	0	4 - 8 μ	.008
031	10-18-79	Canted-42DR Material	2	9C Aluminum Bronze	1500	412	0	4 - 8 μ	.008
032	10-24-79	IV. RD-199 Graphite-Metal Matrix	3	Back Up System I	1500	412	8.57	4 - 8 μ	.001
033	10-25-79	Canted-42DR Material	2	9C Aluminum Bronze	1500	412	0.72	4 - 8 μ	.008

Table II
Seal Test Results

Thus, the seals may have been damaged which resulted in a lifetime of only 2.92 hours for DMT-028.

DMT-029 was a repeat of DMT-028. The test was started and the normal procedure was followed. At 3.17 hours, the test was abruptly ended when the spline at the bottom of the main shaft disengaged from the torque cell. The main shaft was removed and the spline repaired. It was decided to delay further testing of *Grafoil*^R seals until Phase IV in order to test the Canted Seals, which were received at Terra Tek in July, 1979.

During the testing of the *Grafoil*^R seals, an observation was made concerning the manufacture of the seal which could have a large impact on the life of the seal.

The *Grafoil*^R- BeCu and *Grafoil*^R- brass seals, as supplied for testing by Utex Industries, are manufactured in the following way. The *Grafoil*^R supplied to Utex is in ribbon form, approximately 0.5 inches wide, 0.015 inches thick and 25 feet long. The ribbon is wrapped on a mandrel and then cold pressed to the chevron cross section, as shown in Figure 10.

Figure 10
Formation of *Grafoil*^R Seal on Mandrel

Figures 11 and 12 show photographs of a cross section of a *Grafoil*^R seal after formation on the mandrel.

Figure 11
Cross Section of *Grafoil*^R Seal after Formation

Figure 12
Cross Section of *Grafoil*^R Seal with Ribbons Separated

From the photographs in Figures 11 and 12, it is seen that the present method of manufacture of the formed seals leaves many paths for leakage of the lubricant. Two solutions to this problem are proposed. First, the seal could be manufactured with the ribbon wound perpendicular to the axis of rotation before forming. The second solution would be to use another form of the *Grafoil*^R from Union Carbide.

In the ribbon form, *Grafoil*^R exhibits a large difference in thermal conductivity, K , depending on the direction of orientation. Perpendicular to the *Grafoil*^R ribbon, the thermal conductivity is 3 BTU / hr.-ft. °F and parallel to the ribbon the thermal conductivity is 80 BTU / hr.-ft. °F. This is shown in Figure 13.

Figure 13
Thermal Conductivities of *Grafoil*^R Ribbon

In the present method of *Grafoil*^R manufacture, the heat transfer is primarily axial, about 3 BTU / hr.-ft. °F, rather than radial. If the *Grafoil*^R is combined with the elastomer, this change in laminate orientation could be very important to increasing seal life.

2. IV RD-199 Graphite-Metal Matrix

The Generation IV RD-199 Graphite-Metal Matrix seal was tested in DMT-032, and Back Up System I was used with the seal. This test was similar to DMT-027 where the Generation III RD-194 Graphite-Metal Matrix seal was tested with Back Up System I.

This seal started leaking approximately 1.5 hours into the test. The leak was continuous from this time until the end of the test at 8.57 hours, when the failure of the seal was catastrophic. The leakage and failure pattern in DMT-032 was similar to the pattern in DMT-027.

Figure 14 shows a photograph of the outside of the test seal pack, and Figure 15 shows a photograph of the inside of the test seal pack. Note the loss of seal material from the Graphite-Metal Matrix.

Figure 14
DMT-032 Test Seal Pack

Figure 15
DMT-032 Test Seal Pack

3. Canted Seals

Tests DMT-030, DMT-031 and DMT-033 tested the 5 x 6 Canted Seal. The seal material in DMT-030 was 31A (Buna-N and cotton duck); and the seal material in DMT-031 and DMT-033 was 42DR (lubricated Buna N and cotton and nylon).

In tests DMT-030 and DMT-031, the Canted Seals and spacers were installed in the seal tester, the seals were preloaded and finally the shaft was installed. The test was started and the seals in both tests leaked immediately. The seal tester was disassembled and the seals were inspected. Scratches on the outside of the Canted Seal back up system showed that the seals had rotated in the seal tester.

Fred Pippert from Utex Industries, the manufacturer of the Canted Seal, visited Terra Tek on October 25. He supervised the installation of the Canted Seals for DMT-033. The seals were installed in the same manner as in DMT-030 and DMT-031, except that the Canted Seal back up systems and the spacers were all pinned together inside the seal tester.

On Fred Pippert's recommendation, the test was run without heating the vessel. The seals leaked immediately as in DMT-030 and DMT-031. Therefore, a reverse differential pressure was put across the seals to shock the lip on the lower seal pack into place. After this was done, the normal differential pressure was placed across the seals, and the seals held the differential pressure for approximately 45 minutes before they started to leak.

Figure 16 shows a photograph of the upper seal pack after DMT-033 and Figure 17 shows a photograph of the lower seal pack after DMT-033. Note the damaged seal in Figure 17.

Figure 16
Upper Seal Pack After DMT-033

Figure 17
Lower Seal Pack After DMT-033

CONCLUSIONS

The following items are a summary of the major accomplishments made during the second six month period of Phase III - Part 2 of the seal testing portion of this program:

- (1) Test DMT-024, non-elastomer *Grafoil*^R seal with zero clearance back up system, ran for a period of 40.9 hours, the longest running seal to date. Considering the extreme environment to which the seals were exposed in the tester, it was considered a significant step toward finding a seal that will last up to 200 hours under more typical downhole conditions. Other similar tests provided good information on modifications needed to improve the testing equipment which have been made.
- (2) Tests of the Graphite-Metal Matrix seals with a zero clearance back up system showed that the Generation III seals provided by Utex Industries are better than the Generation IV seals also provided by Utex. The longest test of seals of this type (DMT-027) ran 23.5 hours.
- (3) Tests on the Canted Seals demonstrated that the Canted Seal Package must be modified to allow for installation as a cartridge before further tests can be run.

FUTURE WORK

Tests on elastomer and non-elastomer seals have been performed in the DHM Seal Test Machine during Phases II, III - Part 1 and III - Part 2. During Phase IV, testing will continue on the most promising seal concepts identified along with several new candidate seals. A total of 18 tests are planned for Phase IV in the DHM Seal Test Machine. The following sections describe the proposed test matrix.

I. Testing of Non-Elastomer Seals

Table III shows the proposed test matrix for the non-elastomer seals. A total of six tests will be performed:

- a. Two tests on the Generation IV and V Graphite-Metal Matrix seals with Back Up System I; and
- b. Four tests on the Generation III *Grafoil*^R- Bronze seal with Zero Clearance Back Up System.

Table III
Tests on Candidate *Grafoil*^R and Graphite-Metal
Matrix Seals

TEST NO.		SEAL	NO. OF SEAL RINGS	BACK-UP RINGS	RPM	COOLING RATE	SHAFT SLEEVE
01	IV	Utex Graphite-Metal Matrix	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
02	V	Utex Graphite-Metal Matrix	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
03		<i>Grafoil</i> ^R - SAE 660 Bronze	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
04		<i>Grafoil</i> ^R - SAE 660 Bronze	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
05		<i>Grafoil</i> ^R - SAE 660 Bronze	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
06		<i>Grafoil</i> ^R - SAE 660 Bronze	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ

II. Testing of New *Grafoil*^R Seals

The seal test results from Phase III - Part 2 of the program indicate that the life of *Grafoil*^R seals increases with increasing amounts of *Grafoil*^R in the seal cavity. Therefore, new *Grafoil*^R seals that are thicker than the *Grafoil*^R seals previously tested and consist of solid *Grafoil*^R rings will be manufactured and tested during Phase IV of the program. Also, increased thickness of the *Grafoil*^R seal will reduce the chance of damaging the seal during handling. Four tests on these seals will be run with Zero Clearance Back Up Systems. Table IV shows the proposed tests for these seals.

Table IV
Tests on New *Grafoil*^R Seals

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK-UP RINGS	RPM	COOLING RATE	SHAFT SLEEVE
07	<i>Grafoil</i> ^R	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
08	<i>Grafoil</i> ^R	3	Zero Clearance	412	18 GPH	Chrome 4-6 μ
09	<i>Grafoil</i> ^R	5	Zero Clearance	412	18 GPH	Chrome 4-6 μ
10	<i>Grafoil</i> ^R	5	Zero Clearance	412	18 GPH	Chrome 4-6 μ

III. Testing of Canted Seals

The canted seal was first tested during Phase III - Part 2 of the program and the results are described in the Seal Test Results of this report. Further testing of the Generation II preloaded Canted Seal with new higher temperature elastomers will be performed during Phase IV. Three tests on these Canted Seals will be performed and Table V shows the proposed matrix for these tests.

Table V
Tests on II Canted Seals with
High Temperature Elastomers

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK-UP RINGS	RPM	COOLING RATE	SHAFT SLEEVE
11	Canted-Elastomer I	2	SAE 660 Bronze	412	18 GPH	Chrome 16 μ
12	Canted-Elastomer I	2	SAE 660 Bronze	412	18 GPH	Chrome 16 μ
13	Canted-Elastomer II	2	SAE 660 Bronze	412	18 GPH	Chrome 16 μ

IV. Testing of New Candidate Seals

A few new candidate seal designs will be tested during Phase IV. A new seal material, A-Flas, will be one of the candidates tested. This new material was first discussed as a candidate seal material at the project review meeting held at Terra Tek on March 22, 1979. One test of this new material will be performed during Phase IV.

The hybrid seal concept, *i.e.*, a combination of elastomer and non-elastomer seals, will be another candidate tested. Two tests of this material will be performed during Phase IV.

It is anticipated that other new candidate seals not yet identified or refinements of current seal designs will be proposed for testing during Phase IV. Two tests are planned for these new candidate seals.

Table VI shows the proposed test matrix for the A-Flas seal, hybrid seal and new candidate seals.

Table VI
Tests on New Candidate Seals

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK-UP RINGS	RPM	COOLING RATE	SHAFT SLEEVE
14	Aflas	3	SAE 660 Bronze	412	18 GPH	Chrome 16 μ
15	Hybrid Seal	3 - Elastomer 3 - Grafoil [®]	SAE 660 Bronze	412	18 GPH	Chrome 4-6 μ
16	Hybrid Seal	3 - Grafoil [®] 3 - Graphite	SAE 660 Bronze	412	13 GPH	Chrome 4-6 μ
17	New Candidate Seal A	---	SAE 660 Bronze	412	18 GPH	Chrome 16 μ
18	New Candidate Seal A	---	SAE 660 Bronze	412	18 GPH	Chrome 16 μ

As with previous seal tests in this program, the Phase IV proposed seal tests may be modified to take into account new observations and results from the testing program.

BEARING-SEAL PACKAGE TESTING AND EVALUATION

C

C

BEARING-SEAL PACKAGE TEST RESULTS

BSP-01 was completed during this reporting period. BSP-01 was the first of a series of five initial tests for the Bearing-Seal Package Test Facility. The purpose of BSP-01 was to run the Bearing-Seal Package with elastomer seals at a moderate temperature of 200°F for a period of 2 to 8 hours to check out the Bearing-Seal Package and all systems of the Bearing-Seal Package Test Facility.

The following lists the test conditions for BSP-01:

1. Seal Type: *Uneepac*^R - Style 405
2. Shaft Surface: Chrome Plated AISI 4340 Steel
3. Shaft Finish: 4 μ inches, r.m.s.
4. Number of Seal Rings: 3 - Upper Seal Pack
3 - Lower Seal Pack
5. Lubricant - Texaco EP 85-90
6. Nozzle Size: 1 each - 1/4 inch diameter
7. Drilling Fluid Flow (through the string): 12 gpm (water)
8. Pressure Drop: 750 psi
9. Loading: 500 lbs. Constant
10. Hot Water System Temperature: 200°F

The total duration of the test was 2 hours. The system was started and the pressure of the water in the vessel was brought up gradually to balance the pressure of the hot water on the inside of the Hot Water Jacket.

The hydraulic drive motor servovalve did not open completely during the test, and consequently, the maximum rotary speed was 25 rpm, with peaks to 40 rpm. At the end of 2 hours, the test was terminated.

After the test, the Bearing-Seal Package was completely disassembled and inspected. The Bearing-Seal Package parts showed very few signs of wear or deterioration after BSP-01. The test seals and shaft sleeve were also inspected.

The upper seal pack reached a higher temperature than the lower seal pack. This is shown by the fact that the upper seal pack burned slightly and discolored the shaft sleeve.

Figure 18 shows a photograph of the shaft seal sleeve where the discoloration from the upper seal pack can be seen. Figure 19 shows a close-up of the upper seal area of the shaft sleeve; and Figure 20 shows a close-up of the upper seal pack showing the burned area.

Figure 18
Shaft Seal Sleeve

Figure 19
Detail of Upper Seal Area on Shaft Seal Sleeve

Figure 20
Detail of Upper Seal Pack

BSP-01 showed that modifications to the following test facility parts would have to be made before the remaining initial tests (BSP-02 to BSP-05) could be completed:

1. Geothermal Vessel Heaters
2. Hot Water Jacket Seal Ring
3. Load and Torque Cells
4. Servocontroller for the Hydraulic Drive Motor

The modifications are described in detail in the "Bearing-Seal Package Test Facility" section of this report. After completion of these modifications, the remaining initial tests (BSP-02 to BSP-05) as described in the Phase III - Part 2 Semi-Annual (TR 79-38) will be completed.

BEARING-SEAL PACKAGE TEST FACILITY

Bearing-Seal Package Test Facility Modifications

Four modifications to the Bearing-Seal Package Test Facility were made during this reporting period. The need for these modifications came from the results of BSP-01. Following is a description of each modification.

The first modification involved the purchase and installation of new cartridge heaters for the Geothermal Vessel. The old heaters did not have sealed electrical leads, and, as a consequence, shorted out in the damp environment around the Geothermal Vessel. The new heaters contain completely sealed leads to eliminate the shorting problem.

The second modification involved the seal ring for the Hot Water Jacket. During BSP-01, the seal ring moved due to pressure loads and allowed communication between the hot water on the inside of the Hot Water Jacket and the drilling fluid on the outside of the Hot Water Jacket. This communication is undesirable for two reasons: first, the hot water system will become contaminated with drilling fluid; and second, the efficiency of the heating system drops. A new positive locking seal ring, containing shear pins, was manufactured and installed on the Bearing-Seal Package to prevent the seal ring from moving from pressure loads.

The third modification involved the construction of a new load and torque cell on the Dynamic Actuator shaft. At the start of BSP-01, the torque cell was lost; and throughout BSP-01, the load cell signal contained excessive noise. The Dynamic Actuator was completely disassembled and new load and torque cell strain gages were mounted on the Actuator shaft and the Actuator was reassembled. A new preamplifier was constructed to allow greater sensitivity to the load and torque cells and reduce the signal-to-noise ratio.

The fourth modification involved the servocontroller for the hydraulic motor servovalve. During BSP-01, it was observed that the servovalve operating the hydraulic motor did not open completely with the present servocontroller. The servocontroller was modified to allow the servovalve to open completely.

All of these modifications have been completed and the respective parts of the test facility have been reassembled. The remaining initial tests (BSP-02 to BSP-05) will be completed before the testing work described in the Future Work section is started.

It was expected that some modifications would have to be made to the Bearing-Seal Package Test Facility during the initial testing because of the complexity of the facility. The complexity of the facility arises from the fact that there are seven different systems that must all function together to make the facility operate. These systems are shown schematically in Figure 21 and a brief description of each follows:

1. Mechanical - The test vessel, closures and internal string are all components that are linked together mechanically. All of these parts are machined to close tolerances and must fit together precisely.
2. Electrical - The hot water system is heated by electric cartridge heaters which are in a damp environment.
3. Electronic - The major portion of the test facility controls and data acquisition systems are electronically controlled.
4. Hydraulic - A 40 hp hydraulic power supply is used to drive the rotary hydraulic motor and a 100 hp hydraulic power

Figure 21

SYSTEMS

1. MECHANICAL
2. ELECTRICAL
3. ELECTRONIC
4. HYDRAULIC
5. PNEUMATIC
6. HOT WATER
7. MUD CIRCULATION

supply is used to drive the Dynamic Actuator.

5. Pneumatic - Pneumatic controls are used to operate the lower vessel seal pack grease injection system and to operate the hot water system relief valve.
6. Hot Water - A hot water system is used to simulate a geothermal environment around the Bearing-Seal Package.
7. Mud System - A triplex mud pump is used to circulate drilling fluid through the vessel and internal string.

Computer Analysis of Bearing-Seal Package

A computer analysis of the Bearing-Seal Package shaft was performed. The complete analysis will be found in the report, "Bending Stress and Frequency Calculations for the Bearing-Pack Shaft" by Jeff Barnwell and Don W. Dareing, Terra Tek Technical Report No. TR79-26, October 1979. The derivation of equations, figures, graphs and computer printouts of results will all be found in the complete report.

There were three main objectives for the analysis:

1. The first objective was to analyze the bending stresses produced in the shaft by deviation forces acting on the drill bits.
2. The second objective was to perform a fatigue analysis of the highly cycled Bearing-Seal Package shaft.
3. The third objective was to perform a frequency analysis of the Bearing-Seal Package turbine shaft assembly to determine if resonances may occur.

The conclusions from this investigation are as follows:

1. Bearing-Shaft Stresses - The stresses produced by bending are minimal when considered as static stresses and compared to the the yield point of the material. With increasing bit force, linear increases in maximum stress levels were noted. In addition, the deflection has an effect on maximum stress levels at the fixed-bearing end, but the critical stress is always found at the lower box end of the Bearing-Seal Package shaft.
2. Fatigue Analysis - The maximum cyclic stress was much lower than the endurance level for the material. When Soderberg's theory of fatigue failure was applied, a safety factor of 1.65 was found. Although this did not account for stress concentrations, it was assumed all notches had sufficient radii and were polished.
3. Frequency Analysis - Resonance should present no problem since the estimate by the model was 106 rps (=6,420 rpm), which is much higher than any potential use of the assembly.

Interconnecting Parts

Interconnecting parts have been designed which allow the Bearing-Seal Package to be used with the Eastman Whipstock and Dyna Drill drilling motors. These interconnecting parts attach the motor housing to the Bearing-Seal Package housing and the motor shaft to the Bearing-Seal Package drive shaft. In addition, these interconnecting parts provide a passageway to transfer fluid from the drilling motor to the Bearing-Seal Package drive shaft bore. Maurer Engineering will manufacture these parts except for the threaded connections to the Eastman and Dyna Drill motors. These threaded connections

will be machined by the respective companies because they have the necessary thread guages.

CONCLUSIONS

The following items are a summary of the major accomplishments made during the second six month period of Phase III - Part 2 of the Bearing-Seal Package testing portion of this program:

- (1) The initial Bearing-Seal Package test (BSP-01) showed that several modifications were necessary to the heating system, load and torque cell and rotary hydraulic drive motor servocontroller to do further testing. These modifications were completed.
- (2) The Bearing-Seal Package shaft computer analysis showed:
 - a. Bending stresses are minimal when compared to the yield point of the material and the critical stress occurs at the lower box end of the Bearing-Seal Package shaft.
 - b. The maximum cyclic stress is much lower than the endurance level for the material.
 - c. Resonance should present no problem in the Bearing-Seal Package shaft because the estimate by the model is much higher than any potential use of the part.

FUTURE WORK

Extensive testing is planned for the Bearing-Seal Package during Phase IV of the program. A total of 18 tests are planned for the Bearing-Seal Package, and 4 tests are planned for the Bearing-Seal Package with a downhole motor. The following sections describe the tests on the Bearing-Seal Package.

I. - Testing with *Grafoil*^R Seals

From the seal testing program in Phase III - Part 2, it was concluded that the life of *Grafoil*^R seals is directly related to the amount of material in the seal cavity at the beginning of the test. To contain the material in the seal cavity, it is desirable to reduce the clearance between the back up system and rotating shaft to essentially zero. Three different "zero clearance" back up systems are described in the Seal Testing and Evaluation section of this report. These three systems plus a possible fourth zero clearance back up system will be tested during Phase IV. A total of 8 tests will be performed. Table VII shows the proposed test matrix.

Table VII
Bearing-Seal Package Tests with *Grafoil*^R Seals

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK-UP RINGS	RPM	SHAFT SLEEVE
01	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System A	200	Chrome 4-6
02	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System A	800	Chrome 4-6
03	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System B	200	Chrome 4-6
04	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System B	800	Chrome 4-6
05	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System C	200	Chrome 4-6
06	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System C	800	Chrome 4-6
07	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System D	200	Chrome 4-6
08	<i>Grafoil</i> ^R	3 - Upper 3 - Lower	Back-Up System D	800	Chrome 4-6

II. - Testing with Redundant Seals

The two most promising redundant seal designs, as described in the Seals section of this report, will be tested during Phase IV. A total of 4 tests are planned, and Table VIII shows the proposed test matrix.

Table VIII
Bearing-Seal Package Tests with Redundant Seals

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK UP RINGS	RPM	SHAFT SLEEVE
09	Redundant Seal A	3 - Primary 3 - Redundant	Zero Clearance	200	Chrome 4 - 6 μ
10	Redundant Seal A	3 - Primary 3 - Redundant	Zero Clearance	800	Chrome 4 - 6 μ
11	Redundant Seal B	3 - Primary 3 - Redundant	Zero Clearance	200	Chrome 4 - 6 μ
12	Redundant Seal B	3 - Primary 3 - Redundant	Zero Clearance	800	Chrome 4 - 6 μ

III - Testing with Cooling Modifications

In the Phase III - Part 2 Semi-Annual Report (TR79-38), a modification to the Bearing-Seal Package was described in which a portion of the drilling fluid is diverted to flow behind the seal sleeve to cool the seals. This concept is currently used in the Seal Test Machine. In Phase IV, these changes will be incorporated into the Bearing-Seal Package; the Bearing-Seal Package will be tested with these modifications; and the test results will be compared to test results without the modifications to examine any changes in seal life. Two tests will be performed. Table IX shows the proposed test matrix.

Table IX
Bearing-Seal Package Tests with Cooling Modifications

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK-UP RINGS	RPM	SHAFT SLEEVE
13	<i>Grafoil^R</i>	3 - Upper 3 - Lower	Zero Clearance	800	Chrome 4 - 6 μ
14	<i>Grafoil^R</i>	3 - Upper 3 - Lower	Zero Clearance	800	Chrome 4 - 6 μ

IV. - Testing with Different Shaft Coatings

One of the results from the seal tests shows that the life of non-elastomer seals is increased with improved shaft surface finish. In Phase IV, a total of four Bearing-Seal Package tests will be performed with two new shaft coatings. Table X shows the proposed test matrix.

Table X
Bearing-Seal Package Tests with Different Shaft Coatings

TEST NO.	SEAL	NO. OF SEAL RINGS	BACK UP RINGS	RPM	SHAFT SLEEVE
15	<i>Grafoil^R</i>	3 - Upper 3 - Lower	Zero Clearance	200	Surface Coating A 4 - 6
16	<i>Grafoil^R</i>	3 - Upper 3 - Lower	Zero Clearance	800	Surface Coating A 4 - 6
17	<i>Grafoil^R</i>	3 - Upper 3 - Lower	Zero Clearance	200	Surface Coating A 4 - 6
18	<i>Grafoil^R</i>	3 - Upper 3 - Lower	Zero Clearance	800	Surface Coating A 4 - 6

V. - Testing with Full-Scale Motors

Two downhole motors selected from commercially available motors will be tested with the Bearing-Seal Package in the full-scale Downhole Motor Test Facility in Phase IV. The full-scale Downhole Motor Test Facility allows a known input from the Dynamic Actuator to be put on the tool, and the

response of the tool to the input can be measured. Each motor that will be tested will be tested with and without a shock sub. Thus, the advantages and disadvantages of using a shock sub can be determined.

A total of four full-scale motor tests are planned. Table XI shows the proposed test matrix.

Table XI
Full-Scale Motor Testing

TEST NO.	SEAL	DOWNHOLE MOTOR	SHOCK SUB
01	Candidate Selected from Testing	Downhole Motor A	Yes
02	Candidate Selected from Testing	Downhole Motor A	No
03	Candidate Selected from Testing	Downhole Motor B	Yes
04	Candidate Selected from Testing	Downhole Motor B	No

LUBRICANT TESTING AND EVALUATION

LUBRICANT TESTING AND EVALUATION

Two lubricant tests (Tests 162 and 163) were performed with Pacer PLX-014 lubricant to test for any deterioration of the lubricant when contaminated with water. The tests were run at 400⁰F and all test conditions were the same as those listed in Table VI in the Phase III - Part 2 Semi-Annual Report (TR79-38).

The results of the two tests are as follows:

<u>Test Number</u>	<u>Average Wear Scar Width</u>	<u>Nominal Load Bearing Capability</u>
162	0.174 inches	3,276 psi
163	0.108 inches	5,278 psi

The mean wear scar width for Tests 162 and 163 is:

Mean Average Wear Scar Width for Tests 162 and 163 = 0.141 inches

Figures 22 and 23 show photographs of the wear blocks from Tests 162 and 163 respectively.

Figure 22
Wear Block from Test No. 162
(Pacer PLX-014 with water)

Figure 23
Wear Block from Test No. 163
(Pacer PLX-014 with water)

The test procedure for these two tests was as follows:

1. An 85 ml. sample of the Pacer PLX-014 lubricant was placed in the test chamber.
2. 1.5 ml. of water was added to the lubricant in the test chamber.
3. The lubricant sample and the water were mixed.
4. The test was run according to the standard procedure described in the Phase III - Part 2 Semi-Annual Report (TR79-38).

As described in the Phase III - Part 2 Semi-Annual Report (TR79-38), 24 candidate lubricants were tested at a temperature of 400°F; a total of 45 tests were run at that temperature. Of these 45 tests, 5 tests were run on Pacer PLX-014. The mean values of the wear scar widths for the 46 tests and for the 5 PLX-014 tests are as follows:

Mean Average Wear Scar Width for the = 0.169 inches
45 lubricant tests

Mean Average Wear Scar Width for the = 0.070 inches
5 PLX-014 lubricant tests

From these results, it is observed that the mean average wear scar width from Tests 162 and 163 is greater than the mean average wear scar width from the 5 PLX-014 tests but less than the mean average wear scar width from the 46 tests. It is concluded that the addition of water will affect the performance of Pacer PLX-014 but does not completely destroy its lubricating properties.

Samples of the following lubricants have been received from Pacer Lubricants, Inc.: PLX-022, PLX-023 and PLX-024. PLX-022 is a 100 percent synthetic fluid like PLX-014, but is not compatible with elastomers. PLX-023 is a more viscous version of PLX-022. PLX-024 is a more viscous version of PLX-014 and is compatible with elastomers like PLX-014. These lubricants have been tested in the High Temperature Lubricant Tester but the test results have not been analyzed.

PROGRAM STATUS, PLANS AND SCHEDULE

PROGRAM STATUS, PLANS AND SCHEDULE

Seal Testing and Evaluation

Thirty-three seal tests have been completed in the DHM Seal Test Machine. Tests have been run on elastomer and non-elastomer seals. Test results have shown that non-elastomer seals are better candidate seals for achieving the goals of this program than elastomer seals. Tests have also shown that the life of *Grafoil*^R (a non-elastomer) seals is directly related to the amount of seal material in the seal cavity at the beginning of the test. Consequently, design efforts have been aimed at developing a "zero clearance" back up system to contain the *Grafoil*^R seal material in the seal cavity. Three different back up systems were proposed, and Back Up Systems I and II were tested during this reporting period. The longest test to date, 40.9 hours, was run using *Grafoil*^R- BeCu seals with Back Up System I. Back Up System II will be tested during Phase IV.

During Phase IV of this program, seal testing will continue on the following candidate seals:

1. Further tests on *Grafoil*^R seals with "zero clearance" Back Up Systems I and III;
2. New *Grafoil*^R seals that are thicker than previously tested *Grafoil*^R seals with "zero clearance" back up systems;
3. Second generation preloaded Canted Seals;
4. IV and V generation Graphite-Metal Matrix seals; and
5. New candidate seals such as Aflas, hybrid seal, etc.

Bearing-Seal Package Testing

BSP-01 was completed during this reporting period. As a result of this test, a number of modifications were made to the Bearing-Seal Package Test Facility. These modifications were detailed in the "Bearing-Seal Package Test Facility" portion of this report. The modifications have been completed and the remaining initial tests (BSP-02 to BSP-05) will be completed.

After these five tests are completed, a planning and review meeting will be held at Terra Tek to discuss and plan Phase IV testing for the Bearing-Seal Package. Plans call for the testing of the following seal types in the Bearing-Seal Package.

1. *Grafoil*^R seals with "zero clearance" back up systems;
2. Redundant Seal systems using *Grafoil*^R seals;
3. *Grafoil*^R seals with cooling modifications to the Bearing-Seal Package; and
4. *Grafoil*^R seals with different shaft sleeve coatings.

In addition, full-scale tests of the Bearing-Seal Package with two different downhole motors are planned.

The testing in the Bearing-Seal Package will tie all of the seal and lubricant testing work together. From the Seal Testing and Evaluation phase of the program, we have learned that a non-elastomer *Grafoil*^R seal pack with a "zero clearance" back up system has lasted the longest (40.9 hours). The 40.9 hour seal life is a very significant result because the DHM Seal Test Machine tests seals at a 1,500 psi differential pressure which is much greater than the 200 to 300 psi differential pressure at which downhole motors are currently run, and the 1,000 psi differential pressure for rotary seals, that is one objective of this program. Thus, the tests in the DHM Seal Test Machine are accelerated wear tests.

The Lubricant Testing and Evaluation phase of the program has screened candidate high temperature lubricants and selected the best candidate for use in the Bearing-Seal Package. It is possible that the goal of the program (*i.e.*, a seal that will last 200 hours in a geothermal environment) may be achieved by using the *Grafoil*^R seal with a "zero clearance" back up system in a redundant seal configuration and a 500 psi reduction in pressure drop in the Bearing-Seal Package.

Lubricant Testing and Evaluation

The main lubricant testing program has been completed. New candidate high temperature lubricants will be tested as they are received. No additional candidate lubricants have been received at the present time.

The schedule for Phase IV work is shown in the detailed milestone chart in Table XII.

Table XII

Downhole Motor Project
Phase IV Schedule

BIBLIOGRAPHY

DOWNHOLE MOTOR PROGRAM BIBLIOGRAPHY

(1) Terra Tek Reports

- Black, A.D., S.J. Green and W.C. Maurer, "Semi-Annual Report: Program to Develop Improved Downhole Drilling Motors", Terra Tek Technical Report No. TR 76-59, November, 1976.
- Black, A.D., S.J. Green, L.W. Matson, W.C. Maurer, R.R. Nielsen, J.D. Nixon and J.G. Wilson, "Final Report: Program to Develop Improved Downhole Drilling Motors", Terra Tek Technical Report No. TR 77-29, May, 1977.
- Black, A.D., J.G. Wilson and S.J. Green, "Semi-Annual Report: Program for the Improvement of Downhole Drilling Motor Bearings and Seals", Terra Tek Technical Report No. TR 77-107, December, 1977.
- Black, A.D., P.H. DeLafosse, J.G. Wilson, G.A. Tibbitts, S.J. Green and J.D. Nixon, "Phase II - Final Report: Program for the Improvement of Downhole Drilling Motor Bearings and Seals", Terra Tek Technical Report No. TR 78-28, May, 1978.
- Black, A.D., P.H. DeLafosse, J.G. Wilson, G.A. Tibbitts, S.J. Green, W.C. Maurer and D.W. Dareing, "Phase III - Part I Final Report: Program for the Improvement of Downhole Drilling Motor Bearings and Seals", Terra Tek Technical Report No. TR 78-58, November, 1978.
- Tibbitts, G.A., P.H. DeLafosse, J.G. Wilson, S.J. Green, W.C. Maurer, D.W. Dareing, "Phase III - Part 2 Semi-Annual Report: Program for the Improvement of Downhole Drilling Motor Bearings and Seals", Terra Tek Technical Report No. TR 79-38, May, 1979.
- Dareing, D.W., "One Dimensional Heat Transfer Model of Rotary Seals in Downhole Motors", Terra Tek Technical Report No. TR 78-29, September, 1978.
- Dareing, D.W., "Deflections in Rotary Seal Back Up Rings", Terra Tek Technical Report No. TR 78-34, December 4, 1978.
- Dareing, D.W. "Factors Affecting Seal Life in Downhole Motors", Terra Tek Technical Report No. TR 79-5, February, 1979.
- Barnwell, J. and D.W. Dareing, "Bending Stress and Frequency Calculations for the Bearing-Pack Shaft", Terra Tek Technical Report No. TR 79-26, October, 1979.

(2) Papers

Black, A.D., J.G. Wilson, S.J. Green and J.D. Nixon, "Development of Improved Rotary Seals for Downhole Motors in Geothermal Applications", Geothermal Resources Council 1978 Annual Meeting, Hilo, Hawaii, July 25-26, 1978.

DeLaFosse, P.H., G.A. Tibbitts and S.J. Green, "Evaluation of High Temperature Lubricants for Downhole Motors in Geothermal Applications", Geothermal Resources Council 1978 Annual Meeting, Reno, Nevada, September 24-27, 1979.

Wilson, J.G., G.A. Tibbitts, and A.D. Black, "Improvements in Rotary Seals for Downhole Motors in Geothermal Applications", Geothermal Resources Council 1979 Annual Meeting, Reno, Nevada, September 24-27, 1979.

(3) Review Meetings

November 11-12, 1976

Geothermal Projects Review Meeting
Terra, Tek, Salt Lake City.

July 19-20, 1977

Geothermal Well Technology Program
Review Meeting, Albuquerque,
New Mexico

September 7, 1977

Geothermal Drill Bit Program and
Downhole Motor Program Review Meeting,
Terra Tek, Salt Lake City.

February 7, 1978

Sandia / Terra Tek / Maurer
Engineering DOE/DGE Project Review
Meeting, Terra Tek, Salt Lake City.

June 11, 1978

Seal Test Review Meeting, Terra Tek,
Salt Lake City.

June 20-22, 1978

Geothermal Drilling and Completion
Contractor Review Meeting, Washington,
D.C.

March 22, 1979

Sandia / Terra Tek / Maurer
Engineering Downhole Motor Project
Review Meeting, Terra Tek, Salt Lake City.

APPENDIX A - SEAL TEST RESULTS

DMT-028

TESTID : DMT-028

DATAFI : SEAL.028

N	TIME	TORQUE	UPPER SEAL TEMP6 (F)	LOWER SEAL TEMP7 (F)	UPPER SEAL LEAK CU IN	UPPER SEAL LEAK RATE CU IN/HR	LOWER SEAL LEAK CU IN	LOWER SEAL LEAK RATE CU IN/HR
	HRS	FT-LB						
1	0.00	232.	310.	225.	0.0	0.0	0.0	0.0
2	0.25	242.	325.	200.	0.0	0.0	0.0	0.0
3	0.42	232.	450.	210.	0.0	0.0	0.0	0.0
4	0.63	332.	550.	185.	0.0	0.0	0.0	0.0
5	0.80	282.	575.	190.	0.0	0.0	0.0	0.0
6	1.13	0.	270.	150.	0.0	0.0	0.0	0.0
7	1.55	0.	160.	135.	0.0	0.0	0.0	0.0
8	2.05	116.	225.	160.	0.0	0.0	0.0	0.0
9	2.55	120.	240.	165.	0.0	0.0	0.0	0.0
10	2.92	164.	195.	145.	0.0	0.0	0.0	0.0

TESTID : DMT-028

DATAFI : SEAL.028

THERMOCOUPLES(F)

N	1 THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	8 INLET WATER	9 UPPER SEAL OUTLET	10 LOWER SEAL OUTLET
1	75.	245.	285.	285.	240.	80.	95.	90.
2	90.	220.	300.	255.	250.	70.	80.	90.
3	90.	230.	300.	290.	265.	75.	95.	90.
4	95.	210.	245.	285.	290.	65.	80.	95.
5	95.	200.	250.	305.	310.	65.	80.	95.
6	85.	180.	185.	220.	260.	65.	70.	90.
7	85.	200.	170.	215.	240.	60.	65.	90.
8	90.	270.	240.	290.	235.	65.	75.	95.
9	90.	285.	250.	320.	260.	65.	80.	90.
10	90.	315.	255.	315.	275.	65.	65.	90.

DMT-029

TESTID : DMT-029

DATAFI : SEAL.029

N	TIME	TORQUE	UPPER SEAL TEMP6 (F)	LOWER SEAL TEMP7 (F)	UPPER SEAL LEAK CU IN	UPPER SEAL LEAK RATE CU IN/HR	LOWER SEAL LEAK CU IN	LOWER SEAL LEAK RATE CU IN/HR
	HRS	FT-LB						
1	0.00	72.	210.	168.	0.0	0.0	0.0	0.0
2	0.25	76.	245.	171.	0.0	0.0	0.0	0.0
3	0.50	72.	246.	173.	0.0	0.0	0.0	0.0
4	0.75	172.	245.	185.	0.0	0.0	0.0	0.0
5	1.03	102.	273.	190.	0.0	0.0	0.0	0.0
6	1.25	0.	277.	175.	0.0	0.0	0.0	0.0
7	1.50	0.	283.	180.	0.0	0.0	0.0	0.0
8	1.75	0.	282.	175.	0.0	0.0	0.0	0.0
9	2.00	0.	293.	170.	0.0	0.0	0.0	0.0
10	2.25	0.	285.	178.	0.0	0.0	0.0	0.0
11	2.50	0.	288.	180.	0.0	0.0	0.0	0.0
12	2.75	0.	278.	170.	0.0	0.0	0.0	0.0
13	3.00	0.	256.	166.	0.0	0.0	0.0	0.0
14	3.15	0.	305.	580.	0.0	0.0	0.0	0.0
15	3.17	0.	895.	735.	0.0	0.0	0.0	0.0

TESTID : DMT-029

DATAFI : SEAL.029

THERMOCOUPLES(F):									
N	1 THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	8 INLET WATER	9 UPPER SEAL OUTLET	10 LOWER SEAL OUTLET	
1	83.	275.	233.	282.	228.	65.	67.	90.	
2	86.	265.	265.	280.	228.	66.	78.	90.	
3	87.	263.	261.	273.	226.	65.	76.	91.	
4	88.	260.	269.	274.	230.	65.	77.	92.	
5	90.	270.	275.	282.	232.	65.	79.	92.	
6	90.	270.	280.	280.	243.	65.	78.	90.	
7	90.	272.	267.	283.	250.	65.	78.	93.	
8	98.	270.	267.	277.	260.	65.	80.	92.	
9	92.	265.	265.	272.	260.	65.	80.	92.	
10	90.	270.	270.	280.	262.	65.	80.	92.	
11	92.	270.	270.	280.	266.	65.	80.	92.	
12	83.	248.	268.	282.	265.	65.	85.	95.	
13	88.	270.	270.	278.	263.	65.	80.	95.	
14	87.	271.	251.	281.	260.	65.	72.	98.	
15	82.	270.	252.	280.	255.	65.	71.	97.

DMT-032

TESTID : DMT-032

DATAFI : SEAL.032

THERMOCOUPLES(F):

N	1 THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	8 INLET WATER	9 UPPER SEAL OUTLET	10 LOWER SEAL OUTLET
1	95.	195.	230.	170.	265.	60.	65.	80.
2	95.	225.	255.	240.	175.	60.	75.	85.
3	95.	270.	225.	325.	225.	65.	80.	85.
4	95.	290.	260.	310.	235.	65.	80.	85.
5	90.	310.	280.	315.	235.	60.	75.	85.
6	90.	300.	275.	300.	230.	60.	80.	90.
7	90.	270.	230.	240.	230.	60.	80.	80.
8	90.	300.	255.	380.	230.	60.	80.	85.
9	90.	330.	270.	415.	260.	60.	80.	85.
10	90.	365.	300.	405.	280.	60.	80.	90.
11	90.	400.	340.	455.	295.	60.	80.	85.
12	95.	385.	320.	420.	300.	65.	80.	85.
13	95.	375.	300.	445.	305.	60.	75.	90.
14	95.	240.	250.	275.	230.	65.	80.	85.
15	95.	235.	240.	260.	225.	65.	80.	85.
16	95.	240.	230.	255.	220.	65.	80.	85.
17	95.	250.	230.	255.	220.	65.	80.	85.
18	100.	250.	230.	250.	215.	65.	80.	90.
19	100.	245.	220.	240.	210.	65.	80.	90.
20	100.	240.	220.	245.	205.	65.	80.	95.
21	100.	235.	220.	235.	205.	65.	80.	95.
22	100.	245.	240.	315.	220.	65.	80.	95.
23	100.	255.	250.	355.	230.	65.	80.	95.

TESTID : DMT-032

DATAFI : SEAL.032

N	TIME	TORQUE	UPPER SEAL TEMP6 (F)	LOWER SEAL TEMP7 (F)	UPPER SEAL LEAK CU IN	UPPER SEAL LEAK RATE CU IN/HR	LOWER SEAL LEAK CU IN	LOWER SEAL LEAK RATE CU IN/HR
1	0.00	322.	110.	100.	0.0	6.0	0.0	0.0
2	0.25	322.	250.	185.	0.0	0.0	0.0	0.0
3	0.50	292.	245.	225.	0.0	0.0	0.0	0.0
4	0.75	472.	245.	230.	0.0	0.0	0.0	0.0
5	1.00	352.	225.	205.	0.0	0.0	0.0	0.0
6	1.25	352.	225.	205.	0.0	0.0	0.0	0.0
7	1.50	142.	150.	115.	6.8	27.2	0.0	0.0
8	2.00	250.	250.	175.	6.8	0.0	0.0	0.0
9	2.50	262.	245.	200.	6.8	0.0	0.0	0.0
10	3.00	232.	245.	200.	6.8	0.0	0.0	0.0
11	3.50	202.	265.	205.	15.9	18.2	0.0	0.0
12	3.62	172.	305.	200.	22.7	56.8	0.0	0.0
13	4.15	202.	275.	210.	22.7	0.0	0.0	0.0
14	4.65	262.	250.	210.	22.7	0.0	36.3	18.2
15	5.15	262.	235.	205.	25.0	4.5	0.0	18.2
16	5.65	262.	235.	200.	25.0	0.0	0.0	18.2
17	6.15	232.	235.	215.	25.0	0.0	0.0	18.2
18	6.65	232.	235.	200.	25.0	0.0	0.0	18.2
19	7.15	232.	210.	210.	24.1	2.3	0.0	18.2
20	7.65	232.	225.	210.	45.4	38.6	0.0	18.2
21	7.73	262.	205.	205.	45.4	0.0	0.0	18.2
22	8.15	208.	250.	155.	56.8	27.0	5.4	20.4
23	8.57	132.	220.	160.	86.3	70.3	5.4	22.7

DMT-033

TESTID : DMT-033

DATAFI : SEAL.PLT

THERMOCOUPLES(F) :

N	1 THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	6 INLET WATER	7 UPPER SEAL OUTLET	8 LOWER SEAL OUTLET
1	60.	60.	55.	55.	60.	60.	40.	45.
2	65.	60.	50.	120.	90.	45.	50.	55.
3	60.	65.	50.	110.	75.	60.	75.	80.
4	75.	95.	50.	105.	90.	60.	70.	75.
5	80.	105.	50.	120.	95.	60.	70.	75.
6	85.	115.	50.	130.	105.	60.	70.	75.
7	85.	120.	60.	130.	115.	60.	70.	75.

TESTID : DMT-033

DATAFI : SEAL.PLT

N	TIME	TORQUE	UPPER SEAL TEMP (F)	LOWER SEAL TEMP (F)	UPPER SEAL LEAK CU IN	UPPER SEAL LEAK RATE CU IN/HR	LOWER SEAL LEAK CU IN	LOWER SEAL LEAK RATE CU IN/HR
1	0.00	262.	160.	145.	0.0	0.0	0.0	0.0
2	0.03	282.	140.	155.	0.0	0.0	0.0	0.0
3	0.20	152.	120.	110.	0.0	0.0	0.0	0.0
4	0.35	112.	105.	100.	0.0	0.0	0.0	0.0
5	0.47	92.	100.	100.	0.0	0.0	0.0	0.0
6	0.60	82.	140.	105.	97.6	250.8	18.2	139.7
7	0.72	92.	135.	105.	102.2	37.8	20.4	18.9

Distribution:

TID-4500-R66 UC-66c (567)

400	C. Winter*
1000	G. A. Fowler*
1100	C. D. Broyles*
1130	H. E. Viney*
2000	E. D. Reed*
2300	J. C. King*
2320	K. Gillespie*
2325	R. E. Fox*
2328	J. H. Barnette*
2500	J. C. Crawford*
2513	W. B. Leslie
4000	A. Narath*
4200	G. Yonas*
4300	R. L. Peurifoy, Jr.*
4400	A. W. Snyder*
4443	P. Yarrington*
4500	E. H. Beckner*
4700	J. H. Scott
4710	G. E. Brandvold*
4720	V. L. Dugan*
4730	H. M. Stoller
4740	R. K. Traeger
4741	S. G. Varnado (25)
4741	A. B. Maish
4741	J. T. Finger
4742	A. F. Veneruso
4743	H. C. Hardee
4744	H. M. Dodd
4744	C. C. Carson
5000	J. K. Galt*
5512	A. Ortega
5530	W. Herrmann*
5532	B. M. Butcher*
5533	J. M. McGlaun
5600	D. B. Schuster*
5620	M. M. Newsom*
5800	R. S. Claassen
5810	R. G. Kepler*
5812	C. J. M. Northrup, Jr.*
5812	B. T. Kenna
5813	P. B. Rand
5830	M. J. Davis*
5831	N. J. Magnani*
5832	R. W. Rohde*
5832	R. J. Salzbrenner
5833	J. L. Ledman*
5833	J. L. Jellison
3140	T. L. Werner (5)
3151	W. L. Garner (3)
8266	E. A. Aas

* Only abstracts distributed. Full report available upon request if there is interest.