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Program for the Improvement of Downhole Drilling-Motor Bearings and Seals

Phase III, Part 1: Final Report

Terra Tek

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MASTER

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

PHASE III, PART 1: FINAL REPORT

Terra Tek
Salt Lake City, Utah 84108

ABSTRACT

This report summarizes a systematic laboratory testing and evaluation program to select high-temperature seals, bearings, and lubricants for geothermal downhole drilling motors.

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

FOREWORD

This report summarizes the work performed for Phase III - Part 1, "Program for the Improvement of Downhole Drilling Motor Bearings and Seals", under the Department of Energy/Division of Geothermal Energy Contract number 07-7298.

The ultimate goal of this program is the utilization by industry of a significantly improved downhole motor bearing-seal section for geothermal application. In order to accomplish this goal, a systematic laboratory testing and evaluation program is in progress to select candidate high-temperature seals, bearings and lubricants that will be field tested during Phase IV of this program.

This report will be divided into four main sections:

- (1) Summary,
- (2) Seal Testing and Evaluation,
- (3) Bearing-Seal Package Testing and Evaluation, and
- (4) Lubricant Testing and Evaluation.

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INTRODUCTION

There are many potential advantages in using downhole motors over conventional rotary drilling methods to drill geothermal wells including faster drilling; improved directional and side-track drilling; reduced drill string wear, vibration and fatigue failure; reduced casing wear; and improved borehole stability.

With all of these advantages, downhole motors are still not used extensively since short bearing life, resulting from seal failure, increases the cost per foot of holes drilled with a downhole motor over conventional rotary drilling. In the case of geothermal wells, where drilling costs are roughly doubled, the effect of short tool life on drilling economics is even greater. Improvements to downhole motor bearings and seals are, therefore, extremely important for geothermal as well as oil and gas well drilling.

Reduced bearing life has been a direct result of the inability to seal lubricants in the bearing section. Current seal designs also limit pressure drops across the drill bit to only 100 to 300 psi, which is far below the 1,000 to 2,000 psi typically required for good bottom-hole cleaning and bit cooling. With these reduced pressure drops, a normal downhole motor must be run with the weight-on-bit reduced proportionally which, in turn, reduces drilling rate.

The specific objectives of this program are as follows:

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

- (2) Develop an improved rotary seal which allows bit pressure drops over 1,000 psi; and
- (3) Develop a Bearing-Seal Package to operate at 250°F circulating bottomhole temperature.

The following outlines the technical approach that Terra Tek has used in performing the work for this program:

- (1) Candidate seals and candidate lubricants are separately screened in the laboratory in different test machines.
- (2) The screened candidate seals and lubricants are then tested in the full-scale Bearing-Seal Package under simulated downhole conditions. The Bearing-Seal Package Test Facility is fully instrumented to ensure that downhole conditions are simulated.
- (3) The Bearing-Seal Package will be tested in the laboratory with a motor selected from industry.
- (4) The Bearing-Seal Package is then tested in the field only after extensive testing has been completed in the laboratory.

It should be emphasized that the technical approach Terra Tek and Maurer Engineering have used is unique in that screening and full-scale testing under simulated conditions are completed in the laboratory before any field testing is performed. The laboratory tests allow more quantitative information from measurements of loads, thrusts, temperatures, flows, etc.; and, hence, provides data for improvements. This approach is much less expensive than performing all testing in the field and trying to determine needed improvements from such qualitative information.

The work of Phase III - Part 1 of the "Program for the Improvement of Downhole Drilling Motor Seals and Bearings", under the Department of Energy/ Division of Geothermal Energy contract No. 07-7298, is presented in this

report. The Phase II - Part 1 effort was initiated in May, 1978, and completed in November, 1978.

The plan to accomplish the specific program objectives is outlined in the major milestone chart in Table I.

[illegible]

SUMMARY

The approach used by Terra Tek and Maurer Engineering in performing the work for this program is aimed at full-scale laboratory testing and evaluation of a new Bearing-Seal Package under simulated downhole conditions before field testing. The following summary briefly reviews the program.

Initially, a review of existing downhole motors was conducted to define limitations of existing equipment, and to aid in establishing the goals of this program. A brief review is presented in Appendix C. From this review it was concluded that the major problem with most downhole motors is the inability to effectively seal a lubricant in the bearing section of the motor. Therefore, the development of an improved bearing section with better seals is the key to improving downhole motor life.

An outline of the major accomplishments of the completed phases of the program is given below. Note that Phases I, II, and III - Part 1 have concentrated on the background, design work, and seal testing and evaluation. Phases III - Part 2, and Phase IV will concentrate on further testing and evaluation work.

Phase I - Major Accomplishments

- (1) Gathered background information to determine current needs of industry and established a range of conditions need to simulate geothermal conditions -
 - Met with downhole motor experts at Rice University meeting.
 - Jeddy Nixon presented his experiences in downhole motor development at a Review Meeting at Terra Tek, Inc.
 - John Jeter was consulted on Bearing-Seal Package design and the seal tester design.
 - Industry contacts and correspondence were established.

- Information from the Geothermal Bit Program, such as downhole geothermal temperatures, rock formations, and drilling problems, was 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 results in the Semi-Annual (TR 76-59) and Final (TR 77-29) reports.
 - Maurer Engineering presented the economic incentives for geothermal downhole motor development.
 - (3) Performed the preliminary design of the Bearing-Seal Package
 - Maurer Engineering described the Bearing-Seal Package in the Semi-Annual (TR 76-59) and Final (TR 77-29) reports.
 - (4) Candidate "high temperature" seals were identified -
 - A description of the candidate seals was presented in the Semi-Annual (TR-59) and Final (TR 77-29) reports.
 - Bearing application was presented in the Semi-Annual (TR 76-59) and Final (TR 77-29) reports.
 - Candidate lubricants were presented in the Semi-Annual (TR 76-59) report.
 - (5) Design and fabrication of the seal tester was completed -
 - Preliminary concepts and evolution of the final design was presented in the Semi-Annual (TR 76-59) report.
 - John Jeter consulted on the design of the seal tester.
 - Detailed design of the seal tester was completed.
 - Fabrication of the seal tester was completed.
 - (6) Conceptual design of the Bearing-Seal Package Test Facility was conducted.

Phase II - Major Accomplishments

- (1) Seal testing and evaluation -
 - Debugging tests on the seal test system 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 -
 - Terra Tek high-temperature lubricant tester was made operational
 - Lubricant irradiation technique was perfected

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 have been tested
 - Additional high temperature candidate seal types have been tested
 - The seal test system has undergone several modifications to improve ease of handling and for more reliable operation
- (2) Bearing-Seal Package testing and evaluation -
 - Design for solution of 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 its modification for the test facility was started.

- A 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 lubricant tester were obtained
- A survey of downhole motor manufacturers was made to obtain lubricant recommendations. Candidate lubricant matrix was revised.

From the beginning of this program, Terra Tek has tried to communicate the results of this work to industry and government through all available means. So far, five Terra Tek reports and one paper have been published, and results have been presented at six review meetings. A list of the reports, papers and review meetings will be found in the Bibliography and References section of this report.

This communication has generated considerable industry support and interest. Seal molding costs, new high temperature lubricant formulations, and downhole motor and bearing expertise have all been supplied. The reasons for this type of "cost sharing" are that the benefits from this program not only apply to geothermal energy resource recovery but to oil and gas recovery and mining applications as well.

SEAL TESTING AND EVALUATION

SEAL TESTER*

In order to provide a laboratory facility to test downhole motor seals, a range of downhole conditions typically found in geothermal well drilling was defined. Since actual data from downhole geothermal operations are extremely limited and actual conditions vary widely depending on the location, depth and rock type of a particular well, the seal tester was designed to be versatile enough to allow the simulation of conditions over a wide range. The design range for the seal tester is listed in Table II.

TABLE II
Downhole Motor Seal Tester Design Limits

- Ambient pressure to 5,000 psi
- Differential pressure across seal to 5,000 psi
- Temperature to 600°F
- Rotary speed from 100 to 1700 RPM
- Radial eccentricity of shaft to .010 inch
- Shaft diameter of 5 inch
- Pressure medium of lubricant or water
- Other variables such as the number of seal rings, seal cross-section, precompression of seals, rotary shaft material and surface finish and pre-soak temperature

Another important consideration for the seal tests is a definition of seal "failure". Limitations such as volume of lubricant confined in the bearing section of the downhole motor must be considered in the seal

* This section is reproduced from the Phase II Final Report (TR 78-29). It provides a brief description of the seal test facility for background information.

failure analysis. For example, a moderate amount of leakage is normal and necessary for the proper operation of some seals. However, if this leakage rate drains the total lubricant reservoir too fast and allows drilling mud to enter the bearings, the seal is considered unsatisfactory. Seal failure for the downhole motor seals has been defined as the point in time when one gallon of lubricant leaks past the test seal.

A simplified cross-section of the rotary shaft (Figure 1) illustrates the basic design features of the seal tester. The design uses a pressure-balance system where high pressure is introduced between two test seals and lower pressure is introduced between the test seals and the vessel seals. Either two identical or two different seals can be tested at the same time under the same conditions allowing comparison between two different seal designs.

The test seal shaft sleeve is replaceable, so sleeves with different surface coatings, surface finishes and radial eccentricity can be tested. The vessel seals also have replaceable sleeves. The vessel seals are one-half the diameter of the test seals; have essentially no radial eccentricity; are continuously cooled; and are designed with redundant sealing elements for extended life. If one test seal should fail abruptly, an unbalanced force is created forcing the rotating shaft away from the failed seal. A thrust bearing reacts the unbalanced forces while the test is ended.

A detailed layout of the Downhole Motor Seal Tester is shown in Figure 2 . The test seals are heated with 15 KW of power while cooling water is independently directed beneath the replaceable sleeve of the test seals to simulate heat removal by drilling mud flowing through a downhole motor. The seal tester is instrumented with numerous transducers

A Simplified Cross-Section of the Rotary Shaft
Figure 1

DOWNHOLE MOTOR SEAL TESTER

Seal Tester Vessel with Internal Parts
Figure 2

to measure seal temperatures, pressures, differential pressures, torque, RPM, leakage past each test seal as a function of time, cooling water flow rate and inlet and outlet temperatures. Two thermocouples are positioned in the rotating shaft sleeve to measure the temperature of the seal and shaft interface as closely as possible. All variables are continuously monitored on strip chart and analog recorders.

Figure 3 shows the Downhole Motor Seal Tester and associated instrumentation. There is an ongoing program to improve the performance

Figure 3
Downhole Motor Seal Tester

and reliability of the seal tester. Two specific areas have been improved since the beginning of Phase III, Part 1. The cooling water system has had new seals added and is now virtually leak-proof. A torque-limiter coupling has been added to the drive train to protect the drive components and a radial bearing has been added to the drive train to stabilize the slip rings and reduce noise in the rotating transducer signals.

A more detailed description of the Seal Tester can be found in Appendix A of the Phase II - Final Report (TR 78-28).

SEALS AND SEAL TESTS

Description of Baseline Seals and Tests

Tests to determine a baseline of data have been completed on UTEX type 701 seals. These seals are made from a Buna-N compound reinforced with bias-cut cotton duck and molded in a chevron or "V" cross-section as shown in Figure 4. This particular seal was chosen because it is widely used in the petroleum industry for surface and downhole rotary applications and is readily available.

Figure 4
UTEX-Chevron Packing Seal

The test seal for the baseline tests consisted of three pressure rings and flatback rings both front and back. In part of the baseline tests the back-up rings were Buna-N with cotton duck reinforcing, while other tests were run with aluminum-bronze back-up rings.

Some baseline tests were also run using one and two pressure rings for the test seal.

Description of New Seals

Since the completion of the baseline tests on the UTEX type 701 seals, four other seals have been tested. The following description is given of each new seal type.

42D

The first new seal tested was another chevron seal manufactured by Utex Industries, Inc. It is identical in geometry to the type 701 seal and referred to by the manufacturer as "42D". It is made with a BUNA-N compound impregnated with graphite for friction reduction. Like the type 701, it is reinforced with bias-cut cotton duck. The seal rings form a line contact with the rotating shaft surface and they are activated simultaneously. Each withstands a portion of the differential pressure carried by the seal pack.

125K-RD181

This seal is also an elastomer seal manufactured by Utex Industries, Inc. A cross section of this seal is illustrated in Figure 5. The seal consists of two seal rings, a homogeneous viton ring in front of a viton ring reinforced with cotton duck in back. The homogeneous viton ring is

the softest ring tested to date. It was felt that the softer seal ring would give the seal better fatigue life while the harder back-up ring would enable the seal to withstand the required pressure.

Figure 5
125K-RD181 Seal

GRAFOIL^R - BeCu

This seal was the first non-elastomer seal tested. It is manufactured by Utex Industries to the design and specifications of Maurer Engineering, Inc. A cross section of this seal is shown in Figure 6. Thin layers of GRAFOIL^R provide lubricity, high heat conductivity and a seal. GRAFOIL^R is a registered trademark of Union Carbide.

Figure 6
High-Temperature GRAFOIL^R - Be Cu Seals

Graphite-Metal Matrix

This is another non-elastomer seal manufactured by Utex Industries, Inc. to their design and specifications. It is similar to the other chevron seals in geometry. A cross section of this seal is shown in Figure 7. The seal rings are made with a copper wire mesh center to provide resiliency and it is impregnated with graphite and cold pressed into the configuration shown. This seal is more brittle than the GRAFOIL^R seal, but the lubricating and thermal conductivity characteristics are similar.

On hand are three additional seal types that will be tested.

Figure 7
Graphite-Metal Matrix Seal

UNEEPAC^R SEAL

The UNEEPAC^R seal is an elastomer seal manufactured by Johns-Manville. A cross section of these seal rings is shown in Figure 8 . The seal rings are made of neoprene and reinforced with flocked asbestos. These seals were used successfully in Exxon's high pressure swivel at 15,000 psi. A smaller diameter copy of this seal is being used as the vessel seal in the seal tester.

Figure 8
Johns-Manville UNEEPAC^R Seals

Radial Lip Seal

Manufactured by Utex Industries, Inc., these seals are made of a ceramic fiber core sheathed with a fluorocarbon-treated aramid fabric impregnated with graphite. The treated aramid fabric is resistant to 450°F (232°C) while the graphite impregnant reduces friction. Each seal ring is individually supported by an aluminum-bronze back-up ring so that only one seal ring will wear out at a time.

Figure 9
UTEX Conventional Radial Lip Seal

Canted Radial Lip Seal

These seals, shown in Figure 10 , have been specially manufactured by Utex Industries, Inc. They are made of the same materials as the straight radial lip seal above and are individually supported by aluminum-bronze back-up rings. These seals are canted to reduce the temperature extremes generated in a rotary seal by straight line contact with the rotating shaft.

Figure 10
UTEX Canted Radial Lip Seal

Table III lists the candidate new seals in a planned test matrix.
All of the seals listed are on-hand.

TABLE III
TEST MATRIX FOR CANDIDATE IMPROVED HIGH-TEMPERATURE SEALS

<u>Test I.D.</u>	<u>Seal I.D.</u>	<u>Number of Pressure Rings</u>
019	Graphite-metal matrix	3
020	Graphite-metal matrix	1
021	GRAFOIL ^R -BeCu	3
022	UNEEPAC ^R	3
023	UNEEPAC ^R	3
024	GRAFOIL ^R -BeCu	
025	Repeat any of the previous tests as appropriate	
026	Repeat any of the previous tests as appropriate	
027	Repeat any of the previous tests as appropriate	
028	Repeat any of the previous tests as appropriate	
029	Radial Lip	3
030	Canted Radial Lip	3

Adjustments to the test matrix are being made continuously as new results are evaluated and unique and novel seals become available for testing. Recommendations from the seal manufacturing industry offer new

directions to the test program and test results guide the selection of seals and parameters for further testing. Adjustments to the test matrix will continue to be made due to the character of the research.

Testing of the Bearing-Seal Package will continue on schedule with the standard UTEX-type 701 packing for the seal. Testing of improved candidate seals will continue into Phase III - Part 2. The Bearing-Seal Package will be retrofitted with improved seals as seal life is extended significantly in the seal tester.

Industry Interaction

The search for candidate seals to test has served to inform seal manufacturers of the research supported by this contract and the goals involved. Several seal manufacturers contacted are actively interested.

UTEX Industries, Inc., of Houston, Texas, the suppliers of the standard chevron, 42D, 125K-RD181, GRAFOIL^R, Be Cu, Graphite Metal Matrix and the radial lip seals, both straight and canted, has visited Terra Tek, Inc., on several occasions. They have provided valuable insight and observations on some of the early test results and have concurred or made suggestions to the proposed test matrix. A new seal compound has been introduced for future testing, and there are regular communications between the two companies.

Parker Seal Company, with an office in Salt Lake City, has reciprocated visits with Terra Tek, Inc., out of interest for the seal work being done under this contract and the seal work being done under Department of Energy/ Division of Geothermal Energy-Sandia contract No. 13-0226. They have been helpful in supplying background information into seal molding and elastomer compounding. They recommended a couple of seals to test and expressed willingness to participate in any special compounding that might be required.

A representative from Sealol visited Terra Tek and expressed interest in the sealing problem. He asked to be kept informed of the progress.

Gits Brothers Manufacturing Company and Sealol have been supplied with dimensions of the seal tester and asked to submit designs for face seals to be tested in this facility. Gits Brothers claims an early success testing a face seal in a downhole motor.

SEAL TEST RESULTS

Tests DMT-001 through DMT-018 have been completed. A summary of seals tested, test conditions and parameters for these tests are given in Table A-1 of Appendix A. The data from tests 001, 002, 008, 010, 015, and 018 form baseline data for comparing the performance of other seal types.

The baseline tests on the Type 701 Buna-N seals normally were run with an operating upper temperature limit of 250°F (121°C). These seals were exposed to 250°F (121°C) soak conditions before rotation of the shaft began. After rotation was begun and equilibrium reached, the sliding friction generated between the seal and shaft interface gives rise to extreme temperatures at the sealing line. A sharp thermal gradient results in the material of most elastomer seals and a more gradual gradient through the steel of the shaft sleeve. Because of their distance from the seal-shaft interface, the rotating shaft sleeve thermocouples do not measure the highest operating temperature of the seal. Through more complicated and expensive machining methods, thermocouples could be placed closer to the seal-shaft interface. As an alternative, a one-dimensional heat transfer computer model was made by Dr. Dareing at Maurer Engineering. A summary report of the model is included in Appendix B. Utilizing this model, the seal-shaft interface temperature is calculated. The accuracy of the model is checked with the measurement of the thermocouples, which are 0.28 inches beneath the seal-shaft interface.

Upper and lower seal temperatures are measured by thermocouples beneath the seal-shaft interface, placed near the last pressure ring on the low pressure side of the seal pack. This is where the greatest wear, consequently greatest torque and temperature, occurs.

The individual test plots are also in Appendix A. Torque as measured by the torque cell external to the pressure vessel has been corrected for the residual torque of the vessel seals, so that the value for torque is that generated in both test seal packs.

Seven tests have been run on the baseline seal. The second most extensively tested seal is the 42D seal supplied by Utex Industries and described earlier in this report. Five tests were run with this seal type. For a given operating temperature, the operating life of this seal shows an increase over the baseline style 701 seal.

Only two tests have been run on each of the two other seal types. The GRAFOIL^R-BeCu seals exhibit low, average operating temperatures. The viton seals, 125K-RD181, exhibit short operating life with varying operating temperature and torque. This seal generates high torque for a single pressure ring seal.

BASELINE SEAL TESTS

Standard Test Conditions

Standard test conditons for the baseline seals are as outlined below:

● Seal Type	701
● Seal I.D.	5.0 inches
● Seal O.D.	6.0 inches
● Temperature	250°F (121°C)
● Forward Pressure	2,500 psi
● Differential Pressure	1,500 psi
● Back Pressure	1,000 psi
● Number of Pressure Rings	3
● Pressurized Fluid	Texaco EP85 90 Gear Oil
● RPM	412
● Shaft Surface	Hard Chrome
● Surface Finish	16 RMS ± 2
● Cooling Water Flowrate	18 GPH

Test Procedure

The seals are individually dipped in the pressurizing fluid before installation. The heaters are turned on after the seals are installed and the tester and the temperature of the vessel is increased to 250° F. The heating process requires about two hours. Once the vessel is heated, the fluid is pressurized to 1,000 psi on both sides of the test seals. The valves that control the cooling water to the vessel seals are opened 3/4 turn. Immediately prior to rotation of the main shaft, 32 GPH of cooling water is directed beneath the shaft sleeve in the area of the lower seal. Water to cool the test seal is turned on just enough to register on the flowmeter (approximately 6 to 8 GPH) and then rotation is begun. The differential pressure is applied across both seal packs and as this is done, the flow of cooling water in the area of the test seal is increased to 18 GPH. The start time is noted on both the strip chart and the multi-point recorders.

After four hours of continuous running, the differential pressure across the test seals is reduced to zero, the rotation is stopped and the flow of cooling water to the test seals is shut off. The rotation of the main shaft remains stopped for ten minutes. At the end of this time the start-up procedure is repeated.

This procedure is repeated every four hours throughout the life of the seal.

Exceptions from Standard Conditions

DMT-001

- Rotation speed was 212 RPM.
- Pressurized fluid was Mobil 600 W steam cylinder oil.
- Cooling water was turned on to all seals before pressurizing and before rotation.

- Cooling water was controlled at 12 GPH.
- There were no periodic interruptions in this test.
- The seals were not dipped in the steam cylinder oil prior to installation.

DMT-002

- Rotation speed was 212 RPM.
- The cooling water flowrate was varied during the test (6, 3, and 2 GPH).
- There were seven unscheduled shutdowns and restarts.
- Rotation was begun before the flow of cooling water was established.
- Water flow and pressure fluctuated during the test.
- During shutdowns the shaft was removed and replaced several times, sliding in and out of the seal packs.

DMT-008

- There were two seal rings in each pack and brass backup rings.
- The lower seal was designated as the test seal.
- #5 thermocouple was used as feedback for temperature control.
- There was a 12-hour soak at temperature before rotation began.
- Cooling water flow to the test seal varied.
- 1,000 psi was not applied before the initial rotation.

DMT-009

- Two pressure rings were used per seal pack.
- There was cross leaking of cooling water to the lower seal.
- Cooling water flow was reduced to maintain 283°F (139°C) on the upper (test) seal from 18 to 4 GPH.
- 1,000 psi was not applied before the initial rotation.

DMT-010

- Test seal is the upper seal.
- T/C #6 was found to be 1/2 inch below the test seal.
- Two pressure rings were used per seal pack.
- The surface finish of the shaft was 12 RMS.

DMT-015

- There were two unscheduled interruptions of the test.
- A single pressure ring was used in each seal pack.
- 12 RMS shaft finish.
- Cooling water was turned on after rotation.

Leakage

Refer to Appendix A for graphs of the measured parameters versus time of the baseline test results. In one extreme in Test DMT-001 of gradual leakage extending over nearly fifty hours to another extreme in Test DMT-018 of catastrophic leakage after little more than one hour. The plots of seal leak versus time exhibit some trends.

The leak versus time plots of Tests DMT-001 and 002 show gradual increases. The seal in Test 002 began leaking later than the seal in Test 001 but failed sooner. As a point of interest, each of the two plots has three plateaus where the leak stopped for a period of time.

The seal in Test DMT-008 began leading similar to the first two tests and even began decreasing as if the leak were reaching a plateau. At eighteen hours the seal failed catastrophically. If this plot of leak versus time is overlaid on the plot of lower seal temperature versus time for DMT-008, insight is gained into the duration of Buna-N elastomers at extreme temperatures. The lower seal operated at 330° F (166° C) as measured

by a rotating thermocouple for about an hour before the elastomer hardened, and the seal leaked catastrophically.

By overlaying the plots of upper seal temperature and upper seal leak from test DMT-002, less dramatic but definite correlation can be seen between rapid increases in leak and temperature increases.

Except for the seals in test 001, all of the baseline seals failed because of high temperatures generated at the sealing line. The critical temperature appears to be 275 to 300° F (135 to 149° C) for the Buna-N baseline seals. The seals in test 002 began leaking rapidly at about 15 hours elapsed time which coincides with a temperature spike over 275° F (135° C). The plot of temperature versus time shows early in the test a temperature spike to 325° F (163° C) of short duration. The duration of the high temperature excursions is a significant factor in the success or failure of the seal within an upper temperature bound which was not achieved during these tests.

The thermocouple measuring the temperature of the test seal during test 008 indicated an upper temperature of nearly 280° F (138° C) until about 17.5 hours elapsed. The temperature at that time increased to 325° F (163° C). If the temperature and leak plots are overlayed the coincidence of the temperature extreme and catastrophic leak becomes apparent. The duration of the temperature in excess of 300° F was an hour or more.

The temperatures and leak records of test 009 do not reveal as clearly this temperature - catastrophic failure relationship that is seen throughout the baseline test results. It can be said that the operating temperature of the seal was rising, that it did peak at approximately 280° F (138° C) and at that point the seal failed catastrophically. It is felt that the thermocouple in this test may have been farther removed from the seal than in

other tests. The seals in test 015 began leaking only as the temperature, after a gradual increase, reached 320° F (160° C). The temperature stayed near this same level for 1/2 hours until the seals failed catastrophically.

Test 018 was the shortest test on the baseline seals. The seal failed catastrophically in about an hour after the operating temperatures increased rapidly to over 400° F (204° C). This test was the only baseline test with three pressure rings operated at 412 RPM. The cooling water flow rate was established for two pressure rings operating at 412 RPM. Three pressure rings generate significantly more heat than two. This is the reason for the extreme temperature. The seal duration is then dependent on the operating temperature and elapsed time at temperature.

Torque

The torque is measured by a rotating torque cell outside the pressure vessel. Consequently, the torque generated in the vessel seals, the radial bearings and thrust bearings as well as the test seals is registered in the torque cell. The torque data has been reduced so that the plots of torque reflect only the sum torques generated in the two test seals. It is, therefore, very difficult to relate torque anomalies to one or the other test seal.

In general, the torque and the operating temperature of both seals are interdependent in their response patterns. Test 002, for example, in its traces of seal temperatures and torque repeats similar trends. In general, the trace of the operating temperature of the failed seal more closely resembles the torque trace. This is illustrated further by the results of test 009.

Temperature

The operating temperature of the seals is measured by thermocouples that respond slowly to real changes in the shaft-seal interface temperature due to their distance from the interface. There is some variation in the location of the thermocouples since they are removed and replaced for each test. The thermocouple wells in the individual shaft sleeves are all at a different distance from the sleeve surface and the length of the thermocouple varies with each installation.

TYPE 42D SEAL TESTS

Standard Conditions

The standard condition for these tests are the same as those used for the baseline tests.

Exceptions from Standard Conditions

DMT-003

- Rotation speed was 212 RPM.
- Cooling water flow rate - 4 GPH.

DMT-004

- Rotation speed was 212 RPM.
- Cooling water flow rate - 4 GPH.
- Rotation was begun before cooling water was turned on.

DMT-005

- Rotation speed was 212 RPM.
- Cooling water flow rate - 4 GPH.
- Shaft surface finish is questionable.
- Cooling water was turned on after rotation began.

DMT-006

- Rotation speed was 212 RPM.
- Cooling water flow rate - 4 GPH.

DMT-007

- Cooling water flow rate - 4 GPH.

General Results

The condition of the seals after test 003 typify a failure by general wear. The torque decreased during the test and the test ended when the lower seal leaked nearly catastrophically. The lower seal temperature was consistently above 300°F (149°C) in the early part of the test. This seal exhibits better temperature resistance than the baseline seals.

The seals tested in 004 began leaking early in the test and the operating temperature varied between 250°F and 350°F (121°C and 177°C). The seal failed catastrophically when the operating temperature exceeded 350°F (177°C).

The operating temperature of the test seal in 005 was consistently above 300°F (149°C). The seal lasted approximately five hours and then failed catastrophically. This seal type appears to be able to operate at higher temperatures for longer periods of time than the baseline seals.

The seal tested in DMT-006 operated at nearly 350°F (177°C) for three hours before it began to leak. This temperature is 50 to 75°F (10 to 24°C) higher than what was estimated to be the critical operating temperature for the baseline seals. The torque recorded during this test, however, is lower than any recorded during the baseline tests.

Test 007 was the only test run at 412 RPM on type 42D seals. It was only 3.10 hours in duration, but the operating temperature of the test seal was consistently in excess of 300°F (149°C).

It is not clearly understood at this point what caused the sharp increase in torque to occur at about two hours into the test. The torque peaked at about 200 foot-pounds and then decreased to 100 foot-pounds by the end of the test. In some tests, a sharp decrease in torque is accompanied by a large increase in fluid leakage. The leaking fluid cools and lubricates the seal which causes the torque to decrease. For lack of knowledge of other mechanisms effecting the torque, a theory put forth here is that fluid did leak but it was such a small amount that it was imperceptible to the leak rate monitor. The leak rate monitoring system can resolve .45 cubic inches (7.4 cc). The failure modes exhibited by the type 42D seal are similar to the failure modes of the baseline seals. The seal rings, especially the last one on the low pressure side of the seal pack, adhere to the rotating shaft and buckle up. This weak spot then allow the fluid, under pressure, to leak past the seal. The heat generated by seal friction is generally concentrated in this area near the low pressure side of the seal. This is the nature of a stacked seal in which the pressure rings all work simultaneously and the pressure loading is concentrated at the back or low pressure side of the stack.

The varying operating life of the seals is due in part to variability in the manufacturing process and even in the size of the seals from one set to another. The size variability shows up during installation because of how easily the seals fit in the seal housing and over the shaft sleeve. The variability in manufacturing appears as a difference in the amount of reinforcing fibers protruding from the inside lip of the seal ring. Before installation, the inside lip of one seal ring used in Test 005 was coming apart. Loose fibers beneath the surface of the elastomer caused particles of the elastomer to come off easily.

The post-test condition of the shaft sleeve surface was usually a mixture of polished areas, gall marks and ripples in the chrome plating. This condition was typical of the sleeves used in testing the Type 701 baseline seals and the Type 42D seals.

TYPE 125K-RD181 Seal Tests

Standard Conditions

Standard conditions for the 125K-RD181 seal are identical to the baseline seals with the following exceptions:

- Seal type 125K-RD181
- Number of Pressure Rings 1

The test procedures were the same as with the baseline tests.

Rotation was started with 1,000 psi on both sides of the test seal.

General Results

During Test DMT-013, the fluid leaked past this type 125K-RD181 seal in an unusual manner for a seal pack consisting of a single seal ring. The seal leaked abruptly and then stopped. It began to leak again less abruptly and stopped again and then it leaked catastrophically.

There was a noticeable change in torque that occurred at about 3.5 hours elapsed time. The torque increased from about 30 foot-pounds to over 100 foot-pounds in a little over an hour. This step in torque coincides closely with the initial leak of the seal.

The step in torque also coincides with a sharp increase in the operating temperature of the seal. The 70 foot-pound torque increase

follows closely a temperature increase of 60°F (16°C) from 315°F to 375°F (157°C to 191°C). The operating temperature of the test seal was consistently above 300°F (149°C) and at times approached 400°F (204°C). The temperature of the test seal, usually the seal with the highest operating temperature, is influenced by or influences more strongly the torque reading. Rapid increases in torque and other anomalies can, by overlaying the graphs of operating temperature of both seals and torque, be related to the influence of the test seal operating temperature.

The seal tested in DMT-014 leaked catastrophically after 8.6 hours. All of the fluid leaked at once.

This test also had a torque step. At about 3.5 hours the torque increased from 20 foot-pounds to 120 foot-pounds. The record of torque was similar to the torque graph from test 013.

The location of the thermocouple that measured operating temperature is questionable for this test. This seal had a shorter test life and yet a lower indicated operating temperature than the other type RD181 seal.

This seal type with just one pressure lip failed not so much by heat as by wear and extrusion. An examination of the seals reveals wear at the seal lip and indications that the lip was folded or extruded in one or more spots. The viton elastomer of which this seal is made maintains its resiliency and recovery characteristics at higher temperatures than Buna-N rubber but the coefficient of friction is higher. The higher operating temperature that is generated equalizes most of the gain from the better high temperature characteristics.

This seal as tested has inadequate support to seal the 1,500 psi differential pressure. The backup rings allowed extrusion of the seal ring.

Standard Conditions

- Seal Type GRAFOIL^R - BeCu
- Number of Pressure Rings 5

During Test DMT-016, great care was taken to install the test seal. A new tool was used that facilitates the installation of lip type seals. The test required many unscheduled interruptions to repair the test machine. An interruption of the test is not damaging unless the shaft sleeve has to be removed and installed. That operation is not necessarily damaging in itself but the probability of damage occurring to the test seals is greater when they are handled. During this test, the shaft was removed and replaced three times. It was ascertained that the first installation of the seals occurred without damage by observations made when the test seal was removed the first time.

The GRAFOIL^R - BeCu seals during test 016 sealed against a shaft with a surface finish of 12 RMS, a better finish than is specified in the baseline tests.

Test 016 was terminated after 17.5 hours and before a gallon of lubricant had leaked past the test seal. The seal was leaking at a catastrophic rate and these seals have not exhibited the self-healing trait typical of some of the elastomer seals so the test was terminated early.

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surface finish of 11 RMS, again a better finish than is specified in the baseline tests. The test was run continuously without having to remove the main shaft. There were two scheduled ten minute interruptions.

Test 017 was ended after nearly ten hours when the full gallon of lubricant had leaked past the test seal. The leak record for this test shows that the seal was either not leaking at all or was leaking at a catastrophic rate. The leak was arrested twice before failure.

The torque record for test 016 was not unusual. The torque fluctuated, peaked early at 240 foot-pounds and decreased to 100 foot-pounds just before the seal failed. The operating temperature of the test seal does not coincide closely with the torque. A temperature extreme of 450⁰ F (232⁰ C) coincides with the torque peak of 240 foot-pounds after one hour elapsed time and except for a torque spike after about 15 hours elapsed time the torque generally decreased with time as did the temperature.

Throughout Test 017, there appeared to be closer correlation between seal operating temperature and torque. Both transducers measured greater extremes. Both values in general decreased during the test.

Because of the difference in thermal conductivity between the elastomer seals and the GRAFOIL^R - BeCu seals, the temperature distributions in the seal housing are much different. The mechanical energy transformed to heat energy by the elastomer seals at the seal-shaft interface is transmitted into the steel shaft and carried out of the test system by the cooling water. The heaters, whose feedback thermocouple was outside of the seal packs, were required to input energy into the system to maintain the housing temperature at 250⁰ F.

The GRAFOIL^R - BeCu seals with the much higher thermal conductivity

are better able to transmit energy in the form of friction heat out into the seal housing where the thermocouple to control the heaters is mounted. When the tests on the GRAFOIL^R - BeCu seals reached equilibrium, no further electrical energy was input into the system in the form of heat. Enough of the mechanical energy was transformed into heat and transmitted to the seal housing so that the heaters were not turned on.

The GRAFOIL^R - BeCu seals did the least damage to the shaft surface finish. This will be very important to the success of a seal run of 150 to 200 hours.

There is a bonding problem between the GRAFOIL^R and beryllium copper. The soft GRAFOIL^R separates easily from the harder beryllium copper. See the damaged seals in Figure 14.

CONCLUSIONS

Failure Modes

The type 701 seals exhibited two modes of failure. The predominant mode of failure is characterized by one or more of the seal rings grabbing onto the turning shaft at a point and buckling up. This phenomenon is shown in Figure 11. At the resulting weak point in the seal, fluid is allowed to pass and the seal fails.

Figure 11
Type 701 Seals - Failed in Test DMT-002

The secondary mode of failure might best be described as fatigue failure resulting from pressurizing and depressurizing the test seal. Shear failure plays a part in this mode of failure also. The structurally weak point of the seal is a line through the apex of the "V" cross-section and extending along the circumference of the seal. Pressurizing and depressurizing works the seal around this weak point and breaks down the cotton duck reinforcing.

Type 42D seals exhibited the same modes of failure as the Type 701 seal. The buckling of a Type 42D seal is illustrated in Figure 12.

Figure 12
Type 42D Seals - Failed in Test DMT-004

The 125K-RD181 seal fails by wearing and simply leaking a gallon of fluid before catastrophic destruction of the seal occurs. A failed Type 125K-RD181 seal is shown in Figure 13.

Figure 13
Type 125K-RD181 Seals - Failed in Test DMT-013

Figure 14
Type GRAFOIL^R - Be Cu Seals - Failed in Test DMT-017

The GRAFOIL^R - BeCu seal fails by the GRAFOIL^R separating from the beryllium copper. The GRAFOIL^R is so soft that it breaks away from the BeCu Chevron rings, gets pulverized by the turning shaft and is carried away by the leaking fluid. A failed GRAFOIL^R - BeCu seal is illustrated in Figure 14.

Conclusions

The following conclusions are made after evaluating the baseline tests and the tests performed on three additional seal types.

1. The tests on type 701 seals generated baseline data to which other test results can be compared.
2. There is broad scatter in the life of the baseline seals, from one to approximately 30 hours. It is speculated that the large scatter is due to:
 - a. variability in the manufacturing of seals;
 - b. a difference in test procedures that are considered controlled improvements;
 - c. variability in the mechanical set-up that are uncontrolled, such as water leaking and unscheduled interruptions to the test.
3. The industry rule-of-thumb numbers suggest that the environmental temperature (250°F) (121°C) and the differential pressure (1,500 psi) at which the baseline tests are performed are well within the performance range for this seal type. However, the RPM (412) which translates to a linear velocity of about 540 feet per minute is too high for presently available seal configurations and elastomers. The high

linear velocity at the single line of contact between seal and rotating sleeve generate destructive temperatures in the elastomer seal material.

4. Whatever the reasons for the short-lived tests, the elastomeric seals of current configurations subjected to the baseline conditions will never meet the required 200-hour life.
5. The 125K-RD181 seal type of a higher temperature compound and different configuration is not significantly longer-lived than the baseline seal.
6. The GRAFOIL^R-BeCu seals fail by the GRAFOIL^R flowing through small clearances and/or the pressurized fluid permeating into the GRAFOIL^R and destroying the seal from the inside out.

Dr. K. Larry DeVries, an independent consultant, upon reviewing the seal test data, drew these conclusions:

1. The average duration of the four seal types varied from 13.5 hours to 15.2 hours.
2. A trend between temperature and torque was not distinguishable except in a few cases where temperature seemed to follow torque.
3. None of the seals appear very reliable under the conditions at which they were tested.
4. There is not much that would discriminate between the seal types tested thus far.

Seal geometry is an area that will be reevaluated. One particular area that may realize great improvement in seal life is that of redundant seals. Exxon research documented success with this seal configuration at 15,000 psi in a mud swivel. This seal was accessible so that the redundant

seals could be manually activated. The seal concept is promising but other methods of activation will be required downhole.

Some of these seal designs and activation methods are discussed in the following section. These are proposed concepts only. After further evaluation, the more promising concepts will be produced for testing.

REDUNDANT SEALS

Maurer Engineering has begun work on the development of redundant seals for use in the Department of Energy Bearing-Seal Package. This involves the concept of using a set of primary seals for initial sealing and then activating spare or redundant seals when the primary seals fail. It is important in these designs to not subject the spare seals to differential pressure until the primary seals leak to ensure that the spare seals are in new condition when activated.

This concept was used in the Exxon high-pressure oil field swivel shown in Figure 15. This swivel was operated at 15,000 psi for 50 to 80 hour periods.

The lower swivel nut (56) rotates with the drill pipe while the upper swivel nut (46) remains stationary. The floating washpipe (28) is free to rotate with the drill pipe or to remain stationary with the upper nut.

During operation of the swivel, the primary seals (40 and 53) provide sealing and the leak ports (43 and 59) remain open. This prevents pressure from being applied to the spare or redundant seals (41 and 54). After 40 to 60 hours operation at 15,000 psi, the primary seals fail and allow abrasive drilling mud to leak past the seals and

Figure 15
Exxon High-Pressure Swivel Utilizing Redundant Seals
(Maurer et al., 1973)

and through the leak ports (43 and 59). The leak ports are then plugged by plugs 66 and 67, allowing the high-pressure mud to pressurize and activate the spare seals (41 and 54). The worn swivel seals are then replaced during round trips.

This redundant swivel seal operated effectively during the Exxon high-pressure drilling tests and resulted in reduced drilling costs and increased drilling time. A similar concept was used to provide redundant reciprocating seals in the high-pressure pumps used on these tests.

Seal failures in downhole motors are expensive because drilling must be terminated and round trips made to replace the worn seals. The development of a redundant seal system for downhole motors could have a significant positive impact on geothermal and petroleum drilling costs.

Developing redundant seals for downhole motors is more complicated than developing these seals for surface equipment for several reasons, including:

- (1) Downhole space constraints;
- (2) Leak ports cannot be manually closed;
- (3) High temperatures;
- (4) Leaks cannot be observed;
- (5) Seal is at lower end of downhole motor; and
- (6) Fluid erosion.

When the primary seals fail, the spare seals can be activated in several ways including:

- (1) Automatic downhole activation;
- (2) Dropping objects down drill pipe (e.g., Go-devils or balls);
- (3) Activating downhole pressure mechanisms by cycling pump pressure;
- (4) Utilizing borehole measurements while drilling systems (if available;

- (5) Activating downhole mechanical devices by manipulating bit weight or drill string rotation;
- (6) Pumping heavy slugs of mud to produce higher pressure drops;
- (7) Pressurizing wellbore annulus;
- (8) Utilizing downhole packer to create pressure drops;
- (9) Time delay mechanisms (chemical or mechanical);
- (10) Explosive capsule to create high downhole pressure pulses;
- (11) Chemical slug to weaken or dissolve actuation mechanism;
- (12) Wireline mechanisms;
- (13) Floating piston locator activation;
- (14) Hollow shafted motor porting system.

Maurer Engineering has developed a large number of concepts for placing redundant seals in downhole motors. Several of these concepts are shown schematically in Figures 16 to 31. During Phase IV, two or more of the most promising concepts will be developed and tested in the Department of Energy Bearing-Seal-Package. The redundant seals will be designed so that they can be easily adapted to existing motors.

The spare seal shown in Figure 16 is activated by increasing the pressure drop across the bit above its normal operating level and shearing a pin. For example, if the bit is normally operated at 500 psi bit pressure drop, the shear pin would be designed to fail at 800 to 1,000 psi.

During normal operation, the pressure drop occurs across the primary seal and any leakage past the primary seal flows through the leak port and into the wellbore annulus, thereby preventing differential pressure

Figure 16
Pressure Activated Spare Seal

from being applied to the spare seal.

The spare seal is activated by increasing the bit pressure and shearing the shear pin. This allows the primary seal to move downward and seal off the leak port. The high-pressure fluid leaking past the primary seal then activates the spare seal.

The spare seal can be activated by increasing the pressure across the primary seal in several different ways, including:

- (1) Increasing the pump flow rate;
- (2) Dropping frangible balls down the drillpipe to temporarily obstruct the bit nozzles;
- (3) Pumping a slug of heavy or viscous drilling mud down the drillpipe; and
- (4) Firing a propellant charge downhole to temporarily increase flow rate.

The spare seal can be activated automatically by the floating piston locator system shown in Figure 17. A line attached to the floating piston in the lubricant reservoir becomes tight when the piston moves a pre-set distance downward (e.g. half way), thereby releasing a frangible ball which temporarily plugs a bit nozzle and produces a pressure increase.

These frangible balls were successfully used by Exxon to temporarily plug nozzles in high-pressure drill bits. The frangible balls can be designed with roughened outer surfaces or with holes drilled through them so that they leak and do not completely seal the nozzles as shown in Figure 18. The leaking fluid erodes the balls in five to ten minutes with the eroded fragments passing through the nozzles. The pressure

Figure 17
Floating Piston Locator System

increase produced by the frangible ball will automatically activate the spare seal shown in Figure 17 .

Figure 18
Frangible Balls

The pressure increase produced by the frangible balls can be detected by the driller at the surface and therefore the floating piston locator system can be used with any of the techniques where the spare seals are activated from the surface.

The frangible ball can also be used to automatically activate the sliding sleeve spare seal assembly shown in Figure 19 .

With this assembly, lubricant initially bypasses the spare seal through the flow ports so that all of the pressure acts across the primary seal. The spare seal is activated when the frangible ball seats in the sleeve and creates a high-pressure drop. This produces a downward force on the sleeve which shears the shear pin and allows the sleeve to move downward and seal off the upper seal port. This transfers the

Figure 19
Sliding Sleeve Spare Seal

pressure drop to the spare seal and activates it. This sleeve could also be activated by a wireline tool passing through a hollow shaft in the motor.

Figures 20 to 24 show spare seals which are activated when the leakage rate past the primary seal exceeds a critical value. The spring-loaded check valve shown in Figure 20 holds a small back pressure on the primary seal. Leakage past the primary seal passes through this check valve to the wellbore annulus. When the leakage becomes excessive, the check valve closes and transfers the pressure drop to the spare seal, thereby activating this seal.

Figure 20
Leakage Rate Activated Spare Seal #1

Figure 21 shows a variation of this design where three sets of seals and check valves are used. Each set of seals has a different diameter so that the shoulders individually support each set of seals.

Figure 21
Leakage Rate Activated Spare Seal #2

In the assembly shown in Figure 22 , a small port in the spare seal holder allows fluid leaking past the primary seal to pass to the wellbore annulus. As the leakage rate increases, the pressure drop across the spare seal holder increases until the shear pin shears. This allows the holder to move down and seal off the small port, thereby activating the spare seal.

Figure 22
Leakage Rate Activated Spare Seal #3

Figure 23 shows a seal assembly where fluid leaks past the spare seal at low leakage rates, whereas at high leakage rates, the increased pressure drop past the spare seal causes the burst plate to rupture. This allows high-pressure fluid to pass behind the spare seal and activate it.

Figure 23
Leakage Rate Activated Spare Seal #4

Figure 24 shows a similar arrangement except that a pressure relief valve has been substituted for the burst plate.

Figure 24
Leakage Rate Activated Spare Seal #5

These automatic leakage rate activated systems have the disadvantage that they will not activate if a seal leaks continuously at a low flow rate. It is also difficult to activate these systems from the surface.

Figure 25 shows an assembly where the spare seal is activated when a pre-set amount of fluid leaks past the primary seal. The leaking fluid forces the floating piston downward until it seals off the leak port and activates the spare packing.

Figure 25
Floating Piston Spare Seal Assembly

If a small passageway is placed in the floating piston (dashed lines), this becomes a leakage rate activated system. In this case, the piston moves downward and activates the spare seal when the flow rate through the passageway produces sufficient pressure drop to force the piston downward and compress the spring.

Figure 26 shows an assembly where the spare seal is activated by rotating the drive shaft at high speed and allowing an impact hammer to strike and close a valve in the leak port leading to the annulus. The packing arrangement in this case could be identical to that shown in Figure 25 except that it would not be pressure activated.

Figure 26
Centrifugally Activated Spare Seal

This technique would be well adapted to turbodrills which are normally operated at speeds of 400 to 1,000 RPM. The turbodrill could be lifted off bottom and allowed to runaway at high speed (e.g. 2,000 RPM), thereby allowing the impact hammer to activate the spare seal.

Figures 27 to 30 show assemblies where the spare seals are automatically activated after preset times. Figure 27 shows an assembly where the primary seal is contained in a holder supported by a decomposable ring. The strength of this ring decreases with time until it fails and allows the holder to move downward and seal off the leak port. This allows high pressure fluid to activate the spare seal.

Figure 27
Decomposable Ring Activated Spare Seal

Figure 28 shows a variation of this design where an extrudable ring supports the holder. The creep rate of this ring would be adjusted so that the spare seal would be activated after a pre-set time.

Figure 28
Extrudable Ring Activated Spare Seal

Another variation of this is to use a shear pin, the strength of which is chemically reduced with time (e.g., metal pin containing acid) as shown in Figure 29.

Figure 29
Spare Seal Assembly Utilizing Shear Pin Having
Time Dependent Strength

Figure 30 shows an arrangement where the lower seal acts as the primary seal. When the water soluble plug is dissolved (30 to 50 hours), the high-pressure drop causes high flow past the spare seal and through the leak port. This creates a high pressure drop across the spare seal, which shears the pin and allows the holder to move downward and seal off the leak port. As the holder moves downward, the spare seals engage the shaft sleeve and become activated.

Figure 30
Soluble Plug Activated Spare Seal

Figure 31 shows a mechanically activated spare seal which is activated by stopping fluid circulation, setting the motor on the hole bottom and rotating the drillpipe backwards for two or three revolutions. This allows the coarse threads on the splined pin to engage the threads on the stationary nut, forcing the pin downward against the primary seal and shearing the pin. The holder is then forced down to the shoulder where it seals off the leak port and activates the spare packing. The left-handed threads do not engage during normal right-hand operation of the motor.

Figure 31
Mechanical Activated Spare Seal

The redundant seals in Figures 16 to 31 are shown only to illustrate concepts. Several of the designs would work conceptually, but would be difficult to implement into existing motors because of space limitations and other constraints. Additional design will be required before these seals can be incorporated into the Bearing-Seal Package.

If possible, the redundant seal systems should have the following characteristics:

- (1) Allow automatic activation when the floating piston has moved downward a pre-set distance (e.g. half way);
- (2) Allow activation of the spare seal by the driller at the surface;
- (3) Allow activation by a measurements-while-drilling system (if available);
- (4) Signal the driller when the floating piston has moved downward a pre-set distance (e.g. half way);
- (5) Signal the driller when the spare packing is activated;
- (6) Signal the driller when the spare packing wears out or when the floating piston has reached the bottom of the lubricant reservoir;
- (7) Be readily adapted to existing motors;
- (8) Be easily replaceable in the field;
- (9) Have high reliability and long life.

At this time, it appears that the pressure activated spare seals shown in Figure 16 fulfill nearly all of these requirements and are probably the best candidates for use in the Bearing-Seal Package. The

leakage rate activated spare seals have the advantage of simplicity and will also be tested. Other concepts will be reviewed and one or more selected for testing.

**BEARING-SEAL PACKAGE
TESTING AND EVALUATION**

BEARING-SEAL PACKAGE

Maurer Engineering designed and manufactured the bearing-seal package shown in Figure 32. This package, which is designed to be easily adapted to existing drilling motors, contains a sealed lubrication system which allows the thrust bearings and radial bearings to operate in oil or grease. This overcomes one of the major limitations of existing downhole motors where the bearings operate directly in the abrasive drilling mud.

Figure 32
Bearing-Seal Package

The bearing-seal package is shown on a turbodrill in Figure 33. This package can also be used on Moineau motors such as the Dyna-Drill or the Navi-Drill^R.

Figure 33
Downhole Motor with Replaceable Bearing-Seal Package

Major improvements in this bearing assembly include:

(1) Roller Thrust Bearings

The large roller thrust bearings used in this assembly have much higher thrust capabilities and longer life than the ball or rubber thrust bearings used in existing motors.

(2) Roller Radial Bearings

Large roller radial bearings are used to absorb the high bending loads imparted to the downhole motor in directional holes. This increases seal life and reduces dynamic stresses in the motor shafts.

(3) Lubrication System

A floating piston pressurizes a lubricant reservoir allowing the bearings to operate in oil or grease instead of abrasive drilling mud. This increases bearing life 10 to 100 fold.

(4) Seals

The bearing-seal assembly is designed so that it can accommodate different types of seals including: 1) face seals, 2) packing seals, and 3) radial lip seals. The seals being tested in the Seal Tester can be immediately adapted to this assembly.

Additional details on the design and manufacture of this Bearing-Seal Package are presented in the Phase II Semi-Annual Report (TR77-107), and the Phase II Final Report (TR78-28).

 

BEARING-SEAL PACKAGE TEST FACILITY

To test and evaluate the performance of the Bearing-Seal Package, a Bearing-Seal Package Test Facility has been designed by Terra Tek. A cross-sectional view of the facility is shown in Figure 34. The test facility allows controlled and repeatable tests on the Bearing-Seal Package at simulated pressures, temperatures, rotational speeds, mud circulation and dynamic loads. Design details will be found in the Phase II Semi-Annual Report (TR77-107) and the Phase II Final Report (TR78-28), and Appendix B of the Phase II Final Report (TR78-28) contains a detailed description of each major part of the test facility.

Before the release of the detailed design of the test facility, a number of significant problems had to be solved. The following lists the major problems and the solution to each:

1. The most critical problem in the design was to provide a pressure drop across the bearing-seal package and at the same time find a method to prevent fluid erosion by the drilling mud. To solve this problem, Terra Tek designed and tested a fluid absorption and energy dissipation system. Details of this system will be found at the end of this section of the report.

Figure 34
Bearing-Seal Package Test Facility Cross-Section

2. A vessel seal had to be found that would last longer than the seals being tested in the Bearing-Seal Package. To solve this problem, Terra Tek designed a redundant, cascading seal that will be cooled by water.
3. A method had to be found to couple and seal the closures to the ends of the pressure vessel tube. To solve this problem, Terra Tek investigated a number of methods of coupling the closures, including: weld-neck flanges, slip-on flanges, tie rods and threaded closures. The best closure method found was the utilization of metal clamps and seal rings manufactured by Gray Tool Company, Houston, Texas. To utilize these clamps and seal rings, special grooves were machined into the ends of the pressure vessel tubes and closures. Two advantages of using the Grayloc couplings over other methods are: the seal rings are reusable, and the couplings are easy to assemble.
4. A method had to be found to simulate the axial dynamics that will be found in the field. To solve this problem, Terra Tek designed a dynamic actuator system that will simulate field conditions. The actuator consists of a modified hydraulic cylinder, servo-control system and a programmable waveform generator. The actuator provides

the capability of being able to program and execute many waveforms found in the field.

The test facility has been completely designed, and fabrication of all parts will be completed in December, 1978. Assembly and debugging of the test facility will be performed in December, 1978, and January, 1979. Testing will begin in March, 1979.

FLUID EROSION PROBLEMS

Fluid velocities greater than 100 feet per second can be very damaging, especially with slurries. To control fluid erosion, a method must be developed to expend the energy contained in the fluid stream by dissipation through elastic collision.

To solve this problem, Terra Tek designed a series of three subs to absorb the fluid impact and dissipate the energy. The three subs, the nozzle sub, the fluid impact sub and the fluid return sub, are shown in the sub-arrangement view of the Bearing-Seal Package Facility in Figure 36 .

Figure 35
Nozzle Sub

Figure 36
Bearing-Seal Package Test Facility - Sub Arrangement

The nozzle sub, shown in Figure 35, is 7.75 inches in diameter and 18.75 inches long. The sub connects to the Bearing-Seal Package by means of a stub ACME thread. The nozzle sub creates a pressure drop equivalent to the pressure drop across a drill bit.

The fluid discharging from the nozzle sub is directed through the fluid return sub, shown in Figure 37, and into the fluid impact sub, shown in Figure 38. The fluid impact sub is 7.75 inches in diameter and 24 inches long. Inside the fluid impact sub is an impact slug and spring, shown in Figure 39. The fluid stream impacts on the slug and compresses the spring, thereby losing some of its energy.

The impact slug is lined with a formed cup of urethane of 80 - 90 durometer hardness, or lead, or some other replaceable, abrasion-resistant material. After the fluid impinges on the slug, it rebounds into the fluid return sub and exits through ports in the wall of this sub. The fluid return sub is 7.75 inches in diameter and 35.873 inches long.

The three subs, impact slug and spring were manufactured and tested in the Drilling Research Laboratory. The formed cup, which is considered an expendable item, was made of lead for the test.

Abrasive drilling mud, containing 6 to 8% sand, was pumped through the assembly. The pressure drop across the nozzle sub was 1,300 to 1,400 psi. The duration of the test was approximately 28 hours. At the end of the test, the subs were taken apart and inspected. The lead-lined cup was pitted, and the lead had started to peel from the top of the impact slug as shown in Figure 40. The three subs, however, showed

Figure 37
Fluid Return Sub

Figure 38
Fluid Impact Sub

Figure 39
Impact Slug and Spring

Figure 40
Impact Slug Formed Cup

no significant wear.

This test has demonstrated that the fluid absorption and energy dissipation concept used in the Terra Tek design is an acceptable solution to the fluid erosion problem. Thus, one of the major problems in the design of the Bearing-Seal Package Test Facility has been solved.

LUBRICANT TESTING AND EVALUATION

Candidate Lubricants

In the development of improved bearings and seals for downhole drilling motors, it is important that a good lubricant be selected. The proper selection of a lubricant will result in increased bearing and seal life.

Maurer Engineering performed some preliminary tests on candidate lubricants that were described in the Phase II - Final Report (TR 78-28). These tests showed that Pacer SGO-708 synthetic oil performed extremely well at high temperatures and under extreme loading conditions. Pacer has recently formulated five new candidate lubricants for testing: PLX-010, PLX-011, PLX-013, PLX-014 and PLX-015. These five lubricants have superseded the SGO-708 lubricant.

In addition, Maurer Engineering has contacted ten manufacturers of downhole motors to obtain lubricant recommendations. The downhole motor manufacturers contacted are:

- (1) Dyna-Drill
- (2) Baker Service Tools
- (3) Engineering Enterprises, Inc.
- (4) Eastman Whipstock
- (5) NL Petroleum Services
- (6) A-Z International
- (7) Redi-Drill
- (8) Neyrpic

(9) Christensen Diamond Products

(10) General Electric Company

We have had favorable response from many of those contacted, and, so far, two of the contacts have responded with lubricant recommendations.

The lubricant test matrix is shown in Table IV. The selection of candidate lubricants has been based on the preliminary testing done by Maurer Engineering; the lubricant recommendations received so far from the downhole motor manufacturers; and input from the lubricant industry. Maurer Engineering is obtaining a one-gallon sample of each lubricant to be tested. Additional candidate lubricants will be added to test matrix as recommendations are received from downhole motor manufacturers. These additions will be reported in the monthly progress reports.

Table IV

CANDIDATE HIGH TEMPERATURE LUBRICANTS	
<u>COMPANY</u>	<u>LUBRICANT NO.</u>
Amoco	31052
Amoco	M-125
Amoco	LG-1191
Amoco	Andex #2
API	BUC 5A2
Dow-Corning	560
Dow-Corning	710
Dow-Corning	M-77
Jet-Lube	Kopper Kote
Mavom	BSK
Mobil	600W
Optimol-Olwerke	Optimoly White T
Pacer	PLX-010
Pacer	PLX-011
Pacer	PLX-013
Pacer	PLX-014
Pacer	PLX-015
Schmierstoffe	Gleitmo 500
Superior	White
Superior	Moly
Tenneco	Anderol 456
Texaco	EP85-90
Watch	10:1
Wolley Booger	Teflon Grease

Lubricant Tester

A high-temperature lubricant tester was designed and built by Terra Tek as part of a contract with the Department of Energy for the development of improved geothermal drill bits (Contract No. EG-76-C-07-1546). The lubricant test machine is pictured and described in Phase II - Final Report (TR 78-28).

The high-temperature lubricant test machine has been built and debugged and is ready for operation. An adequate number of test rings and blocks have been received, and the testing will begin as soon as the lubricant samples are received. Details of the test procedure will be found in Phase II - Final Report (TR 78-28) - Appendix C, and a sample data sheet for reporting a lubricant test is shown in Figure 41.

The lubricant test matrix will be tested at a temperature of approximately 400°F (204°C) to initially screen the lubricants. Based on the results of the initial test, a certain number of lubricants in the matrix will then be tested at a higher temperature, approximately 450°F (232°C) to 500°F (260°C).

The results of this second screening will then dictate whether or not further testing in the lubricant tester is necessary. The purpose of the testing in the lubricant tester is to select the best 2 or 3 lubricants for testing in the Bearing-Seal Package.

DATE-		LUBRICATION MATERIAL -
TEST#-	LUBRICANT	MANUFACTURER-
TEMP:-	TESTER	RING MATERIAL- Rc-
R. P. M. -		BLOCK MATERIAL- Rc-
WELDING-		CONFINING PRESSURE-
SEIZURE-		NO. OF REV..-

MEASURED FRICTION FORCE 'lb'- 0= / 200= / 600= / 800= / 1000= / 1500= /
 2000= / 2500= / 3000= / 3500= / 4000= /
 5000= / REVOLUTIONS;

COEFFICIENT OF FRICTION- 0= / 200= / 400= / 600= / 800= / 1000= /
 1500= / 2000= / 2500= / 3000= / 3500= /
 4000= / 4500= / 5000= / REVOLUTIONS;

FINAL DATA

TEST LOAD IN- 'lbs' = / 'p. s. i.' = /

WEAR SCAR MEAS., - END= / MIDDLE= / END= /

FINAL LOADING:- P.S.I. = / MPa = /

NOTES-

Figure 41
 Sample Lubricant Test Report

Real-Time Lubricant Analysis

During a Bearing-Seal Package test, it is desirable to have a real-time method of analysis of lubricants so that catastrophic bearing failure can be predicted before the failure actually occurs.

One method described in the Phase II - Final Report (TR 78-28) involves the irradiation of a lubricant sample and counting the elemental isotopes that are formed. The isotope count is directly related to the wear of the bearings. The principal disadvantage of the irradiation technique is the turnaround time of one to three days for obtaining results.

A method of sampling the lubricant during an actual test is being designed into the Bearing-Seal Package Test Facility. Terra Tek is currently searching for a method and commercially available equipment for real-time analysis of lubricant samples.

$$x = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2} \quad \text{and} \quad y = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$$

PROGRAM STATUS, PLANS AND SCHEDULE

Task I Seal Testing and Evaluation

The baseline seal tests on the standard UTEX style 701 seal rings have been completed. The seal testing system has undergone several modifications to improve ease of handling and reliability during testing. Several of the high-temperature candidate seals have been run including the GRAFOIL^R seals. Additional high-temperature candidate seals have been obtained. High-temperature candidate seals will continue to be tested as well as shaft surfaces and coatings as outlined in the program.

Task II Bearing-Seal Package Testing and Evaluation

Final design of the Bearing-Seal Package Test Facility was completed. Fabrication of parts is soon to be complete. The pressure vessels have been machined and are awaiting the completion of the holding fixture fabrication before installation. Many of the long-term equipment items necessary for the facility are completed and have been received including: 100 HP hydraulic power supply furnished by Terra Tek, hydraulic drive, dynamic actuator, and wave form generator. The assembly of the facility is under way and we are expecting most of the system to be installed by January, 1979. Bearing-Seal Package tests will start in March, 1979.

Task III Lubricant Testing and Evaluation

A survey of donwhole motor manufacturers and lubricant suppliers was initiated to obtain lubricant recommendations and state-of-the-art information on available lubricants. Several samples have been received. Wear rings and blocks for the lubricant tests have been received, and a tentative schedule of the lubricant matrix shown in the lubricant test section of this report is ready for implementation as soon as more samples are received.

The schedule for Phase III - Part 2 work is shown in the detailed milestone chart (Table V) as follows.

O N D J F M A M J J A S O

I. PLANNING, COORDINATION AND REPORTING

II. SEAL TESTING AND EVALUATION

1. Baseline Tests on Candidate High-Temperature Seals
2. Baseline Tests on New Candidate Seals
3. Evaluation of Shaft Surface Coating and Finish
4. Comprehensive Tests on Promising Seal Designs
5. Design and Test Self-Actuating, Redundant Seal
6. Effect of Lubricant on Seal Life
7. Design Improved Rotary Seal Rings
8. Evaluation of Seal Test Results

III. BEARING-SEAL PACKAGE TESTING AND EVALUATION

1. Set-up for Bearing-Seal Package Tests
2. Bearing-Seal Package Tests
3. Computer Analysis of Bearing-Seal Package Assembly
4. Evaluation of Bearing-Seal Package Tests

IV. LUBRICANT TESTING AND EVALUATION

V. DEVELOPMENT OF FULL-SCALE DOWNHOLE MOTOR TEST FACILITY

1. Design and Fabricate Dynamometer
2. Provide Long Vessel Lifting Capacity
3. Increase Mud Cooling Capacity
4. Design Interface Members for Existing Motors

VI. OBTAIN INDUSTRY PARTICIPATION

1. Industry Participation - Seal, Bearing, Lubricant Manufacturers
2. Industry Participation - Motor Manufacturers
3. Arrange Field Testing of Bearing-Seal Package

Detailed Milestone Chart
Table V

109-110

BIBLIOGRAPHY AND REFERENCES

(I) SUMMARY REFERENCES

(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

Daering, D.W., "One Dimensional Heat Transfer Model of Rotary Seals in Downhole Motors", Terra Tek Technical Report No. TR 78-29, September, 1978.

(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.

(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, N.M.

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.

(II) REDUNDANT SEAL REFERENCES

Maurer, W.C., J.F. Miller, and I.D. Hickman, 1973, "Swivel", U.S.
Patent No. 3,752,507, August 14, 1973.

Shane, J.H., R.J. Russell, and R.A. Bochman, 1968, "Flexible
Graphite Material of Expanded Particles Compressed Together",
U.S. Patent No. 3,404,061, October 1. Assigned to Union
Carbide Corporation.

Maurer, W.C., J.K. Heilhecker, and R.L. Graham, 1972, "Method for
Sealing Nozzles in a Drill Bit", U.S. Patent No. 3,645,331,
February 29, 1972.

Maurer, W.C., J.K. Heilhecker, and E.H. Lock, "Tandem Packing for
a Reciprocating Pump", U.S. Patent No. 3,776,558, December,
1973.

APPENDIX A

Table A-1
Test Conditions and Parameters

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
001	2/22/78	701	3	Buna-N	1500	211	52.72	16(est.)	Original
002	4/13/78	701	3	Buna-N	1400	211	28.48	16(est.)	Original
003	5/19/78	42D	3	Buna-N	1500	211	20.42	16(est.)	Original
004	6/1/78	42D	3	Buna-N	1500	211	13.12	16(est.)	Original
005	6/8/78	42D	3	Buna-N	1500	211	5.52	16(est.)	Original
006	6/14/78	42D	3	Buna-N	1500	211	24.15	16(est.)	Original
007	6/19/78	42D	3	Buna-N	1500	412	3.10	16(est.)	Original
008	8/3/78	701	2	Brass	1500	412	18.20	17	Original
009	8/9/78	701	2	Brass	1500	412	3.52		
010	8/15/78	701	2	Brass	1500	412	10.30	16	.010 + CD&ID
011	8/22/78	Abort							
012	8/24/78	Abort							
013	8/26/78	RD181	(1+1)Top 2x701 Bottom	Brass	1500	412	11.25	12	.010 + CD&ID
014	8/30/78	RD181	(1+1)Top 2x701 Bottom	Brass	1500	412	8.64	12	.010 + CD&ID
015	9/11/78	701	1	Brass	1500	412	5.47	12	.010 + CD&ID
016	9/26/78	Grafoil	5	Brass	1500	412	17.50	12	Not Turned Down
017	10/13/78	Grafoil	5	Brass	1500	412	9.88	11	.010 + CD&ID
018	10/17/78	701	3	Brass	1500	412	1.15	16	.010 + CD&ID

TESTID : DMT-001

DATAFI : SEAL.DMT001

N	TIME	TORQUE	UPPER SEAL TEMP4	LOWER SEAL TEMP7	UPPER SEAL LEAK	UPPER SEAL LEAK RATE	LOWER SEAL LEAK	LOWER SEAL LEAK RATE
	HRS	FT-LB	(F)	(F)	CU IN	CU IN/HR	CU IN	CU IN/HR
1	0.00	135.	200.	160.	0.0	0.0	0.0	0.0
2	1.00	105.	185.	174.	0.0	0.0	0.0	0.0
3	1.23	107.	181.	144.	0.0	0.0	0.0	0.0
4	2.00	110.	179.	127.	0.0	0.0	0.0	0.0
5	3.00	95.	174.	154.	0.0	0.0	0.0	0.0
6	4.00	65.	162.	145.	0.4	0.4	0.0	0.0
7	5.00	110.	184.	144.	0.4	0.0	0.4	0.4
8	5.34	109.	191.	146.	0.4	0.0	0.4	0.0
9	6.00	105.	201.	150.	0.4	0.0	0.4	0.0
10	6.07	105.	205.	150.	1.0	4.2	1.0	4.2
11	7.00	105.	212.	148.	3.4	2.4	1.7	0.8
12	7.28	102.	214.	149.	3.5	0.3	2.0	1.1
13	8.00	95.	217.	152.	7.9	6.2	2.8	1.2
14	8.07	94.	227.	152.	8.0	0.4	3.0	2.3
15	9.00	85.	222.	147.	9.1	1.2	3.4	0.4
16	10.00	75.	219.	138.	10.8	1.7	4.0	0.4
17	11.00	75.	225.	126.	11.4	0.6	5.1	1.1
18	11.48	86.	228.	127.	12.0	1.4	5.5	0.8
19	12.00	105.	234.	128.	13.4	3.1	5.7	0.3
20	12.50	107.	225.	130.	13.8	0.5	6.5	1.4
21	13.00	75.	210.	132.	14.0	0.2	6.2	0.5
22	13.10	80.	211.	132.	14.1	1.1	4.5	2.5
23	14.00	115.	230.	134.	14.2	0.1	7.9	1.4
24	14.50	110.	234.	140.	14.2	0.0	8.0	0.1
25	15.00	105.	247.	140.	14.2	0.0	8.7	1.5
26	16.00	105.	235.	130.	14.2	0.0	10.2	1.5
27	17.00	105.	235.	130.	17.4	3.4	10.8	0.4
28	18.00	85.	232.	125.	25.0	7.4	12.5	1.7
29	18.60	85.	230.	127.	30.0	8.4	12.8	0.5
30	19.00	85.	230.	129.	34.4	11.5	13.1	0.7
31	20.00	85.	230.	133.	44.0	11.4	13.1	0.0
32	20.20	87.	224.	135.	47.0	5.1	13.2	0.8
33	21.00	95.	195.	120.	53.3	7.9	14.2	1.2
34	22.00	125.	234.	134.	55.4	2.3	15.9	1.7
35	22.70	118.	190.	140.	58.0	82.9	14.5	23.4
36	23.00	115.	167.	134.	59.4	5.3	17.0	1.7
37	23.60	104.	178.	130.	60.0	0.7	19.0	3.3
38	24.00	95.	188.	126.	60.7	1.8	21.0	5.0
39	25.00	115.	213.	131.	77.7	17.0	23.3	2.3
40	25.40	110.	223.	128.	80.0	5.4	23.3	0.0
41	26.00	105.	219.	124.	82.9	4.8	23.3	0.0
42	26.78	105.	227.	120.	89.0	7.9	23.3	0.0
43	27.00	105.	230.	122.	90.2	5.4	23.8	2.5
44	28.00	105.	204.	127.	102.2	11.9	24.4	0.4
45	28.60	105.	204.	130.	107.0	8.1	25.2	1.3
46	29.00	105.	202.	135.	111.2	10.4	25.0	0.4
47	30.00	115.	198.	128.	121.4	10.2	25.5	0.4
48	31.00	125.	198.	128.	131.7	10.2	26.7	1.1
49	32.00	125.	192.	128.	136.2	4.5	31.2	4.5
50	32.50	125.	188.	128.	139.0	5.4	33.2	3.9
51	33.00	125.	190.	120.	140.7	3.5	35.8	5.1
52	34.00	125.	194.	130.	143.4	2.8	45.4	9.4
53	35.00	135.	199.	132.	149.3	5.7	50.5	5.1
54	36.00	135.	204.	134.	153.8	4.5	55.4	5.1
55	37.00	145.	205.	140.	158.9	5.1	58.5	2.8
56	37.60	149.	205.	133.	159.0	0.2	59.5	1.7
57	38.00	155.	205.	128.	160.0	2.4	40.7	3.1
58	38.75	135.	206.	121.	160.0	0.1	41.0	0.4
59	39.00	125.	204.	124.	159.5	2.1	62.4	5.7
60	39.40	140.	210.	121.	159.8	0.9	63.0	1.4
61	40.00	155.	214.	117.	159.5	0.4	63.4	0.9
62	41.00	145.	206.	111.	160.0	0.4	63.4	0.0
63	41.80	145.	197.	106.	161.0	1.2	64.5	1.2
64	42.00	145.	194.	106.	160.4	1.9	64.7	1.0
65	43.00	155.	194.	106.	162.9	2.3	65.8	1.1
66	44.00	135.	206.	106.	163.4	0.4	68.1	2.3
67	45.00	145.	194.	114.	167.4	4.0	69.2	1.1
68	46.00	155.	194.	111.	170.3	2.8	70.9	1.7
69	47.00	155.	194.	108.	175.4	5.1	72.4	1.7
70	48.00	165.	194.	106.	181.4	4.2	77.7	5.1
71	49.00	165.	194.	101.	185.4	4.0	85.7	7.9
72	50.00	135.	181.	94.	193.5	7.9	87.4	1.7
73	51.00	165.	201.	81.	199.2	5.7	93.1	5.7
74	52.00	165.	192.	101.	201.5	2.3	97.4	4.5
75	52.10	163.	191.	100.	202.0	5.4	98.0	3.9
76	53.00	155.	84.	81.	207.1	5.7	103.9	6.5

TESTID : DMT-1A

DATAFI : SEAL.DMT1A

N	TIME	THERMOCOUPLES(F):							
		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
HRS									

1	0.00	134.	128.	252.	248.	210.	44.	48.	80.
2	1.50	0.	154.	258.	254.	198.	52.	84.	42.
3	2.50	156.	160.	252.	240.	204.	52.	88.	40.
4	3.40	152.	160.	248.	252.	238.	52.	84.	44.
5	4.50	152.	160.	248.	252.	196.	52.	90.	40.
6	5.30	152.	158.	248.	254.	202.	52.	94.	40.
7	6.10	150.	158.	244.	254.	200.	52.	94.	58.
8	7.30	150.	154.	244.	253.	198.	52.	98.	54.
9	9.00	150.	158.	250.	258.	204.	52.	102.	74.
10	10.00	148.	154.	250.	250.	204.	52.	94.	48.
11	11.50	148.	160.	250.	244.	208.	52.	94.	0.
12	12.80	148.	160.	252.	244.	212.	52.	100.	74.
13	14.00	160.	164.	252.	244.	212.	52.	100.	0.
14	21.00	150.	162.	250.	244.	210.	52.	94.	0.
15	24.70	156.	160.	252.	248.	212.	52.	92.	94.
16	30.00	160.	164.	252.	244.	210.	52.	88.	92.
17	32.50	156.	164.	252.	247.	212.	52.	88.	94.
18	36.50	156.	164.	252.	248.	212.	52.	96.	94.
19	41.50	152.	156.	248.	244.	200.	52.	84.	94.
20	48.00	156.	164.	252.	260.	200.	52.	88.	94.
21	51.70	160.	0.	240.	260.	204.	52.	92.	100.

TESTID : DMT-002

DATAFI : SEAL.DMT002

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	0.	125.	110.	0.0	0.0	0.0	0.0
2	0.25	205.	240.	200.	0.0	0.0	0.0	0.0
3	0.67	265.	227.	185.	0.0	0.0	0.0	0.0
4	0.75	265.	220.	180.	0.0	0.0	0.0	0.0
5	0.95	235.	210.	315.	0.0	0.0	0.0	0.0
6	1.00	195.	195.	245.	0.0	0.0	0.0	0.0
7	1.17	210.	220.	240.	0.0	0.0	0.0	0.0
8	1.34	220.	240.	380.	0.0	0.0	0.0	0.0
9	1.40	140.	325.	445.	0.0	0.0	0.0	0.0
10	1.67	140.	260.	350.	0.0	0.0	0.0	0.0
11	1.84	130.	260.	360.	0.0	0.0	0.0	0.0
12	2.00	175.	213.	195.	0.0	0.0	0.0	0.0
13	2.17	165.	207.	190.	0.0	0.0	0.0	0.0
14	2.67	200.	242.	242.	0.0	0.0	0.0	0.0
15	3.17	170.	240.	242.	0.0	0.0	0.0	0.0
16	3.50	185.	236.	244.	0.1	0.3	0.0	0.0
17	4.00	215.	245.	247.	0.2	0.2	0.0	0.0
18	5.00	190.	247.	245.	0.3	0.1	0.0	0.0
19	6.00	210.	248.	248.	0.5	0.1	0.0	0.0
20	7.00	205.	248.	245.	0.6	0.1	0.0	0.0
21	8.00	200.	250.	255.	0.7	0.0	0.0	0.0
22	9.00	180.	235.	244.	0.7	0.0	0.0	0.0
23	10.00	175.	230.	235.	1.1	0.5	0.0	0.0
24	11.00	165.	224.	232.	1.4	0.2	0.0	0.0
25	12.00	150.	225.	227.	1.8	0.5	0.0	0.0
26	13.00	170.	225.	227.	2.5	0.7	0.0	0.0
27	14.00	185.	221.	233.	3.2	0.7	0.0	0.0
28	15.00	170.	227.	232.	3.6	0.5	0.0	0.0
29	15.50	240.	285.	241.	4.5	1.8	0.0	0.0
30	16.00	280.	281.	245.	5.0	0.9	0.0	0.0
31	17.00	215.	240.	236.	15.4	10.4	0.0	0.0
32	18.00	215.	245.	240.	22.9	7.5	0.0	0.0
33	18.33	200.	248.	237.	26.8	11.7	0.0	0.0
34	19.00	115.	170.	220.	53.3	35.5	0.0	0.0
35	20.00	110.	197.	225.	61.5	8.2	0.0	0.0
36	21.00	105.	171.	213.	68.8	7.3	0.0	0.0
37	22.00	110.	200.	232.	75.6	6.8	0.0	0.0
38	23.00	95.	200.	228.	77.2	1.6	0.0	0.0
39	23.67	90.	195.	229.	79.5	3.4	0.0	0.0
40	24.17	210.	252.	245.	98.3	37.7	0.0	0.0
41	24.67	195.	247.	242.	111.2	25.9	0.0	0.0
42	24.92	195.	0.	245.	119.5	34.5	0.0	0.0
43	25.34	190.	0.	246.	128.3	20.0	0.0	0.0
44	26.34	145.	0.	251.	133.5	5.2	0.0	0.0
45	27.34	125.	0.	241.	134.4	0.9	0.0	0.0

TESTID : DMT-002

DATAFI : SEAL.DMT1002

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	120.	143.	156.	150.	0.	70.	90.	92.
2	0.	0.	0.	0.	0.	0.	0.	0.
3	154.	182.	256.	244.	195.	52.	113.	104.
4	0.	0.	0.	0.	0.	0.	0.	0.
5	125.	172.	265.	260.	205.	65.	125.	105.
6	95.	155.	260.	255.	200.	64.	97.	95.
7	115.	160.	258.	240.	198.	61.	121.	100.
8	120.	166.	263.	234.	202.	57.	85.	104.
9	145.	167.	265.	231.	202.	58.	90.	100.
10	147.	172.	257.	224.	205.	55.	100.	90.
11	153.	175.	258.	223.	207.	55.	70.	90.
12	142.	186.	257.	247.	205.	58.	113.	107.
13	142.	185.	257.	245.	200.	57.	112.	103.
14	152.	183.	258.	242.	201.	57.	104.	104.
15	140.	183.	258.	242.	202.	57.	105.	87.
16	137.	180.	257.	230.	201.	58.	99.	102.
17	145.	180.	258.	230.	203.	59.	98.	102.
18	143.	184.	259.	232.	205.	60.	100.	100.
19	151.	184.	257.	232.	204.	60.	102.	105.
20	151.	185.	257.	232.	204.	60.	98.	101.
21	145.	186.	257.	283.	206.	59.	98.	101.
22	130.	177.	258.	237.	190.	57.	98.	103.
23	140.	182.	258.	235.	192.	56.	97.	100.
24	152.	185.	257.	235.	204.	55.	100.	100.
25	147.	186.	257.	235.	202.	55.	100.	100.
26	152.	186.	258.	235.	207.	56.	99.	101.
27	153.	186.	257.	236.	208.	58.	99.	101.
28	199.	188.	257.	235.	208.	58.	100.	100.
29	201.	188.	258.	232.	207.	58.	118.	120.
30	235.	189.	257.	230.	202.	58.	120.	122.
31	180.	191.	257.	237.	207.	59.	110.	101.
32	187.	191.	256.	237.	177.	59.	107.	96.
33	160.	190.	257.	237.	200.	59.	110.	97.
34	185.	193.	257.	255.	215.	57.	100.	82.
35	180.	192.	257.	254.	215.	57.	92.	92.
36	181.	192.	257.	254.	220.	57.	100.	76.
37	178.	191.	257.	250.	210.	57.	120.	87.
38	177.	191.	257.	250.	200.	58.	94.	83.
39	180.	191.	257.	253.	204.	58.	92.	83.
40	131.	175.	259.	229.	209.	58.	109.	113.
41	142.	178.	258.	219.	201.	60.	91.	100.
42	175.	183.	257.	235.	220.	61.	90.	85.
43	185.	188.	258.	245.	223.	62.	85.	82.
44	177.	192.	258.	245.	227.	62.	95.	89.
45	194.	196.	258.	245.	227.	63.	88.	85.

TESTID : DMT-003

DATAFI : SEAL.DMT#003

N	TIME HRS	TORQUE FT-LB	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	150.	253.	285.	0.0	0.0	0.0	0.0
2	0.33	165.	320.	375.	0.0	0.0	0.0	0.0
3	0.67	195.	285.	345.	0.0	0.0	0.0	0.0
4	1.00	240.	275.	345.	0.0	0.0	0.0	0.0
5	1.33	280.	290.	375.	0.0	0.0	0.0	0.0
6	1.67	310.	280.	340.	0.0	0.0	0.0	0.0
7	2.00	320.	325.	335.	0.0	0.0	0.0	0.0
8	2.33	350.	335.	330.	0.0	0.0	0.0	0.0
9	2.67	370.	330.	325.	0.0	0.0	0.0	0.0
10	3.00	380.	325.	320.	0.0	0.0	0.0	0.0
11	3.33	370.	330.	310.	0.0	0.0	0.0	0.0
12	3.67	370.	310.	305.	0.0	0.0	0.0	0.0
13	4.00	340.	305.	315.	0.0	0.0	0.0	0.0
14	4.33	380.	300.	405.	0.0	0.0	0.0	0.0
15	4.67	370.	295.	340.	1.7	5.0	0.0	0.0
16	5.00	350.	295.	340.	7.9	18.9	0.0	0.0
17	5.33	380.	305.	375.	21.6	41.3	0.0	0.0
18	5.67	180.	310.	445.	27.8	41.5	0.0	0.0
19	6.00	160.	235.	460.	28.4	1.7	0.0	0.0
20	6.33	220.	275.	415.	35.2	20.6	0.0	0.0
21	6.67	210.	280.	365.	48.8	40.1	0.0	0.0
22	7.00	250.	275.	355.	72.1	70.5	0.0	0.0
23	7.33	205.	320.	345.	88.0	48.2	0.0	0.0
24	7.67	230.	320.	410.	95.9	23.4	0.0	0.0
25	8.00	50.	205.	335.	144.7	147.9	0.0	0.0
26	8.33	120.	190.	360.	144.7	0.0	0.0	0.0
27	8.67	80.	195.	340.	144.7	0.0	0.0	0.0
28	9.00	80.	270.	310.	147.0	6.9	0.0	0.0
29	9.33	50.	185.	320.	148.1	3.4	0.0	0.0
30	9.67	75.	180.	330.	148.1	0.0	0.0	0.0
31	10.00	130.	215.	395.	148.1	0.0	0.0	0.0
32	10.33	140.	225.	365.	148.1	0.0	0.6	1.7
33	10.67	110.	225.	370.	148.1	0.0	0.6	0.0
34	11.00	110.	220.	400.	148.1	0.0	0.6	0.0
35	11.33	110.	220.	380.	148.1	0.0	0.6	0.0
36	11.67	80.	225.	390.	148.1	0.0	0.6	0.0
37	12.00	80.	225.	405.	148.1	0.0	0.6	0.0
38	12.33	130.	220.	455.	148.1	0.0	0.6	0.0
39	12.67	40.	220.	325.	152.1	11.7	0.6	0.0
40	13.00	30.	220.	360.	152.1	0.0	1.1	1.7
41	13.33	20.	225.	355.	152.1	0.0	1.1	0.0
42	13.67	20.	210.	370.	152.1	0.0	1.1	0.0
43	14.00	30.	215.	405.	152.1	0.0	1.1	0.0
44	14.33	40.	220.	435.	152.1	0.0	1.7	1.7
45	14.67	30.	220.	430.	152.1	0.0	1.7	0.0
46	15.00	45.	220.	440.	152.1	0.0	1.7	0.0
47	15.33	40.	225.	450.	152.1	0.0	1.7	0.0
48	15.67	30.	225.	440.	152.1	9.7	1.7	0.1
49	16.00	30.	230.	440.	152.1	0.0	1.7	0.0
50	16.33	40.	220.	420.	152.1	0.0	1.7	0.0
51	16.67	30.	195.	325.	152.1	0.0	1.7	0.0
52	17.00	40.	205.	315.	152.1	8.9	1.7	0.1
53	17.33	40.	195.	310.	152.1	0.0	2.3	1.7
54	17.67	40.	200.	315.	152.1	0.0	3.4	3.3
55	18.00	50.	200.	325.	152.1	0.0	4.5	3.4
56	18.33	40.	215.	345.	152.1	0.0	5.1	1.7
57	18.67	40.	220.	355.	152.1	0.0	6.2	3.3
58	19.00	40.	200.	330.	152.1	0.0	7.4	3.4
59	19.33	40.	205.	330.	152.1	0.0	10.2	8.6
60	19.67	50.	210.	335.	152.1	0.0	8.5	5.0
61	20.00	92.	225.	500.	152.7	1.7	17.0	25.8
62	20.17	110.	230.	500.	154.4	10.0	17.6	3.3
63	20.30	20.	220.	360.	154.4	0.0	26.7	49.6
64	20.33	0.	180.	245.	154.9	18.9	119.7	3102.
65	20.37	0.	185.	225.	154.9	0.0	164.0	1106.
66	20.38	0.	185.	220.	154.9	0.0	185.6	2156.

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	127.	174.	240.	220.	202.	58.	120.	0.
2	118.	177.	257.	222.	212.	58.	129.	0.
3	130.	181.	257.	223.	213.	58.	124.	0.
4	131.	183.	258.	223.	212.	58.	131.	139.
5	142.	183.	258.	222.	209.	58.	125.	142.
6	131.	184.	258.	219.	207.	59.	115.	134.
7	132.	185.	258.	219.	204.	40.	120.	135.
8	132.	185.	257.	218.	205.	40.	123.	142.
9	130.	185.	258.	217.	204.	59.	120.	140.
10	132.	185.	258.	217.	204.	40.	108.	133.
11	133.	185.	257.	214.	202.	40.	119.	133.
12	131.	184.	267.	209.	200.	40.	112.	148.
13	131.	185.	258.	220.	207.	58.	128.	148.
14	132.	186.	256.	221.	211.	40.	124.	147.
15	133.	186.	257.	219.	208.	59.	115.	135.
16	131.	186.	258.	219.	210.	58.	114.	132.
17	55.	144.	241.	204.	179.	40.	107.	138.
18	100.	141.	259.	220.	203.	41.	109.	128.
19	125.	172.	258.	220.	207.	40.	108.	134.
20	125.	174.	259.	218.	205.	40.	107.	122.
21	127.	174.	258.	217.	202.	41.	105.	125.
22	129.	180.	259.	215.	200.	40.	108.	134.
23	131.	181.	257.	215.	202.	41.	111.	140.
24	145.	190.	254.	220.	207.	58.	110.	122.
25	144.	192.	258.	227.	223.	59.	120.	115.
26	249.	192.	257.	224.	218.	57.	111.	114.
27	121.	189.	256.	217.	205.	54.	112.	131.
28	131.	191.	256.	224.	214.	54.	102.	112.
29	133.	192.	257.	227.	215.	57.	105.	112.
30	145.	192.	257.	225.	215.	59.	114.	111.
31	145.	192.	257.	225.	214.	59.	122.	112.
32	152.	192.	252.	223.	214.	54.	110.	99.
33	141.	192.	256.	223.	215.	54.	118.	115.
34	141.	193.	257.	223.	215.	54.	119.	109.
35	143.	193.	257.	222.	213.	55.	112.	94.
36	154.	193.	257.	224.	212.	55.	110.	104.
37	150.	194.	257.	223.	214.	58.	119.	111.
38	113.	192.	256.	221.	204.	57.	98.	87.
39	133.	191.	257.	223.	211.	57.	102.	87.
40	131.	191.	256.	224.	215.	54.	103.	126.
41	130.	192.	256.	225.	217.	54.	105.	100.
42	128.	192.	257.	227.	220.	57.	103.	100.
43	128.	193.	257.	230.	224.	54.	103.	101.
44	124.	193.	256.	230.	227.	57.	104.	98.
45	124.	193.	257.	230.	228.	57.	106.	95.
46	124.	193.	256.	232.	230.	54.	103.	100.
47	125.	193.	256.	232.	230.	54.	105.	98.
48	131.	194.	256.	232.	231.	57.	105.	93.
49	120.	190.	257.	228.	219.	57.	102.	94.
50	128.	191.	255.	228.	221.	54.	97.	100.
51	174.	189.	256.	224.	211.	54.	99.	95.
52	179.	188.	256.	220.	208.	57.	99.	99.
53	175.	188.	256.	219.	206.	54.	99.	100.
54	128.	188.	256.	219.	207.	54.	100.	101.
55	174.	189.	257.	220.	208.	57.	99.	94.
56	171.	189.	256.	220.	210.	57.	99.	94.
57	172.	189.	256.	220.	209.	54.	104.	100.
58	148.	189.	256.	220.	207.	57.	100.	100.
59	173.	189.	256.	220.	208.	57.	101.	100.
60	173.	189.	256.	220.	207.	54.	101.	101.
61	160.	189.	258.	228.	221.	57.	80.	99.
62	175.	192.	256.	233.	230.	57.	124.	114.
63	172.	194.	255.	235.	238.	58.	115.	109.
64	160.	195.	250.	230.	234.	57.	113.	98.
65	151.	194.	252.	226.	234.	54.	109.	97.
66	143.	191.	253.	228.	224.	54.	106.	94.

INLET WATER, UPPER SEAL OUT. US TIME DMT-003

UPPER VESSEL US TIME DMT-003

INLET WATER, LOWER SEAL OUT US TIME DMT-01

MID VESSEL 3 US TIME (DMT-003)

LOWER VESSEL US TIME DMT-003

MID VESSEL 4 US TIME DMT-003

TESTID : DMT-004

DATAFI : SEAL.DMT004

N	TIME	TORQUE	UPPER SEAL TEMP4 (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	70.	250.	270.	0.0	0.0	0.0	0.0
2	0.33	70.	345.	370.	0.0	0.0	0.0	0.0
3	0.67	70.	345.	350.	0.0	0.0	0.0	0.0
4	1.00	80.	310.	335.	0.0	0.0	0.0	0.0
5	1.33	90.	310.	330.	0.0	0.0	0.4	1.7
6	1.67	80.	335.	350.	0.4	1.7	0.4	1.7
7	2.00	80.	285.	325.	1.7	3.4	0.4	0.0
8	2.33	90.	255.	330.	2.3	1.7	0.4	0.0
9	2.67	80.	275.	340.	2.8	1.7	0.4	0.0
10	3.00	80.	270.	340.	3.4	1.7	0.4	0.0
11	3.33	80.	275.	340.	4.0	1.7	0.4	0.0
12	3.67	80.	270.	345.	4.5	1.7	1.1	1.7
13	4.00	90.	270.	340.	4.5	0.0	1.1	0.0
14	4.33	80.	275.	290.	5.1	1.7	1.1	0.0
15	4.67	80.	275.	310.	5.7	1.7	1.1	0.0
16	5.00	80.	280.	300.	5.7	0.0	1.1	0.0
17	5.33	80.	275.	295.	5.7	17.2	1.7	1.7
18	5.67	80.	270.	290.	4.2	1.7	1.7	0.0
19	6.00	80.	265.	290.	4.2	0.0	1.7	0.0
20	6.33	80.	275.	290.	4.8	20.4	1.7	0.0
21	6.67	70.	275.	290.	4.8	0.0	1.7	0.0
22	7.00	80.	275.	295.	4.8	20.4	1.7	0.0
23	7.33	80.	295.	290.	7.4	1.7	1.7	0.0
24	7.67	80.	295.	295.	7.4	0.0	2.3	1.7
25	8.00	90.	255.	285.	7.4	22.4	2.3	0.0
26	8.33	90.	290.	300.	7.9	1.7	2.3	0.0
27	8.67	90.	300.	300.	7.9	4.7	2.3	0.0
28	9.00	90.	295.	305.	8.5	1.7	2.3	0.0
29	9.33	90.	300.	295.	9.1	1.7	2.8	1.7
30	9.67	80.	300.	295.	9.1	0.0	2.8	0.0
31	10.00	80.	300.	290.	9.4	1.7	2.8	0.0
32	10.33	80.	305.	290.	9.4	0.0	2.8	0.0
33	10.67	80.	330.	305.	10.2	1.7	2.8	0.0
34	11.00	80.	350.	305.	10.2	0.0	2.8	0.0
35	11.33	80.	330.	305.	10.8	1.7	2.8	0.0
36	11.67	80.	335.	295.	11.9	3.3	3.4	1.7
37	12.00	80.	350.	305.	12.5	1.7	3.4	0.0
38	12.22	190.	395.	320.	13.1	2.4	3.4	0.0
39	12.27	80.	240.	270.	65.8	1055.	3.4	0.0
40	12.33	40.	220.	235.	178.2	1872.	3.4	0.0
41	12.37	60.	220.	220.	225.9	1191.	3.4	0.0

TESTID : DMT-004

DATAFI : SEAL.DMT1004

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	118.	182.	260.	217.	163.	55.	107.	109.
2	111.	177.	259.	215.	161.	61.	113.	124.
3	110.	181.	259.	215.	165.	60.	116.	124.
4	110.	182.	258.	214.	165.	60.	118.	124.
5	110.	184.	258.	214.	166.	60.	117.	127.
6	108.	183.	260.	212.	164.	60.	115.	127.
7	107.	183.	257.	215.	165.	59.	107.	115.
8	107.	184.	257.	216.	166.	59.	105.	115.
9	106.	184.	257.	216.	167.	60.	105.	113.
10	106.	184.	257.	217.	167.	59.	103.	112.
11	105.	184.	257.	217.	168.	60.	105.	115.
12	106.	185.	257.	218.	168.	60.	102.	112.
13	105.	185.	256.	217.	168.	60.	103.	111.
14	106.	184.	258.	215.	165.	59.	104.	112.
15	106.	182.	256.	213.	164.	59.	102.	103.
16	106.	182.	256.	213.	164.	59.	102.	100.
17	108.	182.	256.	212.	164.	59.	102.	96.
18	108.	181.	256.	212.	164.	59.	100.	96.
19	107.	181.	256.	212.	163.	58.	101.	95.
20	107.	181.	256.	211.	163.	58.	100.	92.
21	108.	180.	256.	211.	162.	58.	99.	90.
22	109.	181.	256.	211.	163.	58.	100.	95.
23	110.	181.	256.	210.	162.	58.	100.	90.
24	120.	181.	256.	210.	162.	58.	102.	84.
25	116.	182.	256.	212.	162.	59.	103.	103.
26	125.	182.	256.	211.	171.	59.	100.	90.
27	127.	182.	256.	210.	162.	59.	104.	90.
28	125.	182.	256.	211.	163.	59.	102.	80.
29	128.	183.	256.	211.	163.	58.	103.	78.
30	129.	183.	256.	211.	163.	58.	95.	77.
31	145.	183.	256.	211.	162.	58.	104.	77.
32	143.	183.	256.	211.	161.	58.	90.	75.
33	125.	183.	257.	210.	163.	59.	103.	61.
34	120.	183.	258.	210.	162.	59.	103.	75.
35	117.	182.	257.	209.	162.	59.	98.	77.
36	117.	181.	256.	208.	161.	58.	102.	76.
37	121.	182.	259.	210.	161.	56.	106.	108.
38	122.	181.	265.	209.	161.	56.	107.	102.
39	123.	181.	245.	207.	162.	55.	105.	99.
40	123.	182.	253.	211.	163.	56.	100.	74.
41	123.	182.	255.	212.	163.	55.	98.	72.

TESTID : DMT-005

DATAFI : SEAL.DMT#005

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	85.	300.	255.	0.0	0.0	0.0	0.0
2	0.17	95.	330.	290.	0.0	0.0	0.1	0.7
3	0.33	90.	333.	290.	0.0	0.0	0.2	0.7
4	0.50	90.	330.	290.	0.0	0.0	0.5	1.3
5	0.83	95.	342.	303.	0.0	0.0	0.7	0.7
6	1.17	90.	335.	310.	0.0	0.0	0.9	0.7
7	1.50	95.	340.	313.	0.0	0.0	1.1	0.7
8	1.83	95.	325.	313.	0.0	0.0	1.1	0.0
9	2.17	90.	325.	300.	0.0	0.0	1.1	0.0
10	2.50	95.	340.	303.	0.0	0.0	1.2	0.3
11	2.83	100.	355.	307.	0.0	0.0	1.4	0.3
12	3.14	105.	352.	295.	0.0	0.0	1.5	0.3
13	3.50	100.	340.	290.	0.0	0.0	1.6	0.3
14	3.83	100.	343.	290.	0.0	0.0	1.6	0.0
15	4.14	95.	315.	280.	0.0	0.0	7.9	19.3
16	4.33	95.	345.	310.	0.2	1.3	8.2	1.3
17	4.41	90.	370.	300.	0.5	2.8	8.3	1.4
18	4.50	85.	255.	295.	0.7	2.5	8.4	1.3
19	4.66	80.	255.	290.	1.4	4.3	8.4	0.0
20	4.83	80.	200.	290.	1.8	2.7	8.4	0.0
21	4.96	40.	240.	250.	2.0	1.7	8.5	0.9
22	5.00	40.	205.	230.	51.1	1225.	21.6	326.3
23	5.03	40.	185.	205.	96.5	1513.	45.4	794.5
24	5.07	40.	180.	190.	141.9	1135.	65.4	499.4
25	5.10	40.	195.	195.	120.3	718.8	69.9	151.3
26	5.12	40.	185.	190.	152.1	1589.	104.0	1702.

TESTID : DMT-005

DATAFI : SEAL.DMT005

THERMOCOUPLES(F):

	1 N THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	6 INLET WATER	9 UPPER SEAL OUTLET	10 LOWER SEAL OUTLET

1	109.	150.	259.	208.	139.	58.	100.	83.
2	114.	156.	259.	210.	143.	50.	101.	83.
3	117.	158.	259.	211.	142.	58.	104.	83.
4	118.	158.	258.	211.	150.	58.	107.	83.
5	116.	157.	258.	213.	153.	58.	106.	84.
6	116.	157.	257.	214.	154.	58.	104.	84.
7	119.	158.	257.	214.	158.	57.	107.	84.
8	119.	158.	257.	215.	160.	57.	106.	85.
9	117.	156.	257.	214.	160.	57.	106.	85.
10	117.	153.	257.	213.	160.	56.	105.	85.
11	116.	151.	257.	214.	161.	56.	105.	85.
12	116.	150.	257.	213.	161.	56.	105.	85.
13	114.	147.	257.	212.	160.	56.	103.	86.
14	113.	145.	257.	212.	160.	56.	103.	86.
15	114.	146.	257.	216.	160.	56.	89.	86.
16	113.	146.	259.	217.	163.	56.	75.	86.
17	114.	146.	260.	218.	164.	56.	70.	86.
18	116.	147.	253.	217.	165.	56.	100.	86.
19	117.	145.	255.	217.	165.	55.	97.	86.
20	116.	144.	256.	217.	164.	55.	90.	86.
21	117.	145.	245.	213.	164.	55.	86.	86.
22	117.	151.	245.	209.	167.	55.	86.	86.
23	117.	160.	252.	210.	169.	55.	86.	86.
24	116.	156.	256.	216.	169.	55.	86.	86.
25	116.	152.	265.	216.	168.	54.	84.	86.
26	115.	150.	255.	214.	167.	54.	75.	86.

TESTID : DMT-006

DATAFI : SEAL.DMT006

N	TIME	TORQUE	UPPER SEAL TEMP4 (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	40.	230.	230.	0.0	0.0	0.0	0.0
2	0.50	110.	320.	295.	0.4	1.1	1.1	2.3
3	1.00	35.	345.	315.	0.4	0.0	2.3	2.3
4	1.50	30.	340.	310.	0.4	0.0	3.4	2.3
5	2.00	25.	355.	285.	1.1	1.1	4.0	1.1
6	2.50	50.	320.	300.	1.1	0.0	5.1	2.3
7	3.00	40.	350.	245.	1.7	1.1	5.1	0.0
8	3.50	50.	205.	240.	4.2	9.1	4.2	2.3
9	4.00	20.	275.	275.	7.4	2.3	4.2	0.0
10	4.50	125.	250.	270.	8.5	2.3	4.8	1.1
11	5.00	140.	245.	245.	10.2	3.4	7.4	1.1
12	5.50	135.	300.	300.	10.2	0.0	7.9	1.1
13	6.00	130.	305.	300.	10.8	1.1	9.6	3.4
14	6.50	120.	260.	0.	10.8	0.0	9.6	0.0
15	7.00	105.	240.	0.	11.4	1.1	10.2	1.1
16	7.50	110.	255.	0.	11.4	0.0	10.2	0.0
17	8.00	120.	275.	0.	11.9	1.1	10.8	1.1
18	8.50	120.	270.	0.	12.5	1.1	10.8	0.0
19	9.00	125.	270.	0.	12.5	0.0	11.4	1.1
20	9.50	125.	270.	0.	12.5	0.0	11.4	0.0
21	10.00	125.	245.	0.	13.1	1.1	11.4	0.0
22	10.50	125.	260.	0.	13.1	0.0	11.9	1.1
23	11.00	120.	260.	0.	13.4	1.1	11.9	0.0
24	11.50	120.	265.	0.	13.4	0.0	11.9	0.0
25	12.00	120.	275.	0.	13.4	0.0	11.9	0.0
26	12.50	120.	260.	0.	13.4	0.0	11.9	0.0
27	13.00	125.	255.	0.	14.2	1.1	12.5	1.1
28	13.50	125.	255.	0.	14.8	1.1	12.5	0.0
29	14.00	125.	260.	0.	14.8	0.0	12.5	0.0
30	14.50	135.	280.	0.	14.8	0.0	12.5	0.0
31	15.00	130.	260.	0.	15.3	1.1	12.5	0.0
32	15.50	120.	255.	0.	15.3	0.0	12.5	0.0
33	16.00	130.	210.	0.	15.3	0.0	12.5	0.0
34	16.50	115.	215.	0.	15.3	0.0	12.5	0.0
35	17.00	120.	210.	0.	15.9	1.1	13.1	1.1
36	17.50	115.	200.	0.	15.9	0.0	13.4	1.1
37	18.00	105.	210.	0.	15.9	0.0	13.4	0.0
38	18.50	110.	210.	0.	15.9	0.0	13.4	0.0
39	19.00	115.	210.	0.	15.9	0.0	14.2	1.1
40	19.50	110.	210.	0.	15.9	0.0	14.8	1.1
41	20.00	110.	210.	0.	15.9	0.0	14.8	0.0
42	20.50	100.	245.	0.	15.9	0.0	14.8	0.0
43	21.00	95.	250.	0.	16.5	1.1	14.8	0.0
44	21.50	85.	260.	0.	16.5	0.0	15.3	1.1
45	22.00	85.	250.	0.	16.5	0.0	15.9	1.1
46	22.50	85.	260.	0.	16.5	0.0	16.5	1.1
47	23.00	90.	265.	0.	16.5	0.0	17.6	2.3
48	23.50	85.	255.	0.	16.5	0.0	18.7	2.3
49	24.00	100.	250.	0.	16.5	0.0	19.9	2.3
50	24.03	220.	205.	0.	17.0	18.9	26.7	227.0
51	24.12	180.	230.	0.	19.3	25.2	26.7	0.0
52	24.18	180.	165.	0.	97.4	4.0	26.7	1.1
53	24.20	85.	160.	0.	130.5	1645.	26.7	0.0
54	24.22	85.	155.	0.	162.3	1589.	26.7	0.0
55	24.23	80.	160.	0.	179.9	1759.	26.7	0.0

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	100.	118.	240.	198.	132.	44.	85.	110.
2	110.	125.	259.	208.	152.	43.	100.	130.
3	113.	140.	257.	223.	166.	42.	95.	130.
4	121.	136.	256.	225.	173.	42.	120.	130.
5	134.	134.	268.	224.	173.	42.	95.	124.
6	137.	130.	255.	224.	175.	43.	80.	137.
7	141.	133.	258.	223.	175.	42.	105.	145.
8	127.	131.	257.	218.	170.	40.	95.	120.
9	122.	143.	263.	218.	169.	40.	88.	117.
10	127.	162.	257.	220.	169.	40.	102.	118.
11	127.	165.	262.	222.	170.	57.	95.	123.
12	129.	166.	264.	222.	168.	57.	98.	120.
13	129.	170.	270.	249.	168.	58.	100.	112.
14	108.	100.	258.	224.	173.	57.	95.	114.
15	103.	96.	255.	228.	175.	57.	95.	112.
16	116.	140.	256.	232.	178.	56.	89.	113.
17	115.	126.	256.	230.	176.	57.	96.	100.
18	113.	119.	256.	229.	177.	57.	93.	105.
19	112.	114.	256.	230.	177.	57.	84.	100.
20	111.	111.	256.	227.	174.	57.	96.	101.
21	110.	112.	256.	226.	172.	57.	93.	102.
22	112.	120.	256.	228.	175.	57.	100.	103.
23	112.	118.	255.	227.	174.	57.	97.	106.
24	108.	113.	255.	227.	174.	57.	97.	104.
25	115.	110.	255.	226.	173.	57.	95.	103.
26	114.	115.	255.	225.	170.	57.	96.	110.
27	115.	118.	255.	227.	173.	57.	96.	108.
28	115.	117.	255.	227.	176.	57.	77.	107.
29	115.	118.	255.	224.	171.	57.	99.	102.
30	117.	122.	256.	224.	171.	57.	98.	100.
31	122.	129.	255.	223.	170.	57.	95.	107.
32	120.	130.	255.	224.	171.	58.	95.	110.
33	125.	138.	252.	222.	172.	59.	95.	112.
34	122.	134.	256.	224.	172.	57.	93.	106.
35	120.	133.	256.	226.	174.	58.	90.	112.
36	119.	131.	256.	227.	175.	57.	88.	118.
37	118.	126.	255.	229.	177.	57.	84.	112.
38	122.	130.	256.	229.	176.	56.	86.	102.
39	115.	125.	256.	229.	177.	57.	80.	107.
40	113.	122.	256.	230.	180.	57.	77.	110.
41	113.	122.	257.	232.	181.	57.	76.	113.
42	118.	128.	257.	227.	176.	59.	105.	113.
43	118.	130.	257.	225.	174.	57.	98.	112.
44	117.	133.	257.	225.	173.	58.	96.	105.
45	115.	133.	257.	225.	172.	58.	99.	108.
46	116.	135.	257.	225.	171.	58.	98.	102.
47	116.	135.	257.	225.	173.	58.	95.	108.
48	115.	135.	257.	228.	175.	59.	95.	110.
49	115.	135.	257.	232.	178.	59.	96.	116.
50	119.	140.	259.	228.	176.	58.	102.	107.
51	118.	138.	255.	230.	175.	58.	96.	112.
52	118.	149.	246.	232.	179.	58.	88.	102.
53	118.	150.	248.	234.	180.	58.	88.	100.
54	118.	152.	253.	235.	181.	57.	88.	100.
55	118.	152.	267.	236.	181.	58.	102.	96.

INLET WATER, UP SEAL OUT. US TIME DMT-006

UPPER VESSEL US TIME DMT-006

INLET WATER, LOW SEAL OUT. US TIME DMT-006

MID VESSEL 3 US TIME DMT-006

LOWER VESSEL US TIME DMT-006

MID VESSEL 4 US TIME DMT-006

TESTID : DMT-007

DATAFI : SEAL.DMT007

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	123.	171.	257.	210.	185.	57.	75.	69.
2	149.	187.	260.	217.	191.	60.	140.	110.
3	147.	185.	257.	240.	194.	59.	108.	130.
4	149.	185.	257.	218.	201.	59.	106.	127.
5	150.	185.	258.	223.	205.	59.	100.	127.
6	150.	185.	258.	221.	206.	58.	107.	128.
7	147.	183.	255.	223.	207.	58.	105.	120.
8	142.	178.	258.	226.	210.	58.	103.	120.
9	141.	176.	258.	230.	212.	58.	101.	125.
10	147.	181.	256.	227.	213.	58.	105.	125.
11	149.	182.	258.	230.	214.	58.	104.	130.
12	148.	181.	257.	230.	215.	58.	102.	127.
13	150.	181.	258.	232.	216.	59.	104.	124.
14	139.	175.	257.	230.	214.	57.	102.	127.
15	135.	174.	257.	231.	214.	57.	100.	124.
16	135.	174.	256.	230.	216.	57.	101.	121.
17	135.	174.	255.	231.	217.	57.	102.	120.
18	135.	175.	256.	234.	220.	57.	100.	113.
19	104.	245.	317.	260.	244.	58.	98.	110.
20	101.	232.	316.	278.	260.	57.	114.	106.
21	100.	253.	292.	277.	265.	56.	115.	97.
22	100.	270.	288.	276.	267.	57.	119.	97.

TESTID : DMT-007

DATAFI : SEAL.DMT#007

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	90.	180.	170.	0.0	0.0	0.0	0.0
2	0.17	45.	380.	240.	0.0	0.0	0.0	0.0
3	0.33	95.	310.	275.	0.0	0.0	0.0	0.0
4	0.50	125.	315.	270.	0.0	0.0	0.0	0.0
5	0.67	145.	320.	320.	0.0	0.0	0.4	3.3
6	0.83	145.	325.	245.	0.0	0.0	0.6	0.0
7	1.00	140.	295.	295.	0.0	0.0	0.4	0.0
8	1.17	145.	300.	285.	0.0	0.0	0.6	0.0
9	1.33	160.	310.	355.	0.0	0.0	0.6	0.0
10	1.50	175.	310.	280.	0.0	0.0	0.6	0.0
11	1.67	190.	325.	345.	0.0	0.0	1.1	3.3
12	1.83	200.	325.	320.	0.0	0.0	1.1	0.0
13	2.00	210.	330.	365.	0.0	0.0	1.1	0.0
14	2.17	195.	325.	305.	0.0	0.0	1.1	0.0
15	2.33	170.	330.	320.	0.0	0.0	1.1	0.0
16	2.50	175.	330.	310.	0.0	0.0	1.1	0.0
17	2.67	140.	270.	340.	0.0	0.0	1.1	0.0
18	2.83	150.	280.	335.	0.4	3.5	1.7	3.5
19	3.00	155.	290.	325.	22.7	130.2	2.3	3.3
20	3.17	100.	250.	255.	97.0	437.3	2.3	0.0
21	3.20	95.	145.	250.	181.6	2818.	2.3	0.0
22	3.22	115.	185.	250.	238.9	2865.	2.3	0.0

TESTID : DMT-008

DATAFI : SEAL.008

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	75.	270.	240.	0.0	0.0	0.0	0.0
2	0.50	140.	320.	240.	0.0	0.0	0.0	0.0
3	1.00	110.	290.	210.	0.0	0.0	0.0	0.0
4	1.50	80.	290.	230.	0.0	0.0	0.0	0.0
5	2.00	80.	340.	300.	0.0	0.0	0.0	0.0
6	2.50	70.	310.	280.	0.0	0.0	0.0	0.0
7	3.00	52.	270.	250.	0.2	0.5	0.0	0.0
8	3.50	40.	280.	270.	1.8	3.2	0.5	0.9
9	4.00	40.	300.	280.	5.0	6.4	1.1	1.4
10	4.50	50.	280.	260.	7.9	5.9	1.1	0.0
11	5.00	70.	300.	270.	11.4	6.8	1.7	1.1
12	5.50	55.	300.	270.	13.4	4.5	1.8	0.2
13	6.00	100.	300.	230.	19.3	11.4	1.8	0.0
14	6.50	120.	270.	250.	19.3	0.0	2.3	0.9
15	7.00	110.	260.	250.	19.5	0.5	2.5	0.5
16	7.50	90.	300.	265.	19.7	0.5	3.2	1.4
17	8.00	85.	300.	270.	20.0	0.5	4.1	1.8
18	8.50	70.	300.	260.	20.0	0.0	5.2	2.3
19	9.00	70.	270.	240.	20.2	0.5	7.3	4.1
20	9.50	40.	240.	250.	20.4	0.5	10.9	7.3
21	10.00	100.	290.	270.	21.6	2.3	14.1	6.4
22	10.50	120.	295.	275.	22.2	1.4	17.3	6.4
23	11.00	130.	295.	275.	22.7	0.9	21.3	8.2
24	11.50	120.	300.	280.	23.7	0.0	25.4	8.2
25	12.00	110.	300.	280.	23.2	0.9	30.6	10.4
26	12.50	130.	300.	280.	23.6	0.9	36.3	11.3
27	13.00	140.	295.	280.	24.3	1.4	43.1	13.6
28	13.50	85.	280.	285.	24.3	0.0	46.1	5.9
29	14.00	35.	290.	275.	24.7	0.9	47.8	3.4
30	14.50	60.	315.	280.	25.0	0.5	49.7	3.0
31	15.00	30.	320.	275.	25.0	0.0	51.1	3.6
32	15.50	50.	325.	290.	25.0	0.0	54.0	5.9
33	16.00	50.	325.	280.	25.0	0.0	55.4	2.7
34	16.50	75.	315.	275.	25.0	0.5	57.9	5.0
35	17.00	65.	310.	280.	25.4	0.5	59.9	4.1
36	17.50	75.	340.	330.	25.4	0.0	62.0	4.1
37	18.00	70.	380.	330.	48.8	46.8	63.1	2.3
38	18.07	120.	410.	340.	40.8	0.0	63.3	3.2
39	18.10	45.	235.	240.	48.8	0.0	100.8	1248.
40	18.17	50.	235.	225.	48.0	0.0	201.6	1439.
41	18.20	30.	235.	220.	48.8	0.0	244.7	1437.

TESTID : DMT-008

DATAFI : SEAL.008

THERMOCOUPLES(F):

N	1 THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	8 INLET WATER	9 UPPER SEAL INLET	10 LOWER SEAL OUTLET
1	150.	290.	325.	265.	250.	66.	80.	105.
2	140.	237.	280.	250.	255.	78.	135.	105.
3	275.	282.	322.	282.	253.	80.	115.	102.
4	305.	277.	308.	269.	253.	80.	115.	102.
5	0.	275.	270.	275.	238.	65.	83.	80.
6	128.	220.	250.	260.	252.	66.	83.	81.
7	128.	225.	262.	272.	252.	66.	82.	80.
8	127.	223.	258.	268.	252.	65.	84.	76.
9	125.	223.	257.	265.	253.	66.	83.	82.
10	114.	221.	253.	266.	252.	65.	82.	80.
11	112.	219.	253.	267.	254.	65.	83.	81.
12	111.	216.	247.	262.	251.	65.	82.	80.
13	114.	232.	266.	272.	252.	65.	91.	88.
14	115.	232.	265.	267.	253.	65.	93.	90.
15	118.	235.	267.	265.	252.	65.	93.	90.
16	118.	233.	255.	256.	252.	66.	91.	90.
17	117.	222.	255.	254.	252.	66.	89.	86.
18	116.	220.	253.	253.	252.	67.	86.	84.
19	118.	225.	252.	253.	251.	67.	88.	87.
20	118.	230.	260.	260.	251.	66.	85.	83.
21	120.	225.	257.	251.	252.	66.	92.	89.
22	127.	223.	257.	240.	251.	67.	93.	91.
23	117.	221.	257.	248.	251.	66.	95.	94.
24	118.	218.	255.	247.	251.	67.	94.	92.
25	116.	223.	259.	248.	251.	67.	92.	90.
26	119.	225.	260.	247.	250.	66.	92.	90.
27	118.	227.	262.	247.	250.	67.	95.	94.
28	122.	236.	295.	279.	257.	65.	85.	83.
29	117.	208.	255.	252.	250.	65.	85.	80.
30	111.	200.	247.	243.	250.	65.	87.	85.
31	107.	199.	249.	245.	252.	64.	81.	79.
32	104.	201.	250.	244.	251.	64.	80.	78.
33	103.	206.	254.	244.	251.	65.	82.	80.
34	106.	202.	253.	247.	252.	66.	86.	85.
35	107.	203.	255.	248.	251.	65.	85.	82.
36	115.	233.	284.	281.	260.	75.	87.	86.
37	112.	191.	225.	232.	249.	71.	85.	83.
38	122.	229.	270.	300.	262.	65.	81.	79.
39	122.	223.	242.	275.	253.	65.	81.	77.
40	127.	228.	232.	261.	248.	66.	83.	80.
41	125.	230.	233.	256.	246.	65.	81.	78.

TESTID : DMT-009

DATAFI : SEAL.009

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	130.	165.	165.	0.0	0.0	0.0	0.0
2	0.33	100.	220.	210.	0.0	0.0	0.0	0.0
3	0.67	80.	235.	210.	0.0	0.0	0.0	0.0
4	1.00	60.	235.	210.	0.0	0.0	0.0	0.0
5	1.33	65.	235.	215.	0.0	0.0	0.0	0.0
6	1.67	50.	245.	230.	0.0	0.0	0.0	0.0
7	2.00	70.	245.	225.	0.0	0.0	0.0	0.0
8	2.33	75.	265.	250.	0.0	0.0	0.0	0.0
9	2.67	70.	270.	250.	0.0	0.0	0.0	0.0
10	3.00	85.	275.	250.	0.0	0.0	0.0	0.0
11	3.20	80.	285.	250.	0.0	0.0	0.0	0.0
12	3.30	90.	265.	250.	6.8	48.1	0.0	0.0
13	3.40	110.	280.	250.	10.2	34.0	0.0	0.0
14	3.45	60.	240.	200.	51.1	81.2	0.0	0.0
15	3.48	40.	230.	200.	128.3	2572.	0.0	0.0
16	3.52	30.	225.	200.	204.3	1901.	0.0	0.0

TESTID : DMT-009

DATAFI : SEAL.009

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	118.	213.	248.	240.	218.	60.	67.	70.
2	128.	215.	253.	245.	227.	65.	100.	72.
3	128.	223.	250.	233.	217.	65.	120.	73.
4	130.	223.	248.	225.	210.	65.	115.	73.
5	130.	225.	248.	225.	212.	65.	122.	73.
6	133.	225.	248.	225.	217.	65.	127.	73.
7	133.	225.	248.	225.	212.	65.	125.	73.
8	132.	225.	250.	220.	208.	65.	137.	73.
9	127.	225.	248.	217.	205.	65.	135.	72.
10	130.	225.	248.	215.	207.	65.	140.	70.
11	130.	225.	250.	215.	207.	65.	140.	70.
12	135.	220.	243.	215.	209.	65.	137.	70.
13	137.	223.	250.	215.	210.	65.	143.	70.
14	132.	225.	240.	212.	210.	65.	135.	70.
15	132.	240.	225.	215.	215.	65.	125.	70.
16	132.	262.	235.	230.	230.	65.	110.	70.

TESTID : DMT-010

DATAFI : SEAL.010

N	TIME HRS	TORQUE FT-LB	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	130.	20.	110.	0.0	0.0	0.0	0.0
2	0.50	20.	253.	160.	0.0	0.0	0.0	0.0
3	1.00	100.	260.	160.	0.0	0.0	0.0	0.0
4	1.50	75.	265.	160.	0.0	0.0	0.0	0.0
5	2.00	100.	280.	165.	0.0	0.0	0.0	0.0
6	2.50	80.	280.	165.	0.0	0.0	0.0	0.0
7	3.00	70.	270.	175.	0.0	0.0	0.0	0.0
8	3.50	20.	285.	175.	0.0	0.0	0.0	0.0
9	4.00	20.	285.	175.	0.0	0.0	0.0	0.0
10	4.50	120.	300.	190.	0.0	0.0	0.0	0.0
11	5.00	135.	300.	180.	2.3	4.5	2.3	4.5
12	5.50	130.	320.	180.	2.3	0.0	2.3	0.0
13	6.00	145.	350.	180.	4.5	4.5	2.3	0.0
14	6.50	155.	370.	180.	5.7	2.3	3.4	2.3
15	7.00	135.	375.	185.	5.7	0.0	4.5	2.3
16	7.50	140.	370.	200.	6.8	0.0	4.5	0.0
17	7.83	145.	360.	210.	6.8	0.0	4.5	0.0
18	8.33	130.	390.	210.	9.1	4.5	5.7	2.3
19	8.83	115.	390.	210.	9.1	0.0	6.8	2.3
20	9.33	120.	380.	210.	10.2	2.3	7.9	2.3
21	9.50	105.	320.	250.	22.7	73.4	9.1	6.7
22	9.70	70.	310.	210.	74.9	261.1	9.1	0.0
23	9.90	70.	290.	200.	127.1	261.1	9.1	0.0
24	10.10	70.	290.	210.	181.8	272.4	9.1	0.0
25	10.30	0.	180.	19.	235.4	283.6	18.2	45.4

TESTID : DMT-010

DATAFI : SEAL.010

THERMOCOUPLES(F):

N	1 THRUST BEARING	2 UPPER VESSEL	3 MID VESSEL	4 MID VESSEL	5 LOWER VESSEL	8 INLET WATER	9 UPPER SFAL OUTLET	10 LOWER SEAL OUTLET
1	88.	217.	248.	210.	202.	72.	70.	62.
2	98.	196.	248.	200.	203.	68.	82.	42.
3	90.	194.	248.	203.	208.	68.	102.	44.
4	93.	195.	248.	207.	213.	70.	102.	64.
5	102.	193.	250.	210.	213.	72.	100.	64.
6	102.	195.	248.	210.	215.	72.	100.	64.
7	102.	197.	250.	212.	218.	70.	102.	64.
8	102.	195.	248.	214.	218.	70.	95.	64.
9	100.	198.	248.	215.	221.	70.	93.	64.
10	100.	182.	250.	211.	222.	70.	93.	64.
11	98.	182.	250.	210.	221.	70.	97.	64.
12	100.	182.	250.	210.	218.	70.	94.	64.
13	100.	180.	250.	208.	215.	70.	95.	64.
14	100.	178.	250.	207.	213.	70.	95.	64.
15	100.	176.	250.	200.	210.	70.	90.	64.
16	98.	176.	250.	202.	221.	70.	93.	64.
17	98.	176.	250.	205.	218.	70.	93.	64.
18	96.	182.	250.	203.	220.	70.	86.	64.
19	96.	183.	250.	203.	218.	70.	87.	64.
20	95.	183.	250.	202.	220.	70.	85.	64.
21	95.	188.	250.	201.	220.	65.	85.	64.
22	96.	191.	248.	212.	228.	66.	80.	64.
23	96.	193.	248.	215.	230.	65.	80.	64.
24	96.	194.	248.	218.	233.	65.	80.	64.
25	96.	195.	248.	220.	235.	65.	80.	64.

TESTID : DMT-013

DATA1 : SEAL.013

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	35.	230.	205.	0.0	0.0	0.0	0.0
2	0.50	30.	240.	230.	0.0	0.0	0.0	0.0
3	1.00	37.	260.	238.	0.0	0.0	0.0	0.0
4	1.50	60.	340.	255.	0.0	0.0	0.0	0.0
5	2.00	70.	340.	300.	0.0	0.0	0.0	0.0
6	2.50	45.	340.	260.	0.0	0.0	0.0	0.0
7	3.00	45.	320.	235.	0.0	0.0	0.0	0.0
8	3.50	30.	315.	230.	0.0	0.0	0.0	0.0
9	4.00	55.	320.	235.	0.0	0.0	0.0	0.0
10	4.50	95.	325.	215.	0.0	0.0	0.0	0.0
11	5.00	110.	375.	220.	0.5	0.9	0.0	0.0
12	5.50	90.	330.	200.	15.4	30.0	0.0	0.0
13	6.00	80.	330.	200.	15.4	0.0	0.0	0.0
14	6.50	85.	345.	220.	15.4	0.0	0.0	0.0
15	7.00	85.	360.	200.	1.5	27.0	0.0	0.0
16	7.50	80.	350.	200.	15.4	27.0	0.0	0.0
17	8.00	100.	300.	220.	16.3	1.0	0.0	0.0
18	8.50	85.	335.	240.	17.3	1.0	0.0	0.0
19	9.00	105.	350.	220.	23.2	11.0	0.0	0.0
20	9.50	105.	350.	210.	36.5	26.0	0.5	0.9
21	10.00	90.	360.	240.	45.1	13.2	0.5	0.0
22	10.50	90.	390.	240.	49.3	12.3	3.4	5.9
23	11.00	90.	365.	225.	49.3	0.0	11.4	15.9
24	11.15	100.	360.	220.	49.5	1.5	16.6	34.0
25	11.20	60.	280.	210.	121.4	1439.	19.5	59.0
26	11.25	90.	270.	210.	221.1	1993.	22.2	54.5

TESTID : DMT-013

DATAFI : SEAL.013

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	108.	217.	240.	192.	202.	64.	76.	72.
2	120.	215.	249.	207.	215.	68.	79.	76.
3	122.	213.	250.	208.	215.	68.	80.	78.
4	120.	204.	250.	202.	214.	67.	83.	80.
5	120.	208.	250.	205.	216.	67.	82.	80.
6	120.	205.	249.	201.	212.	65.	82.	79.
7	124.	146.	250.	199.	208.	69.	86.	82.
8	121.	146.	249.	200.	207.	69.	85.	81.
9	123.	148.	248.	199.	209.	71.	89.	85.
10	113.	149.	250.	203.	214.	65.	84.	80.
11	116.	145.	248.	201.	213.	66.	83.	80.
12	117.	149.	250.	205.	217.	66.	83.	80.
13	112.	148.	248.	203.	215.	65.	80.	77.
14	110.	145.	248.	203.	215.	60.	78.	75.
15	110.	147.	248.	200.	212.	65.	80.	77.
16	109.	147.	249.	200.	212.	64.	80.	76.
17	108.	146.	249.	200.	218.	64.	79.	76.
18	108.	145.	248.	203.	216.	64.	78.	76.
19	108.	145.	248.	204.	218.	64.	79.	76.
20	110.	145.	248.	204.	220.	65.	81.	78.
21	110.	139.	248.	204.	215.	65.	80.	77.
22	109.	145.	249.	199.	207.	65.	80.	78.
23	109.	142.	248.	195.	205.	65.	80.	77.
24	110.	147.	247.	195.	203.	66.	83.	79.
25	112.	155.	233.	197.	205.	65.	85.	82.
26	115.	163.	246.	200.	216.	65.	93.	91.

TESTID : DMI-014

DATA1 : SEAL.014

N	TIME	TORQUE	UPPER SEAL TEMP	LOWER SEAL TEMP	UPPER SEAL LEAK	UPPER SEAL LEAK RATE	LOWER SEAL LEAK	LOWER SEAL LEAK RATE
	HRS	FT-LB	(F)	(F)	CU IN	CU IN/HK	CU IN	CU IN/HK
1	0.00	50.	180.	185.	0.0	0.0	0.0	0.0
2	0.50	55.	230.	230.	0.0	0.0	0.0	0.0
3	1.00	70.	260.	220.	0.0	0.0	0.0	0.0
4	1.50	60.	305.	235.	0.0	0.0	0.0	0.0
5	2.00	75.	310.	240.	0.0	0.0	0.0	0.0
6	2.50	50.	280.	250.	0.0	0.0	0.0	0.0
7	3.00	55.	265.	250.	0.0	0.0	0.0	0.0
8	3.50	20.	275.	260.	0.0	0.0	0.0	0.0
9	4.00	90.	270.	260.	0.0	0.0	0.0	0.0
10	4.50	120.	290.	255.	0.0	0.0	0.0	0.0
11	5.00	120.	300.	270.	0.0	0.0	0.0	0.0
12	5.50	130.	240.	270.	0.0	0.0	0.0	0.0
13	6.00	130.	280.	255.	0.0	0.0	0.0	0.0
14	6.50	110.	250.	240.	0.0	0.0	0.0	0.0
15	7.00	120.	285.	250.	0.0	0.0	0.0	0.0
16	7.50	110.	255.	240.	0.0	0.0	0.0	0.0
17	8.00	140.	275.	260.	0.0	0.0	0.0	0.0
18	8.50	45.	220.	225.	1.8	3.6	0.0	0.0
19	8.55	40.	150.	170.	2.3	9.1	0.0	0.0
20	8.60	35.	150.	190.	107.8	211.1	0.0	0.0
21	8.64	35.	150.	200.	211.1	2582.	0.0	0.0

TESTID : DMF-014

UNITAF1 : SEAL-014

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	109.	136.	250.	197.	200.	70.	90.	86.
2	126.	138.	250.	205.	214.	70.	97.	94.
3	129.	139.	249.	200.	206.	75.	99.	96.
4	126.	140.	249.	195.	206.	71.	90.	87.
5	125.	141.	250.	196.	208.	69.	95.	91.
6	125.	143.	250.	202.	216.	66.	90.	87.
7	125.	145.	250.	208.	221.	66.	92.	90.
8	124.	209.	250.	210.	221.	65.	92.	88.
9	125.	210.	250.	209.	220.	65.	88.	84.
10	125.	208.	250.	208.	220.	66.	87.	84.
11	125.	207.	250.	207.	222.	66.	90.	88.
12	126.	206.	249.	206.	223.	68.	92.	88.
13	128.	207.	250.	213.	220.	69.	92.	90.
14	129.	207.	250.	205.	218.	68.	90.	88.
15	125.	205.	250.	204.	218.	67.	89.	85.
16	120.	220.	252.	205.	215.	70.	91.	88.
17	129.	204.	250.	200.	213.	70.	93.	91.
18	128.	210.	250.	205.	220.	70.	95.	94.
19	130.	215.	241.	206.	214.	72.	95.	92.
20	131.	227.	243.	209.	217.	70.	95.	92.
21	132.	230.	249.	214.	222.	70.	95.	92.

TESTID : DMT-015

DATAFI : SEAL.015

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	20.	150.	150.	0.0	0.0	0.0	0.0
2	0.33	55.	275.	245.	0.0	0.0	0.0	0.0
3	0.67	40.	250.	220.	0.0	0.0	0.0	0.0
4	0.77	35.	320.	250.	0.0	0.0	0.0	0.0
5	0.82	40.	265.	210.	0.0	0.0	0.0	0.0
6	0.92	65.	260.	235.	0.0	0.0	0.0	0.0
7	1.42	50.	290.	235.	0.0	0.0	0.0	0.0
8	1.92	55.	290.	215.	0.0	0.0	0.0	0.0
9	2.42	25.	300.	230.	0.0	0.0	0.0	0.0
10	2.92	35.	310.	250.	0.0	0.0	0.0	0.0
11	3.42	20.	315.	250.	0.0	0.0	0.0	0.0
12	3.92	25.	320.	250.	0.0	0.0	0.0	0.0
13	4.42	30.	315.	255.	1.1	2.3	0.0	0.0
14	4.72	30.	315.	270.	2.3	3.0	0.0	0.0
15	4.97	65.	325.	265.	1.1	4.5	0.0	0.0
16	5.22	5.	150.	235.	0.0	4.5	0.0	0.0
17	5.27	55.	295.	270.	45.4	900.0	0.0	0.0
18	5.30	55.	295.	265.	79.5	1135.	0.0	0.0
19	5.35	55.	280.	265.	136.2	1135.	0.0	0.0
20	5.38	55.	280.	270.	170.2	1399.	0.0	0.0
21	5.43	55.	280.	270.	223.6	900.0	0.0	0.0
22	5.47	60.	280.	270.	247.4	595.9	0.0	0.0

TESTID : DMT-015

DATAFI : SEAL.015

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	115.	228.	250.	200.	211.	72.	78.	75.
2	125.	215.	243.	200.	200.	72.	82.	78.
3	125.	216.	250.	196.	196.	72.	82.	78.
4	126.	220.	250.	196.	196.	74.	83.	79.
5	114.	225.	255.	198.	180.	71.	78.	75.
6	128.	218.	250.	188.	193.	67.	77.	75.
7	126.	215.	250.	190.	190.	67.	82.	78.
8	130.	216.	250.	190.	190.	66.	85.	81.
9	131.	216.	250.	192.	192.	67.	88.	84.
10	133.	216.	250.	192.	194.	68.	85.	81.
11	133.	216.	250.	192.	194.	68.	83.	79.
12	140.	218.	250.	192.	194.	68.	84.	80.
13	140.	219.	250.	193.	194.	68.	84.	80.
14	142.	220.	250.	194.	194.	68.	84.	80.
15	142.	214.	250.	195.	197.	70.	88.	85.
16	149.	213.	250.	193.	200.	68.	87.	83.
17	148.	228.	250.	195.	200.	69.	94.	92.
18	148.	226.	252.	196.	203.	70.	100.	95.
19	150.	225.	248.	199.	203.	70.	105.	100.
20	152.	227.	250.	202.	205.	69.	102.	98.
21	151.	229.	250.	202.	206.	69.	102.	98.
22	151.	229.	250.	203.	206.	69.	102.	98.

TESTID : DAF-016

DATAFILE : SEAL.016

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	135.	260.	250.	0.0	0.0	0.0	0.0
2	0.50	60.	225.	250.	0.0	0.0	0.0	0.0
3	1.00	240.	445.	260.	0.0	0.0	0.0	0.0
4	1.50	100.	310.	255.	0.0	0.0	0.0	0.0
5	2.00	120.	310.	285.	0.0	0.0	0.0	0.0
6	2.50	105.	280.	290.	0.0	0.0	0.0	0.0
7	3.00	135.	290.	285.	0.0	0.0	0.0	0.0
8	3.50	130.	295.	285.	0.0	0.0	0.0	0.0
9	4.00	155.	255.	280.	0.0	0.0	0.0	0.0
10	4.50	150.	235.	290.	0.0	0.0	0.0	0.0
11	5.00	180.	0.	285.	0.0	0.0	0.0	0.0
12	5.50	190.	0.	285.	0.0	0.0	0.0	0.0
13	6.00	150.	0.	275.	0.0	0.0	0.0	0.0
14	6.50	115.	0.	275.	0.0	0.0	0.0	0.0
15	7.00	125.	225.	280.	0.0	0.0	0.0	0.0
16	7.50	135.	220.	275.	0.0	0.0	0.0	0.0
17	8.00	140.	215.	270.	0.0	0.0	0.0	0.0
18	8.50	145.	215.	275.	0.0	0.0	0.0	0.0
19	9.00	105.	220.	280.	0.0	0.0	0.0	0.0
20	9.50	110.	225.	285.	0.0	0.0	0.0	0.0
21	10.00	100.	225.	285.	0.0	0.0	0.0	0.0
22	10.50	110.	230.	290.	0.0	0.0	0.0	0.0
23	11.00	135.	235.	290.	0.0	0.0	0.0	0.0
24	11.50	155.	230.	290.	0.0	0.0	0.0	0.0
25	12.00	100.	240.	285.	0.0	0.0	0.0	0.0
26	12.50	115.	250.	300.	0.0	0.0	0.0	0.0
27	13.00	0.	240.	295.	0.0	0.0	0.0	0.0
28	13.50	130.	245.	305.	0.0	0.0	0.0	0.0
29	14.00	90.	210.	290.	0.0	0.0	0.0	0.0
30	14.50	105.	330.	285.	0.0	0.0	0.0	0.0
31	15.00	110.	350.	170.	0.0	0.0	0.0	0.0
32	15.50	90.	350.	205.	0.0	0.0	0.0	0.0
33	16.00	100.	280.	355.	0.0	0.0	0.0	0.0
34	16.50	60.	240.	355.	0.0	0.0	0.0	0.0
35	17.00	40.	190.	355.	13.0	27.2	0.9	1.8
36	17.50	10.	200.	295.	20.8	114.4	3.9	5.9

TEST ID : DMF-016

DATA 1 : SEAL-016

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	105.	220.	310.	191.	204.	66.	81.	78.
2	125.	210.	251.	195.	212.	69.	84.	80.
3	130.	260.	428.	187.	214.	68.	87.	83.
4	137.	252.	305.	197.	218.	69.	88.	85.
5	132.	213.	281.	188.	209.	68.	88.	84.
6	124.	200.	260.	183.	210.	66.	88.	84.
7	123.	201.	269.	180.	206.	69.	93.	87.
8	124.	197.	263.	182.	208.	69.	92.	88.
9	120.	216.	288.	204.	215.	71.	96.	92.
10	124.	202.	272.	187.	209.	72.	95.	91.
11	132.	197.	260.	180.	206.	71.	98.	94.
12	132.	195.	261.	178.	205.	71.	100.	94.
13	135.	197.	267.	177.	202.	70.	98.	94.
14	131.	200.	266.	177.	200.	68.	93.	89.
15	125.	215.	283.	198.	210.	67.	84.	80.
16	113.	205.	272.	184.	205.	66.	87.	84.
17	111.	199.	271.	179.	201.	66.	87.	83.
18	109.	199.	274.	176.	197.	66.	88.	84.
19	109.	230.	298.	184.	214.	65.	85.	80.
20	117.	250.	315.	217.	234.	66.	86.	82.
21	120.	250.	314.	216.	233.	65.	84.	80.
22	126.	250.	314.	219.	235.	65.	84.	80.
23	128.	247.	318.	217.	234.	65.	85.	81.
24	126.	235.	314.	203.	221.	64.	84.	81.
25	129.	250.	307.	240.	254.	64.	71.	68.
26	108.	250.	304.	235.	251.	63.	75.	70.
27	110.	240.	304.	235.	251.	63.	74.	71.
28	112.	230.	290.	230.	250.	64.	75.	71.
29	113.	225.	290.	195.	216.	67.	68.	70.
30	182.	250.	325.	244.	218.	67.	75.	72.
31	125.	235.	293.	225.	210.	70.	79.	76.
32	125.	204.	292.	211.	202.	66.	79.	76.
33	104.	200.	260.	174.	213.	58.	72.	70.
34	102.	222.	248.	185.	227.	58.	74.	70.
35	120.	260.	240.	198.	246.	60.	93.	90.
36	137.	275.	250.	200.	237.	60.	108.	104.

TESTID : DMT-017

DATAFI : SEAL.017

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	10.	250.	215.	0.0	0.0	0.0	0.0
2	0.17	155.	275.	210.	0.0	0.0	0.0	0.0
3	0.33	215.	350.	210.	0.0	0.0	0.0	0.0
4	0.53	335.	490.	220.	0.0	0.0	0.0	0.0
5	0.77	370.	510.	255.	0.0	0.0	0.0	0.0
6	0.93	305.	425.	290.	0.0	0.0	0.0	0.0
7	1.12	315.	460.	295.	0.0	0.0	0.0	0.0
8	1.25	310.	475.	250.	0.0	0.0	0.0	0.0
9	1.58	155.	330.	250.	0.0	0.0	0.0	0.0
10	1.92	210.	375.	260.	0.0	0.0	0.0	0.0
11	2.25	195.	375.	260.	0.0	0.0	0.0	0.0
12	2.58	225.	425.	255.	0.0	0.0	0.0	0.0
13	2.92	140.	305.	255.	0.0	0.0	0.0	0.0
14	3.25	140.	295.	300.	0.0	0.0	0.0	0.0
15	3.58	130.	300.	255.	0.0	0.0	0.0	0.0
16	3.92	85.	300.	250.	0.0	0.0	0.0	0.0
17	4.18	100.	325.	255.	0.0	0.0	0.0	0.0
18	4.23	25.	250.	170.	0.0	0.0	0.0	0.0
19	4.28	40.	190.	180.	0.0	0.0	0.0	0.0
20	4.62	130.	260.	175.	0.0	0.0	0.0	0.0
21	4.95	85.	215.	170.	1.1	3.4	4.5	13.8
22	4.98	75.	200.	160.	1.1	0.0	45.4	1362.
23	5.02	70.	190.	145.	1.1	0.0	99.0	1362.
24	5.05	40.	150.	140.	3.4	75.7	138.5	1286.
25	5.38	40.	170.	215.	3.4	0.0	138.5	0.0
26	5.72	50.	180.	230.	3.4	0.0	138.5	0.0
27	6.05	185.	160.	430.	3.4	0.0	138.5	0.0
28	6.32	190.	160.	470.	3.4	0.0	138.5	0.0
29	6.43	185.	160.	430.	3.4	0.0	138.5	0.0
30	6.48	55.	160.	230.	3.4	0.0	179.3	817.2
31	6.57	35.	160.	200.	3.4	0.0	240.6	681.0
32	6.90	85.	165.	260.	3.4	0.0	244.0	10.3
33	7.23	90.	160.	265.	3.4	0.0	244.0	0.0
34	7.57	135.	165.	265.	3.4	0.0	244.0	0.0
35	7.90	135.	165.	275.	3.4	0.0	244.0	0.0
36	8.23	130.	165.	280.	3.4	0.0	244.0	0.0
37	8.57	130.	165.	285.	3.4	0.0	244.0	0.0
38	8.90	135.	165.	280.	3.4	0.0	244.0	0.0
39	9.02	130.	170.	280.	3.4	0.3	244.0	26.7
40	9.08	90.	175.	260.	63.6	1002.	244.0	0.0
41	9.12	90.	170.	265.	63.6	0.0	244.0	0.0
42	9.45	90.	180.	270.	63.6	0.0	244.0	0.0
43	9.72	120.	200.	270.	64.7	4.2	244.0	0.0
44	9.77	5.	255.	240.	64.7	0.0	244.0	4880.
45	9.80	15.	185.	230.	166.8	3405.	244.0	0.0
46	9.83	25.	195.	235.	225.9	1967.	244.0	0.0
47	9.88	0.	170.	230.	271.3	908.0	240.3	45.4

TESTID : DMT-017

DATAFI : SEAL.017

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	107.	270.	255.	293.	277.	76.	88.	83.
2	120.	228.	286.	250.	231.	68.	97.	94.
3	120.	214.	324.	228.	210.	67.	94.	91.
4	123.	248.	462.	250.	203.	66.	97.	93.
5	130.	297.	510.	288.	220.	66.	102.	98.
6	128.	243.	400.	260.	233.	105.	69.	67.
7	132.	268.	445.	275.	237.	108.	70.	67.
8	132.	268.	445.	268.	225.	108.	70.	67.
9	130.	232.	315.	230.	221.	110.	70.	68.
10	127.	237.	355.	229.	215.	103.	69.	67.
11	135.	255.	365.	240.	214.	105.	68.	65.
12	130.	270.	408.	250.	218.	102.	65.	64.
13	126.	243.	300.	231.	220.	100.	65.	62.
14	123.	220.	283.	213.	207.	98.	64.	62.
15	122.	212.	286.	208.	205.	100.	65.	62.
16	117.	208.	287.	208.	202.	90.	64.	60.
17	115.	210.	300.	208.	200.	87.	64.	60.
18	105.	232.	275.	245.	230.	78.	72.	67.
19	115.	235.	308.	242.	235.	92.	77.	72.
20	125.	237.	312.	223.	217.	68.	89.	65.
21	111.	230.	278.	210.	207.	68.	85.	82.
22	113.	227.	262.	208.	203.	67.	85.	81.
23	113.	227.	242.	200.	198.	67.	85.	81.
24	110.	234.	230.	197.	202.	65.	82.	78.
25	132.	263.	233.	283.	275.	67.	80.	77.
26	133.	275.	250.	305.	292.	67.	81.	78.
27	138.	266.	250.	342.	400.	67.	85.	83.
28	137.	247.	250.	356.	420.	67.	87.	85.
29	135.	245.	248.	346.	385.	67.	87.	83.
30	131.	260.	242.	330.	337.	67.	82.	78.
31	128.	282.	242.	325.	320.	66.	82.	78.
32	135.	275.	250.	307.	297.	65.	82.	78.
33	135.	267.	250.	304.	301.	65.	82.	78.
34	135.	276.	245.	315.	300.	70.	92.	88.
35	133.	271.	236.	305.	293.	69.	91.	87.
36	133.	283.	236.	315.	300.	68.	85.	82.
37	137.	285.	238.	318.	302.	68.	84.	81.
38	138.	287.	238.	320.	303.	68.	85.	81.
39	137.	287.	238.	320.	302.	68.	84.	81.
40	112.	277.	228.	296.	278.	65.	78.	75.
41	120.	278.	228.	296.	282.	64.	78.	76.
42	150.	281.	230.	310.	292.	63.	78.	76.
43	163.	290.	243.	312.	287.	62.	74.	72.
44	132.	256.	232.	267.	242.	78.	60.	58.
45	128.	262.	215.	268.	250.	73.	60.	58.
46	125.	265.	218.	272.	252.	72.	60.	58.
47	117.	267.	217.	278.	250.	65.	59.	57.

TESTID : DMT-018

DATAFI : SEAL.018

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	80.	230.	210.	0.0	0.0	0.0	0.0
2	0.50	100.	255.	300.	0.0	0.0	0.0	0.0
3	1.00	105.	330.	300.	0.5	0.9	0.0	0.0
4	1.05	125.	405.	290.	1.0	27.2	0.0	0.0
5	1.10	30.	160.	240.	95.3	1870.	0.9	18.2
6	1.15	30.	140.	245.	199.0	2088.	0.9	0.0

TESTID : DMT-018

DATAFI : SEAL.018

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	75.	258.	250.	273.	249.	60.	62.	78.
2	118.	265.	250.	279.	252.	60.	62.	78.
3	114.	245.	262.	255.	235.	61.	62.	80.
4	115.	243.	276.	248.	227.	61.	62.	80.
5	117.	253.	230.	245.	217.	60.	61.	77.
6	115.	268.	219.	252.	224.	58.	61.	75.

APPENDIX B

HEAT TRANSFER ANALYSIS

Heat generation in downhole motor seals is a major cause of seal failures. This problem is compounded by the high differential fluid pressures and the high rotary speeds. The seals in the Terra Tek Bearing-Seal Package are contained at the bottom of the assembly as shown in the cross sectional view in Figure B1. Heat generated by the seals is dissipated to the drilling mud circulating through the tool and in the wellbore annulus.

Figure B1
BEARING-SEAL PACKAGE

The motor seal in the Terra Tek Bearing-Seal Package operates against a rotating wear sleeve attached to the drive shaft as shown in Figure B2 .

Figure B2
BEARING SEAL ASSEMBLY

Seal wear is simulated in the Terra Tek Seal Tester shown in Figure B3. Thermocouples measure temperatures in the wear sleeves and in the housings, since they cannot be placed in direct contact with the sliding seal interfaces.

Maurer Engineering conducted a heat transfer analysis to calculate the seal temperatures at the sliding interfaces. This analysis showed that, although the measured temperatures in the sleeves and housings were only in the range of 250°F to 350°F (121°C to 177°C), temperatures in excess of 500°F (260°C) were present at the sliding interfaces (Figure B4). This is an important finding, since the Buna-N seal rings deteriorate rapidly at a temperature in excess of 350°F (177°C). This apparently explains why these seals have not been successful in downhole motors.

The coefficient of friction of the GRAFOIL^R seals is much lower than the Buna-N seals. The computer analysis (Figure B5) shows that the seal interface temperature decreases from 535°F to 308°F (279°C to 153°C) when the coefficient of friction is reduced by 50 percent (i.e., reducing the friction power loss from 2 horsepower to 1 horsepower). This calculation assumes that the thermal conductivity was not changed (0.1 BTU/hr-ft - °F).

The thermal conductivity of the GRAFOIL^R seals is 800 times greater than that for the Buna-N seals (80 vs 0.1 BTU/hr-ft - °F). This higher thermal conductivity allows heat to flow through the GRAFOIL^R seal and to the mud in the annulus, thereby reducing the seal interface temperature from 535°F to 420°F (279°C to 216°C) (Figure B6). This calculation assumes the same coefficient of friction (i.e. 2 horsepower frictional heat). With the GRAFOIL^R seals, the temperature gradient in the housing is steep, indicating that considerable heat is flowing through the housing to the mud in the wellbore. This steep gradient was observed in the first test of the GRAFOIL^R seals (i.e., 86 hour test).

These tests have indicated that the heat transfer analysis is accurate and that it is a useful tool for designing seals and for analyzing test results. Maurer Engineering is currently conducting a parametric study to determine the effect of different parameters on the seal interface temperature. Preliminary results indicate that seal temperatures in the Terra Tek Bearing-Seal Package tester can be significantly reduced by reducing the wall thickness of the drive shaft and by using heat sinks in the shaft or housing to help dissipate heat from the seal area. Some of these improvements will be adapted to the Bearing-Seal Package during Phase IV of the program. A more detailed description of the heat transfer model is presented in D.W. Dareing, "One Dimensional Heat Transfer Model of Rotary Seals in Downhole Motors", Terra Tek Technical Report No. TR 78-29, September, 1978.

Figure B3
CROSS SECTION OF TERRA TEK SEAL TESTER

Figure B4
COMPARISON OF CALCULATED AND MEASURED TEMPERATURES

Figure B5
TEMPERATURE PROFILES ACROSS SEAL TESTER
(UTEX STYLE 701 CHEVRON SEAL)

Figure B6
TEMPERATURE PROFILES ACROSS SEAL TESTER
(2 HORSEPOWER)

APPENDIX C

DOWNHOLE MOTOR REVIEW

Figure C1 shows the Dyna-Drill Moineau motor which is the most widely used drilling motor in the United States. This motor utilizes an eccentric rotor (C) in a rubber stator (B) to provide power to the bit. A flow constrictor (K_1) is used to limit mud leakage through the ball thrust bearing (L_1 and N_1).

Figure C1
Unsealed Dyna-Drill Moineau Motor

Christensen is currently marketing a similar Moineau motor called the Navi-Drill^R. This motor also uses flow constrictors (H and L) to limit mud leakage through the ball thrust bearings (I and J) as shown in Figure C2.

Figure C2
Christensen Unsealed Navi-Drill^R Moineau Motor

Baker is marketing a sealed Moineau motor which delivers higher torque than either the Dyna-Drill or Navi-Drill^R Moineau Motor. This motor contains a three-lobed rotor and a four-lobe stator as shown in Figure C3. This designs allows higher fluid displacement and higher power output.

Figure C3
Baker Sealed Moineau Motor

Dowell-Schlumberger has developed a 5/6-lobe sealed Moineau motor in which the bit is attached to the outer rotating housing (C) as shown in Figure C4. Ball bearings (G) operate in a sealed lubrication system.

Figure C4
Dowell-Schlumberger Sealed Moineau Motor

The Russians are currently using the 9/10 Moineau motor shown in Figure C5 in their oil field drilling operations. A flow constrictor allows drilling mud to leak through the ball thrust bearings (G).

Figure C5
Russian Unsealed Moineau Motor

NL Petroleum Services is currently developing the sealed Garrison vane motor shown in Figure C6. This motor utilizes a sealed speed reducer to reduce the rotary speed of the bit.

Figure C6
NL Petroleum Services Sealed Vane Motor

Christensen and Shell are jointly working on the development of the sliding vane motor shown in Figure C7. Excessive blade wear is currently a problem with this motor.

Figure C7
Christensen/Shell Vane Motor

The Russians are using sealed electrodrills, as shown in Figure C8 in their oil field drilling operations.

Figure C8
Russian Sealed Electrodrill

General Electric is developing the sealed electrodrill shown in Figure C9. This motor utilizes a planetary drive to reduce the bit rotary speed.

Figure C9
General Electric Sealed Electrodrill

The unsealed Neyrpic turbodrill shown in Figure C10 utilizes a labyrinth flow constrictor (B) to limit mud leakage from the turbodrill. The thrust bearings (E) in this tool are located above the turbine blades (D).

Figure C10
Neyrpic Unsealed Turbodrill

The unsealed Eastman turbodrill (Figure C11) utilizes a rubber marine bearing (A) to limit mud flow through rubber thrust bearings (B). Turboservice and Salzgitter turbodrills use similar rubber marine bearings as shown in Figures C12 and C13.

Figure C11
Eastman Unsealed Turbodrill

Figure C12
Turboservice Unsealed Turbodrill

Figure C13
Salzgitter Unsealed Turbodrill

Figure C14 shows a Russian turbodrill which utilizes rubber thrust bearings (G) at the top of the tool and a marine bearing (A) at the bottom.

Figure C14
Russian Unsealed Turbodrill

Figure C15 shows a Russian turbodrill which utilizes a flow constrictor (F) to limit mud leakage through ball thrust bearings (D).

Figure C15
Russian Unsealed Turbodrill

Maurer Engineering has developed a sealed turbodrill which utilizes a floating piston to maintain pressure on the sealed bearing assembly as shown in Figure C16. This turbodrill utilizes roller thrust bearings which have much higher load capacity than the ball and rubber bearings used in other motors. An unsealed version of this turbodrill is used for geothermal applications.

Figure C16
Maurer Engineering Sealed Turbodrill

Engineering Enterprises has developed a sealed turbodrill which utilizes ball thrust bearings as shown in Figure C17. This turbodrill has been successfully tested in several oil wells.

Figure C17
Engineering Enterprises Sealed Turbodrill

In France, ARTEP has developed a turbine reduction gear (Figure C18) for use on the Neyrpic turbodrills. This speed reducer which has a 3.16:1 reduction ratio is sealed so that the bearings and reduction gears operate in lubricant.

Figure C18
ARTEP Sealed Turbine Speed Reducer

Neyrpic patented a sealed bearing assembly which utilizes a labyrinth seal (A) as shown in Figure C19. This assembly has the advantage that there is no pressure drop across the seals (B and H) holding lubricant in the reservoir surrounding the bearings.

Figure C19
Neyrpic Sealed Bearing Assembly

When development is completed, the new Department of Energy sealed bearing assembly can be quickly adapted to all of these drilling motors. In many cases, adaptations will consist of only making a housing adapter sub and a turbine shaft adapter sub.

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