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ELECTRODRIL SYSTEM FIELD TEST PROGRAM
PHASE II TASK C
DEEP DRILLING SYSTEM DEMONSTRATION

FINAL REPORT

October, 1979

Work Performed for the Department of Energy
Under Contract EY-76-C-02-4033 A 006

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SPACE DIVISION
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ELECTRODRIL SYSTEM FIELD TEST PROGRAM

PHASE II TASK C

DEEP DRILLING SYSTEM DEMONSTRATION

ABSTRACT

This report documents the results of the Phase II, Task C, Electrodril Deep Drilling System drilling demonstrations. Task C, initiated in November 1978, followed the successful completion of the Systems Verification test program and consisted of two drilling demonstrations under operational conditions at two operational well sites. These two demonstrations were conducted in April & June, 1979.

The criteria established to guide selection of drilling sites for the demonstration is included. The test planning developed for each demonstration site is also included. Accomplishments are delineated as are the post test analyses from both drill sites.

The report concludes that, from a technical viewpoint, the fundamental concept of Electrodril remains valid. The post test analyses indicate that the system problems are limited to the connectors and are centered around their manufacturing process. Recommendations for changes in the connector process, inspection and acceptance test are provided. Finally, the testing required to qualify new connectors and demonstrate functional integrity is outlined.

1.0 SUMMARY

This report documents the results of the Phase II Task C drilling demonstration program which was conducted from November 1978 to July 1979.

This operational demonstration of the Deep Drilling System was the culmination of over two years of Department of Energy, industry, and General Electric effort. The demonstration program was structured to evaluate both the technical and economic viability of the Electrodril System. In planning the program, maximum advantage was taken of the lessons learned in conducting the Phase I program. Equipment design modifications, identified as desirable during the Phase I program, were incorporated into the Phase II system design. These modifications were aimed at making the drilling system a better operational tool by ruggedizing the design at the points where maximum wear or crew handling could be expected.

To assure that the actual drilling demonstrations were effective, site selection criteria (Appendix A) and site-specific detailed test plans (Appendix B) were developed. In addition, definitive measures of system effectiveness were established to form a baseline against which the Electrodril System performance could be judged and the ultimate technical and economic utility of the system could be evaluated. This data is also embodied in each site-specific test plan and is presented in the pertinent appendices of this report.

The first operational demonstration of the Electrodril Deep Drilling System was conducted on an Exxon well site near Beaumont, Texas. The Electrodril System was deployed on April 7, 1979, in a 9 7/8 inch hole at a depth of 6973 feet. The downhole motor and instrument assembly were connected to one 5000-foot cable,

one 1000-foot cable and eight 90-foot stands of prewired drill pipe. A series of surface equipment calibration runs were made by electrically energizing the downhole assemblies. No drilling was attempted at this time. After satisfactorily completing these calibration runs, the motor was re-energized to begin the drilling process. It was at this point that an electrical failure in the downhole system was identified and the demonstration was aborted on April 14, 1979. Appendix C documents the Site I Test Report.

The Electrodril System was returned to Houston and refurbished. The primary cause of the system failure at Beaumont was identified as a connector in the instrument harness assembly. The harness assembly was, consequently, refurbished and retested. The Electrodril System was subsequently made ready for a second demonstration, with preparations completed in Mid-May 1979.

The second demonstration of the Electrodril Deep Drilling System was conducted on a Shell well near McCook in South Texas. The Electrodril System was deployed on June 27, 1979 in a 9 7/8 inch hole at a depth of 5220 feet. The downhole motor and instrument assembly were connected to one 5000-foot cable. This drill string makeup had approximately 20 feet of the electrified kelly remaining to be drilled down. After initial system calibration, the kelly was drilled down without incident. During this time, all downhole data was transmitted and displayed at the surface in the data analysis trailer and the driller's display unit. The process of adding a 30-foot prewired joint to the drill string, however, was unsuccessful due to electrical problems.

The decision was made to drill ahead conventionally an additional 60 feet using the Electrodril motor and bit, to a point where a prewired 90-foot stand of pipe could be introduced. The 90-foot dedicated pipe was picked up, added to the string and checked electrically. Drilling continued until a short developed in the 90-foot stand. The shorted stand was replaced and the kelly was once again drilled down. An additional 60 feet was drilled by conventional means because of continuing electrical-mating problems with the reworked 30-foot dedicated joints. At this time it was determined that the resistance to ground below the top of the 5000-foot cable had degraded to the point where equipment damage could result if power were applied. The decision was made on July 1, 1979, to come out of the hole after approximately 60 feet of hole was made by electrical bit rotation.

The Electrodril System was returned to Houston July 4, 1979, and an intensive failure investigation was conducted. The results indicate that the primary cause for the system failure at McCook centered around the failure of the female field replaceable connector. The failures are primarily precipitated by water ingress into the core of the connector causing a high electrical leakage to ground. Not all of the female connectors tested had failed; those that passed the initial post test analysis were subjected to an additional series of mated and unmated pressure tests from which it was concluded that the fundamental design of the field replaceable connector is sound. The Site II Test Report is contained in Appendix D.

A secondary problem was found when the motor and bit shaft were disassembled. An upper seal insert and a lower seal O-ring had failed. A fix has since

been made to prevent recurrence but it is not covered in this report. The problem is discussed more fully in Appendix D.

The connector failures experienced at McCook have been attributed to process problems in manufacturing. The manufacturer is now aware of the problem and a new series of connectors is being made for evaluation during the first quarter of calendar year 1980 under Phase II, Task C-1.

2.0 INTRODUCTION

Electrodril is an advanced drilling system incorporating a downhole electric drill motor and a downhole sensor and telemetry system. The downhole motor provides high horsepower and torque at the bit face in combination with high rotational speed and the ability to vary this speed as required between 40 and 400 rpm. The sensor and telemetry system provides real time (MWD) surface readout of downhole parameters. Sixteen channels of data are updated twice per second.

The Phase II Electrodril Deep Drilling Demonstration program has been executed in three distinct tasks. The initial Phase II Task A effort, begun in July 1977, encompassed the engineering, design and preprocurement documentation activity required for the procurement of long-lead-time equipment. Task B included final design reviews of key system elements, the completion of all engineering documentation and release for fabrication. This procurement process was begun in April 1978. In addition, Task B included the assembly and subsystem testing of the Deep Drilling System and concluded with system verification testing of the total system at the Brown Oil Tools test facility, Houston, Texas. This Task B effort was successfully concluded in September 1978.

This report covers the Phase II Task C effort which followed the successful completion of the systems verification test of the Deep Drilling System and consisted of two drilling system demonstrations under operational conditions at two separate well sites. These two drilling demonstrations were concluded in the first and second calendar quarters of 1979.

	1976				1977				1978				1979			
<u>PHASE I</u>																
KEY ELEMENT DEMONSTRATED																
<u>INTERIM PHASE II</u>																
FIELD REPLACEABLE CONNECTORS ADDED																
<u>PHASE II</u>																
TASK A EFFORT - THE DESIGN OF THE DEEP DRILLING SYSTEM.																
TASK B EFFORT - THE PROCUREMENT & SYSTEM VERIFICATION TEST																
TASK C EFFORT - THE SYSTEM DEMO AT TWO OPERATIONAL WELL SITES																

TABLE 1
SUMMARY PROGRAM SCHEDULE

3.0 PROGRAM OBJECTIVES

The objectives of the Phase II Deep Drilling System demonstration program have long been established:

- ° Electrodril System Operational Performance. Establish the integrity of system's functional performance in terms of the capability of all subsystems to sustain drilling operations within the constraints of expected subsystem life and maintenance requirements.
- ° Electrodril System Economic Performance. Determine the economic viability of the system as a function of the operating performance characteristics derived from the planned deep drilling demonstrations.

Task C objectives can be summarized as follows:

- ° The development of the detailed planning, procedures, and measures of system effectiveness necessary to optimize the conduct of the operational demonstration of the Deep Drilling System.
- ° The implementation of the Deep Drilling System demonstration program at three operational drilling sites. The three-site demonstration was cut back to two sites in December 1978 due to funding limitations.

Specific objectives of the Task C effort are detailed below:

TEST PLANNING

1. Develop a set of drill site selection criteria to assure that Field Test demonstrations are each conducted in formations having known characteristics

so that performance measurements are consistently obtained and meaningful.

2. Develop a uniform set of measures of effectiveness so that the system and operational test data derived will provide a valid and consistent yardstick against which system performance can be evaluated.
3. Develop a test plan for each operational test site.

FIELD TEST DEMONSTRATION

1. Demonstrate the capability of the 285-HP Electrodrill System using variable frequency power and its associated power cable deployment and retrieval system in deep, tough formations.
2. Demonstrate the capability of the 285-HP Electrodrill System, with its instrumentation and telemetry system to drill effectively in tough formations.

4.0 PROGRAM PLANNING

In preparation for the two-site drilling demonstration, a series of planning documents was developed. These documents were developed to facilitate the objective selection of the drill sites and the orderly conduction of the Electrodril System evaluation.

The first document, presented in Appendix A, was one in which drill site selection criteria were developed. These criteria were not site-specific but identified preferred site characteristics. Three general well site areas were identified, representing an increasing order of drilling difficulty. The preferred hole dimensions for each well site were identified, as were the operational deployment depths best suited to an Electrodril demonstration, commensurate with well safety.

A generic test plan was then developed which restated the demonstration objectives and delineated the preferred cadence of system deployment. From this skeletal document, site specific test plans were written for each of the two finally selected drilling sites. These documents are presented in pertinent appendices of this report.

Measures of system effectiveness were also developed to assure that the information obtained during each Electrodril demonstration would permit meaningful performance evaluation of the system. These measures of system effectiveness were grouped into three categories: Economic, Functional and Safety. This data is also embodied in each site-specific test plan and is presented in the pertinent appendices of this report.

5.0 BASELINE SYSTEM DESCRIPTION

A schematic of the Deep Drilling System is shown in Figure 1. The System is composed of both downhole and surface components. The downhole components consist of an electric drill motor and its mechanical assemblies; cable and connectors; and the instrumentation assembly. The surface components consist of cable skids; power generation equipment; cable handling equipment; power control equipment; and the telemetry, instrumentation, surface processing, display and control unit.

These system components have been structured to permit their addition in modular fashion to standard rotary drilling rigs depending upon the objectives of the operator of the rig and the configuration of the equipment at the well site. The installation and operating procedures for Electrodril have been designed to be compatible with existing rigs and conventional drilling operations.

A detailed description of the Deep Drilling System can be found in the U.S. Department of Energy document BETC-4033-3.

FIGURE 1
DEEP DRILLING SYSTEM
SCHEMATIC

6.0 SYSTEM DEPLOYMENT METHOD

Two basic activities are necessary to receive the Electrodril at a rig site -- the deployment of the ground support equipment in the vicinity of the rig and the assembly in the rig of some key Electrodril elements. These two basic activities can be done independently.

A general layout of the surface elements of Electrodril is shown in Figure 22. Typically, this ground support equipment is deployed more than 100 feet away from the rig. There is the need, however, to accommodate 1000 feet of "dedicated" drill pipe on the pipe rack. In addition, an electric power cable is run from the Electrodril power generating equipment to the base of the rig, up a derrick leg and along the standpipe and mud hose to the rig swivel. This cable will eventually be mated to the slip ring assembly which will be located above the kelly (Figure 23).

There are two primary assembly tasks to be accomplished in the rig before Electrodril is deployed:

1. Eleven 90-foot stands of drill pipe must be assembled and electrified with standard Electrodril cable and connectors. One stand serves as a spare, in the event it is needed.

FIGURE 2
SURFACE ELEMENTS
DEEP DRILLING SYSTEM

FIGURE 3
Showing Routing of Electrodrill
Power Cable

2. The kelly must likewise be electrified with standard cable and connectors, and the slip ring assembly must be installed between the kelly and swivel.

Assembly of the eleven 90-foot stands of dedicated (prewired) drill pipe is accomplished using the 1000 feet of drill pipe delivered with the Electrodrill equipment. The use of this drill pipe is necessitated only because the length of each joint has been carefully measured and the mating cable lengths have been cut and terminated to suit a particular three-joint combination. This 1000 feet of pipe is run in the hole as part of the conventional string during normal drilling operations. As the drill string is pulled out, 90-foot stands of the Electrodrill pipe are isolated prior to deployment of the Electrodrill system and electrified by suspending the mating cable/connector lengths and securing them into each stand. Each completed prewired stand is then stood back in the rack.

The electrification of the kelly is accomplished by threading an electrical cable through the kelly bore. The upper end of the cable is brought out of the bore by a special crossover sub and terminated at a connector. The slip ring assembly is mounted on this crossover sub and electrical connections made between the connector and slip ring. The top of the slip ring is mated with the electrical cable that runs up the derrick and along the mud hose.

To minimize the time consumed in these assembly activities, the preferred cadence is to separate and "setback" the 11 dedicated (prewired) stands, then to electrify the kelly, set it in the rat hole and finally pick up the motor subsystem and leave it in the slips ready to be run in the hole.

After completion of the previously described preparations, Electrodril is ready for downhole deployment. If the "in rig" preparations are done in the recommended sequence, the motor subsystem will be in the slips and ready to go down hole.

The instrumentation subsystem is first mounted to the top of the motor and the combined Electrodril downhole assembly is lowered until the top of the non-magnetic collar is in the slips. An electrical check is made at this time to assure the system is in functional order. Upon successful completion of these electrical checks, approximately 5000 feet of rig drill pipe is run in the hole on top of two special collars and the motor/instrumentation assembly. During this process an accurate pipe tally must be kept, as the length of drill pipe run in the hole must match that of the cable which is to be installed in it. The Electrodril system inventory provides sufficient pup joints of various lengths to facilitate matching drill string and cable lengths. At the completion of the length-matching task, a special landing sub is installed on the drill pipe to facilitate the suspension of the power cable.

The rig floor and traveling sheaves (Figures 24 and 25) are then installed, in a similar manner to that used for conventional wireline logging operations. In addition, a prewired sinker bar with a female connector attached is set in the drill pipe in special slips (Figure 26), and the Electrodril power cable is brought over from the cable skid and mated to it (Figure 27). The power cable is routed under the rig floor sheave and over the traveling sheave similar to conventional wireline logging procedures.

Figure 4
ELECTRODRIL RIG FLOOR SHEAVE

Figure 5
ELECTRODRIL TRAVELING SHEAVE

Figure 6

SINKER BAR IN SPECIAL SLIPS
SUSPENDED IN DRILL PIPE

Figure 7

CABLE ADAPTOR BEING PREPARED
FOR SINKER BAR

With the power cable and sinker bar mated, the assembly is run into the hole. Cable deployment can be accomplished at up to approximately 400 feet per minute although towards the end of the cable run-in procedure, care must be exercised by utilizing a fairly slow cable speed to provide greater control. At the point where the cable is about to be run off the cable reel (Figure 28), the reel is stopped so that the cable end can be removed from its reel attachment. The cable is secured in the drill pipe using special cable slips (Figure 29). These cable slips allow the cable end to be slackened off, removed from the reel and attached to a wire rope. The wire rope, which is mounted on a stinger winch, controls the final deployment of the cable over the sheaves into the landing sub. At this point the downhole male connector is mated with the female connector at the end of the cable length being deployed. Just prior to seating the cable, the slips are used to permit the attachment of the cable landing shoe and male connector (Figure 30).

This cable deployment process is repeated, depending on depth, until the bit is on bottom and a cable/connector string connecting the Electrodril downhole assembly (motor assembly and instrumentation subsystem) is at the rig floor level. Electrodril power cable is provided in lengths of 5000 feet and 1000 feet and shorter lengths are available by using prewired 90-foot stands and 30-foot joints. Once the system is fully deployed and checked electrically, the prewired kelly (Figures 31 and 32) is attached, and the downhole motor is turned on using the driller's console (Figure 33).

After the kelly has been drilled down, a conventional mousehole connection is made first with one and then with the second of the prewired Electrodril 30 foot

Figure 8

ELECTRODRIL POWER CABLE SKID
CAPACITY - 19000 FEET

Figure 9
ELECTRODRIL CABLE SLIPS

Figure 10
UPPER END OF POWER CABLE SHOWING
LANDING SHOE

Figure 11
CABLE CROSSOVER ABOVE KELLY

Figure 12
SLIP RING ASSEMBLY INSTALLED
ABOVE CABLE CROSSOVER

Figure 13
ELECTRODRIL DRILLERS CONSOLE

joints and drilling is continued. When 90 feet has been drilled with the kelly and two prewired 30-foot joints, the kelly is set in the rat hole and two prewired 30-foot joints are laid down and replaced by one of the prewired 90-foot stands. The kelly is then picked up and drilling is continued. When 1000 feet has been drilled, all ten 90-foot lengths of prewired pipe and the two prewired 30-foot lengths are set back from the hole and 1000 feet of conventional drill pipe is run into the hole. A landing sub and pup joints are used to make the pipe tally fit the length of cable to be deployed. A 1000 foot length of Electrodrill cable is then deployed in a similar manner to that previously described. Drilling again proceeds, using the kelly, the two prewired joints and the prewired 90 foot stands until another 1000 feet has been made. When 5000 feet of hole has been drilled, four 1000 foot cables, ten 90-foot stands and two 30-foot prewired joints will have been deployed. These are all removed in sections, and rig drill pipe is run back in. A 5000-foot length of Electrodrill cable is then deployed, landed and checked electrically. Drilling then continues as before. It should be noted that, to minimize time, bit trips will be used as much as possible to facilitate these pipe manipulations. At any time the 1000-foot and 5000-foot lengths of cable can be removed from the pipe with a wireline fishing tool. To accommodate this requirement, the 90-foot stands of prewired pipe are run in the hole on top of a safety joint.

7.0 SITE I RESULTS SUMMARY

The first Task C drilling demonstration site was the Exxon I.C.H. Matthews Well Number 1 located near Beaumont, Texas. Transportation of the Electrodril Deep Drilling System to this Beaumont site began on April 4, 1979. General views of the rig site are shown in Figures 34 through 38. Initial plans called for the deployment of Electrodril at a depth of 5876 feet after 2000 feet of surface casing had been set. Bit size to be used with Electrodril was 9 7/8 inches.

Surface deployment of Electrodril was completed April 7. The downhole assembly was then tested electrically on the surface. During this surface checkout of the system, a problem was diagnosed in the voltage control unit, which necessitated return of the instrument sub to Houston for repair. While this repair was being made, Exxon continued rotary drilling.

Electrodril was subsequently deployed at 6973 feet with 6000 feet of cable (one 5000-foot and one 1000-foot length) and eight 90-foot stands of prewired drill pipe to hole bottom. This drill string with the Electrodril downhole system was checked electrically and found to be operationally ready. The motor was started and shut down five times to calibrate the motor control servo loop. At the time the drilling demonstration was to begin, the motor failed to start. An electrical short was isolated to the downhole assembly below the armored cable. Consequently, the Electrodril demonstration was discontinued.

The electrical short was located in the lower instrument sub power connector (Figures 39 and 40). The failure was in the connector harness rather

Figure 14

Figure 15

Figure 16

GENERAL VIEWS OF BEAUMONT TEST SITE

Figure 17

ELECTRODRIL MOTOR AND INSTRUMENT ASSEMBLIES
AT BEAUMONT TEST SITE

Figure 18

ELECTRODRIL CABLE SKID WITH 19,000 FEET OF CABLE
AT BEAUMONT TEST SITE

Figure 19

LOWER INSTRUMENT SUB POWER CONNECTOR ASSEMBLY

Figure 20

POWER CONNECTOR

than in the field replaceable connector proper. The probable cause of this connector failure is centered around a mechanical interference in the multi-pin mating connector adaptors, which impaired complete makeup of the connector. A more complete failure analysis is presented in Appendix D.

Despite this connector failure and the resulting shutdown of the demonstration, a number of significant accomplishments were achieved:

- ° The cable reel skid was successfully used for the first time to deploy and retrieve a 5000-foot cable.
- ° The actual deployment of a 5000-foot cable was also a first, proving the cable armoring capability and the stinger winch's ability to retrieve the cable.
- ° In addition, the rig floor system (i.e., both sheaves and the method of control) was successfully exercised for the first time using the 5000-foot cables.
- ° Although the motor voltage servo control loop had been extensively exercised, the full capability of the loop and its transient response characteristics could not be fully evaluated except in a full downhole deployment. The five successful motor starts at 7000 feet depth before connector failure represent a major technical accomplishment. In addition, the ability of the servo loop to shut itself down immediately after cable failure attests to the correct design of the automatic shutdown circuit in the static inverter.

The final downhole configuration included:

- one - 5000-foot cable
- one - 1000-foot cable
- eight - 90-foot stands
- one - 45-foot electrified kelly

This configuration represents a total of 12 "Bayonet" cable connectors plus those in the instrument assembly and motor. At the time of cable deployment, before connector failure, there was resistance to ground of approximately five megohms or better on each leg of the power conductors. This was a remarkable achievement and proves the soundness of the basic connector design.

The experience gained during the deployment process indicated very strongly that in a fully operational situation, Electrodril deployment can be accomplished within a reasonable time frame and without excessive cost consequences.

8.0 SITE II RESULTS SUMMARY

The second Task C Drilling Demonstration site was the Shell Martinez Well Number 4 in the La Copita Field, Starr County, Texas. Transportation of the Electrodril Deep Drilling System to this well site began on June 25, 1979. General views of the rig site are shown in Figures 41 through 43. Plans were to deploy Electrodril at the 5180 foot depth after surface casing had been set. Bit size to be used by the Electrodril was 9 7/8 inches with three 11/32-inch diameter jets.

Surface deployment of the Electrodril was completed June 27, and a surface test of the downhole assembly was successfully concluded June 28. The voltage control servo loop was also successfully exercised at this time using the static inverter, the downhole sensing unit and 5000 feet of cable.

Electrodril was deployed downhole on June 29 at a depth of 5220 feet. Initial makeup of the drill string was the bottom hole assembly comprising the motor and instrument assemblies, 17 drill collars (including two Electrodril collars), and sufficient drill pipe to land 5000 feet of cable. The electrified kelly was made up on this assembly and drilling commenced at 12:30 a.m. The remainder of the kelly was drilled down (21 feet) with the motor running at 60 rpm and with 8000 lbs. weight on bit. During this process, all aspects of the downhole instrumentation subsystem functioned properly. Samples of the real time data received, displayed and recorded in the instrumentation trailer are shown in Table 2 and Figure 44.

Figure 21

Figure 22

GENERAL VIEWS OF RIG AT MC COOK SITE

Figure 23

ELECTRODRIL MOTOR AND INSTRUMENT ASSEMBLIES
ON PIPE RACK WITH SINKER BAR BELOW

COMPANY: GE

FIELD: LACOPITO

LEASE: MARTINEZI

WELL NO: HARKINS#1TY: STARR

STATE: TX

DATE: 07/01/79

TIME HR:MM	DEPTH FEET	PEN F/H	DRET DEG	AZMTH DEG	TFACE DEG	MTR UGF	INS UGF	ANN UGF	MTR AMP	DPRS PSI	SURF PSI	VOL GPM	GMMA CNT	HANGWT POUNDS	SPD RPM
00:32	05203.3	000	00.3	219.0	000.0	151	131	147	000	1417	1862	465	0043	000000	000
00:32	05203.3	000	00.0	339.0	000.0	152	130	147	000	1409	1858	465	0042	000000	000
00:32	05203.3	000	00.4	230.6	000.0	152	130	147	000	1259	1633	370	0042	000000	000
00:32	05203.3	000	00.3	073.3	000.0	152	130	147	001	1418	1953	412	0044	000000	000
00:33	05203.3	000	00.9	034.6	331.7	152	130	147	000	1413	1955	423	0043	000000	000
00:33	05203.3	000	00.3	309.5	000.0	152	130	147	001	1418	1841	402	0041	000000	000
00:33	05203.3	000	00.3	303.9	000.0	152	130	147	022	1423	1849	402	0047	000000	000
00:33	05203.3	000	00.7	306.9	000.0	152	131	147	021	1417	1840	455	0045	000000	000
00:34	05203.3	000	01.6	263.4	234.5	151	131	147	021	1407	1836	455	0047	000000	000
00:34	05203.3	000	00.5	104.0	000.0	151	130	147	000	1418	1324	412	0047	000000	000
00:34	05203.3	000	01.0	354.2	349.4	151	130	147	000	1428	1841	423	0048	000000	000
00:34	05203.3	000	00.5	360.0	000.0	151	130	147	000	1423	1818	423	0048	000000	000
00:35	05203.3	000	00.5	124.3	000.0	151	130	147	000	1423	1825	391	0043	000000	000
00:35	05203.3	000	00.4	109.4	000.0	151	130	147	000	1423	1831	370	0043	000000	000
00:35	05203.3	000	01.6	295.2	053.1	151	130	147	000	1428	1814	370	0044	000000	000
00:35	05203.3	000	00.3	360.0	000.0	151	130	147	000	1423	1824	423	0044	000000	000
00:36	05203.3	000	00.2	130.0	000.0	151	131	147	000	1445	1823	412	0043	000000	000
00:36	05203.3	000	01.0	176.2	301.6	150	130	147	000	1423	1816	370	0040	000000	000
00:36	05203.3	000	00.3	360.0	000.0	151	131	147	000	1445	1814	349	0042	000000	000
00:36	05203.3	000	01.0	162.9	142.4	150	130	147	000	1423	1807	402	0046	000000	000
00:37	05203.3	000	00.1	231.3	000.0	150	130	147	000	1437	1812	391	0047	000000	000
00:37	05203.3	000	00.7	102.1	000.0	151	131	147	000	1445	1815	402	0046	000000	000
00:37	05203.3	000	00.3	031.2	000.0	150	130	147	000	1423	1801	391	0046	000000	000
00:37	05203.3	000	00.3	169.3	113.3	150	130	147	000	1447	1797	402	0050	000000	000
00:38	05203.3	000	00.7	273.0	000.0	150	130	147	000	1437	1805	423	0043	000000	000
00:38	05203.3	000	00.4	076.7	000.0	150	131	147	000	1445	1797	434	0044	000000	000
00:38	05203.3	000	00.4	041.3	000.0	150	130	147	000	1437	1779	434	0042	000000	000
00:38	05203.3	000	00.6	237.0	000.0	150	130	147	000	1437	1796	455	0044	000000	000
00:39	05203.3	000	00.0	196.0	000.0	150	130	147	000	1437	1775	465	0046	000000	000
00:39	05203.3	000	00.3	017.1	000.0	150	130	147	000	1437	1738	423	0045	000000	000
00:39	05203.3	000	00.4	360.0	000.0	150	130	147	000	1447	1805	381	0043	000000	000
00:39	05203.3	000	00.6	125.5	000.0	150	130	147	000	1447	1813	370	0045	000000	000
00:40	05203.3	000	00.3	076.3	000.0	150	130	146	000	1456	1908	391	0041	000000	000
00:40	05203.3	000	00.4	032.3	000.0	150	130	146	000	1456	1926	370	0041	000000	000
00:40	05203.3	000	00.3	229.1	000.0	150	130	146	000	1456	1924	444	0045	000000	000
00:40	05203.3	000	00.4	130.0	000.0	150	130	146	000	1456	1818	455	0045	000000	000
00:41	05203.3	000	00.3	360.0	000.0	150	130	146	000	1456	1814	402	0045	000000	000
00:41	05203.3	000	00.7	304.4	000.0	150	130	146	000	1447	1816	391	0044	000000	000
00:41	05203.3	000	00.1	102.6	000.0	150	130	146	000	1447	1815	370	0044	000000	000
00:41	05203.3	000	00.0	073.1	000.0	150	130	146	000	1447	1809	370	0046	000000	000
00:42	05203.3	000	00.3	276.3	000.0	149	130	147	000	1454	1809	402	0046	000000	000
00:42	05203.3	000	00.4	220.9	000.0	149	130	146	000	1447	1304	434	0044	000000	000
00:42	05203.3	000	00.2	032.5	000.0	149	130	146	000	1437	1813	436	0044	000000	000
00:42	05203.3	000	00.9	360.0	000.0	149	130	146	000	1437	1304	402	0041	000000	000

TABLE 2

SILENT 700 PRINTOUT OF McCOOK DATA

FIGURE 24

EXAMPLES OF MCCOOK BRUSH RECORDER DATA

Upon completion of drilling down the kelly, the use of a prewired 30 foot joint of drill pipe was required to drill ahead as detailed in Section 6 of this report. The first 30-foot prewired joint of pipe was made up and an electrical problem in the connectors of this prewired pipe was encountered. Three 30-foot prewired joints were subsequently rejected (one being damaged by the rig hands). At this point, it was decided to conventionally drill an additional 60 feet. This would permit drilling with Electrodril to continue by using a 90 foot prewired stand of pipe and the electrified kelly.

The process of drilling ahead 60 feet utilizing the Electrodril string and rotary power was successfully completed and a 90-foot stand of prewired pipe was added and a part of the kelly was drilled down using Electrodril when a short developed. The short was traced to the 90-foot stand which was then replaced. The Electrodril System was again used to complete the drill down of the kelly. Real time data from the downhole instrumentation subsystem was again received, displayed and recorded in the instrument trailer.

During this drilling ahead period, the connectors on the prewired 30 foot joints were replaced and made ready for reuse. However, none of these reworked prewired joints were successfully mated electrically in the drill string. The decision was subsequently made to again drill ahead 60 feet using conventional rotary power and the Electrodril. This process was accomplished without incident.

A second 90-foot stand of prewired pipe was then added to the string. This process was not successful, however, due to indications of electrical leakage

to ground. A replacement 90 foot prewired stand was also unsuccessfully introduced and after a third unsuccessful attempt to obtain electrical continuity, the Electrodril demonstration was discontinued. Although a major cause for this decision was the inability to make up the 90-foot prewired stands, the primary cause was the identification of increasing electrical leakage ($<500K \Omega$ to ground) in the downhole electrical string. This electrical leakage represented an equipment failure potential and was located somewhere in the 5000-foot cable string or in the Electrodril downhole assembly. Subsequent analyses indicate that the female connectors downhole were the probable cause of this failure. A more detailed failure analysis is presented in Appendix D.

Despite the power cable/connector failures and the resulting demonstration shutdown, a number of significant accomplishments were achieved.

- ° The motor voltage feedback loop successfully controlled the motor voltage during some 20 motor stops and starts, under varying loads and frequencies.
- ° The operation of the motor while drilling ahead approximately 60 feet at rates up to 120 feet per hour was a major accomplishment.
- ° All channels of the instrumentation system functioned before, during, and after drilling with Electrodril. Real time downhole position data, gamma log data, mud temperature inside and outside the drill string, motor temperature, differential mud pressure (inside drill pipe pressure minus annulus pressure), vibration spectrum, motor voltage and instrument voltage were received and recorded on the surface. In addition, several surface parameters were monitored, processed and recorded. Included was depth, penetration rate, mud flow rate, mud pressure, motor current, and motor voltage.

- ° Demonstrated the ability of the Electrodril motor assembly to compensate for Electrodril System failures by drilling ahead while rotating the drill string conventionally. A total of 160 feet was drilled in this manner.
- ° Downhole pressure zones indicated pressure drop across bit nozzles was close to surface test reading. While pulling up to make connection, pressure reading decreased showing suction effect of bit.
- ° Downhole temperature readings showed effect of circulating mud on motor temperature.
- ° The static inverter allowed the driller to control the bit speed. The motor was run at 60 rpm, 120 rpm and 200 rpm.

The failure to successfully complete this drilling demonstration was particularly disappointing as the probable cause still appears to be centered around the malfunctioning of the connectors. Knowing that the connector assemblies are key to the functional success of the Electrodril concept, much testing had been conducted to assure their functional compatibility. It is apparent that more work is needed in this area before additional system demonstrations are attempted.

9.0 CONCLUSIONS

An objective review of both Electrodril demonstrations leads to the conclusion that accomplishments made at the well sites fall far short of program expectations. The fact that very little footage was actually drilled sharply limits the ability to form judgements regarding the economic viability of the system.

Electrodril was, however, deployed at two operational drilling sites and successfully retrieved. At no time was there any hint of an unsafe situation. Any apprehension exhibited by rig crews and their supervisory staff regarding the power levels being used was quickly allayed. The fact that the system was demonstrated to be compatible with a conventional drilling operation (rig and crews) validates one of the most important design goals and is of great significance.

From a technical viewpoint, the fundamental concept of Electrodril remains valid. The method of cable deployment through the use of multiple length cable assemblies also appears technically viable, given that the connector problems can be resolved. The post-test analyses from both drill sites indicates that the problems are limited to the connectors and are centered around their manufacturing process. No basic connector design flaw has been identified. The selection of a parallel connector mating member, in lieu of the tapered design evaluated in 1976, appears to be valid for the 30-foot and 90-foot prewired cable assemblies. This technical approach is particularly important in supporting the drive to minimize the number of "special" subsystem designs.

The Electrodril "measurement-while-drilling" system has worked extremely well throughout the demonstration program. The motor voltage control loop with the surface static inverter, after initial calibration, has worked steadily and without problems. The bit shaft and motor assembly has functioned well. The gearbox and lube compensation system has performed extremely well, although the bit shaft seals need adjustment to reduce the leakage. A summary of the system development status is shown in Table 3.

The need now exists to implement the necessary manufacturing process changes for the connectors. A limited number of "new" connectors should then be manufactured and exhaustively tested to demonstrate the functional readiness of these connectors to be once again deployed in an operational well to support the evaluation of Electrodril's economic viability.

TABLE 3

DEVELOPMENT STATUS OF SYSTEM

POWER GENERATION	OPERATIONAL
REELS AND DRIVES	OPERATIONAL
CABLE & CONNECTORS	CABLES OPERATIONAL CONNECTOR PROBLEMS UNDER INVESTIGATION
INSTRUMENTATION	OPERATIONAL
MOTOR	OPERATIONAL
BIT SHAFT	SEAL PROBLEMS - REQUIRE ADJUSTMENT
INTEGRATED SYSTEM OPERATION	COMPATIBILITY WITH RIG AND CREW DEMONSTRATED

ELECTRODRIL
DEEP DRILLING SYSTEM

FIELD TEST PROGRAM
PHASE II TASK C

SITE SELECTION CRITERIA

GENERAL ELECTRIC

Thermal Systems

Houston Texas

INTRODUCTION

This report documents the site selection criteria used to identify drill site areas in support of the Phase II, Task C Electrodril demonstration program. The drilling demonstration program is designed to qualify the Electrodril Deep Drilling System for use by the oil industry in deep tough drilling conditions. This demonstration/qualification program has two major thrusts:

- ° Demonstrate the operational capability of the Electrodril Deep Drilling System by drilling below 10,000 feet in at least two operational wells.
- ° Demonstrate the economic viability of the Deep Drilling System through analysis of operational data and comparison of results obtained during demonstration drilling operations with established economic models.

The specific objectives of the demonstration program are:

1. Demonstrate the capability of the 285-HP Electrodril System, with its associated power cable deployment and retrieval system, in tough formations deeper than 10,000 ft. Penetration rates and drill bit life are expected to exceed current rotary system performances by virtue of the Electrodril System's ability to provide high torques at the bit with a variable speed range from 40 to 400 rpm.

2. Demonstrate the capability of the 285-HP Electrodril System, with its downhole sensor and telemetry system, to drill in tough formations while transmitting to the surface downhole data on borehole environment and drill bit parameters.
3. Demonstrate the capability of the 285 HP-Electrodril System with its downhole sensor and telemetry system and a remotely controllable deviation sub, to drill effectively in tough formations and compensate for crooked hole situations.

Initial testing of the Phase II Electrodril System was accomplished in a test well at Brown Oil Tools during October 1978. Tests were conducted to insure that system elements were functionally compatible and to identify and resolve any field deployment problem areas prior to operational field deployment.

Selection Criteria

The successful completion of the Systems Verification of Electrodril in a test well has proven that the system is compatible as a modular add-on and operational with conventional drilling rigs. This unique drilling method is now ready to be moved from the test well environment to actual field applications where demonstration drilling is planned for three areas selected to provide successively more challenging conditions.

The well site for the initial operational demonstration will be selected to meet the following criteria:

- o Be near the Houston Electrodrill base, to ease logistics and support considerations.
- o In a proven field where correlation, with previously drilled wells, is available.
- o In medium hard, ductile formations, which would, with conventional rotary drilling, reduce the penetration rate significantly. Formations where gas-cut mud and lost circulation allow tests of the downhole sensors without unduly exposing the drilling operation to hazardous conditions.
- o On a land-based drilling rig with a well-trained crew.
- o Drilling parameters:
 - Hole size - $9\frac{1}{2}$ " to $12\frac{1}{4}$ ".
 - Hole depth - starting below 6,000' drilling to 8,000' or more.
 - Hole drift not to be more than 3° .
 - Hole temperature not to exceed 250°F .

The field test program will be initiated at a well drilling site in the middle Gulf Coast region, the Victoria-Bay City area, where wells are drilled to the Frio in the Oligocene or deeper wells are drilled to the Wilcox in the Eocene.

The well site for the second Electrodril test will be selected from an active drilling area in the lower Gulf Coast region which meets the following criteria.

- o Proven field where the formations are well defined and correlation with previously drilled wells is available.
- o The formations due to overburden and hydrostatic pressure reduces conventional penetration rates.

In the deeper zones abnormal pressures cause intermittent gas flow into the hole necessitating mud weights of 13-16 lbs.

- o Land-based rig with a well-trained crew.
- o Drilling parameters:

Hole size - $9\frac{1}{2}$ " to $12\frac{1}{4}$ ".

Hole depth - starting below 8,000' drilling to 12,000' or more.

Hole drift not to be more than 3° .

Hole temperature not to exceed 250°F .

Mud weight not to exceed 16 lbs.

In the Corpus Christi-Laredo-Brownsville area, wells are drilled to the Vicksburg in the Oligocene to 14,500 feet. Deep wells in the same area are drilled to the Edwards in the Cretaceous to 18,000 feet. The second Electrodril test in the deeper zones may encounter unconformities, anticlinal and fault traps in a continually changing strata which will show the advantages of this system.

The well site for the third Electrodril test will be selected for a change of drilling conditions in the West Texas region which meets the following criteria:

- o Proven field, where drilling conditions are well defined and where correlation with previously drilled wells is available.
- o Formations are hard and abrasive, which will provide a significant challenge to the drilling system. Also, the intrusion of gas and salt water and a continual change in formation characteristics will thoroughly test the downhole sensors.
- o Well-designed drilling rig with a well-trained crew.
- o Drilling parameters:

Hole size - $9\frac{1}{2}$ " to $12\frac{1}{4}$ ".

Hole depth - starting below 11,000', drilling to 16,000 to 21,000'

Hole drift not to be more than 3° .

Hole temperature not to exceed 250°F.

In the Ft. Stockton area of the Delaware Basin, wells are drilled to the Fusselman in the Silurian to 14,000 feet. Deep wells in the same area are drilled to the Ellenberger in Ordovician to 21,000 feet. The third Electrodril test will penetrate the Mississippian Limes, Devonian Cherts, Silurian Shales and Simpson Sands, showing the superiority of this system.

CONCLUSION

In summary then, the field test of the Phase II Electrodril System will be accomplished in operating wells selected to provide increasingly more challenging drilling conditions. Demonstrations will be established in operating wells in the following areas:

- ° In the Gulf Coast, in the Victoria-Bay City, Texas Area where medium hard formations are encountered at 10,000-15,000 feet with a minimum potential for hazardous conditions.
- ° In the South Texas Area near Laredo and Brownsville where formations are somewhat harder and higher temperatures and pressures are encountered. Drilling is planned at depths of 12,000-17,000 feet.
- ° In the West Texas - Fort Stockton Area where varied formations are expected with potential for hazardous conditions. Drilling at depths of 11,000-18,000 feet is planned.

OPERATIONAL DEMONSTRATION OF THE
ELECTRODRIL DEEP DRILLING SYSTEM

TEST PLAN

For

SITE I - January, 1979

SITE II - June, 1979

Note: Since the test at Site I was aborted with no actual drilled footage, the test plan for Site II was exactly the same, except for names and location. To reduce repetition, the specific data for Site II has been inserted in parenthesis.

GENERAL ELECTRIC

Thermal Systems
Houston Texas

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1.0 INTRODUCTION

This report documents the test plan for the performance evaluation of the Electrodrill Deep Drilling System at the first operational drilling site in support of the Phase II, Task C activity. This drill site, tentatively selected, is the Exxon I.C.H. Matthews Well No. 1 near Beaumont, Texas. (Site II is Shell Oil Company's Martinez Well No. 4, La Copita Field near McCook, Texas.)

2.0 OBJECTIVE

The objective of the Task C drilling demonstration of the Electrodrill Deep Drilling System is to evaluate both the technical and economic viability of the Electrodrill System. The operational readiness of the system will also be demonstrated by drilling in test sites in the Texas Gulf Coast Area. The economic viability of the system will be demonstrated through analysis of operational data and comparison of results obtained during drilling operations with established economic models.

3.0 TEST REQUIREMENTS

3.1 GENERAL

It is anticipated that the Electrodrill Deep Drilling System will be deployed initially after the surface casing has been set. For this first well site, this will be at approximately 7000' (Site II at 5180') which is typical for wells along the Texas Gulf Coast. Test drilling will be conducted for about two weeks.

3.2 SCHEDULE

A typical schedule for a test site is shown in Table 1 and is centered around two 100-hour drilling demonstrations. It should be noted that the exact timing for big changes is not known, and thus, scheduling is an approximation.

3.3 TECHNICAL APPROACH

The plan for this drilling demonstration is to verify that the Electrodril penetration rate is the same or better than previous drilling operations when using a similar bit and rotating at the same rate. Subsequently, an optimum rotational speed will be selected, still using the same bit, to verify the technical contention that higher drilling rates can be obtained using a "constant power" approach to drilling. Subsequent to this initial comparative evaluation of drilling rates, a series of exploratory combinations of bit speed and weight on bit will be made to determine the drilling characteristics and operating regime of Electrodril when using this particular bit.

Upon the completion of this series of drilling tests, the drill string will be removed and a single-shot well survey made to establish well alignment. A second Electrodril motor and bit shaft will then be run in the hole for drilling evaluation. The bit used for this second drilling demonstration will maximize the high-speed, high-torque potential of Electrodril. The bit selection will, of course, be made commensurate with the formation to be drilled.

The second drilling demonstration at the well site will maximize penetration rate. Rotational speeds and weights on bit will be varied to identify the

TEST TIME IN DAYS

B-3

Table 1
TYPICAL WELL SITE SCHEDULE

drilling characteristics of the new bit with Electrodril. In addition, close observation will be made of the rig floor operations to identify and measure the drilling "dead time" (viz. pipe-changing and cable-rigging time which extends normal drilling dead time). Post-test analyses will assess the economic viability of the total drilling system.

3.4 DATA

The Electrodril Instrumentation Subsystem shown schematically in Figure 1, provides the ability to sense the surface and downhole parameters (Table 2) in real time and thus aids significantly in controlling the drilling operation. For the two-site drilling demonstration, the downhole instrument package of Electrodril will perform the following functions:

1. Receives from the surface 120 VAC 1000 Hz electric power and converts and distributes same to support the downhole instrumentation.
2. Monitors the analog and digital downhole parameters and processes (multiplex) this data.
3. Sends the processed data in pre-established digital formats to the surface.
4. Receives heat sub and vibration sensor control commands from surface equipment for execution by the downhole units.

INSTRUMENTATION SUBSYSTEM

Figure 1

Table 2

SUMMARY

ELECTRODRIL DATA AVAILABILITY

	Driller's Console	Driller Control/ Display Unit	Data Analysis Trailer	Remarks
Time, Hours/Minutes	no	no	yes	
Depth, Feet	no	no	yes	
Pen. Rate F/H	no	no	yes	
*Drift. Deg.	no	yes	yes	
*Azimth Deg	no	yes	yes	
*Tool Face Deg	no	yes	yes	
*Mtr Temp °F	no	yes	yes	
*Instr Temp °F	no	yes	yes	
*Annulus Temp °F	no	yes	yes	
Motor Amps	yes	no	yes	
*Motor volts	no	yes	yes	
*Delta Press PSI	no	yes	yes	
Surf Press PSI	no	no	yes	
Mud Vol GPM	no	no	yes	
*Gamma Count	no	yes (1)	yes	(1) Digital format, not gamma count directly
*Instrument Voltage	no	yes	yes	
Motor RPM	yes (2)	no	yes	(2) Setting device only.
*Vibration	no	yes	yes	
Hang Weight	no	no	yes	

* Sensed Downhole

The surface equipment, consisting of the driller's Control and Display Unit and the Data Analysis Trailer, receives the downhole data, establishes bit and frame synchronization, checks parity, decides on the data acceptability, performs data transformation, routes and displays the data. It also monitors, processes and displays data from the surface sensors.

A surface equipment power supply provides the 1000 Hz power for the downhole instruments. The surface support equipment includes two data display stations:

1. The Display and Control Unit (Figure 2) located on the rig floor in the driller's mud house, displays the three-axis hole direction data and has one other display window for any other selectable downhole data.
2. Electronics in the Data Analysis Trailer (Figure 3) permit system diagnostics to be performed and enhance the analysis capabilities for supporting Electrodril System performance evaluation. In addition, raw downhole data can be decoded, converted, and displayed independently from the rig floor Display and Control Unit. Two types of hard copy output are provided. A printer periodically prints downhole and surface parameter values as a function of time while two strip chart recorders record parameters as a function of time and as a function of depth. A typical printer output is shown in Table 3, while typical strip chart recorder traces are shown in Table 4.

Figure 2
DISPLAY AND CONTROL UNIT

Figure 3

INTERIOR OF DATA ANALYSIS TRAILER
SHOWING PRINTOUT DEVICES

TYPICAL ELECTRODRILL RECORDER OUTPUT

DATE: - MM DD YY HHMM - 11/07/78 13:53
 COMPANY: - GENERAL ELECTRIC
 FIELD: - BROWN OIL TOOL
 LEASE: - BOT
 WELL NO.: - TEST
 COUNTY: - HARRIS
 STATE: - TEXAS
 MAGNETIC DIP ANGLE: - 55.7
 TRUE NORTH CORRECTION: - 1
 CURRENT DEPTH: - 1015.9
 GAMMA MULTIPLIER: - 1
 GAMMA CORRECTION RATIO: - 1
 MUD PUMP DIAMETER: - 7
 MUD PUMP STROKE LENGTH: - 6
 NO. MUD PUMP CYLS: - 2

COMPANY: GENERAL ELECTRIC FIELD: BROWN OIL TOOL LEASE: BOT
 WELL NO: TEST COUNTY: HARRIS STATE: TEXAS DATE: 11/07/78

TIME HH:MM	DEPTH FEET	PEN F/H	DRFT DEG	AZMTH DEG	TFACE DEG	MTR DGF	INS DGF	ANN DGF	MTR AMP	DPRS PSI	SURF PSI	VOL GPM	GAMMA CNT	HANGWT POUNDS	SPD RPM
P.15															
13:55	01015.9	000	00.2	180.5	000.0-401	059	034	000	0032	0508	443	0000	000000	000	
13:55	01015.9	000	00.2	180.5	000.0-401	059	034	000	0032	0520	472	0000	000000	000	
13:55	01015.9	000	00.1	180.5	000.0-400	059	034	000	0035	0571	520	0000	000000	000	
13:55	01015.9	000	00.1	180.5	000.0-400	059	034	000	0035	0537	504	0000	000000	000	
13:56	01015.9	000	00.0	180.5	000.0-401	059	034	000	0032	0513	328	0000	000000	000	
13:56	01015.9	000	00.1	180.5	000.0-400	059	034	029	0032	0518	472	0000	000000	002	
13:56	01015.9	000	00.2	180.5	000.0-401	059	034	022	0035	0518	472	0000	000000	065	
13:56	01015.9	000	00.1	180.5	000.0-400	059	034	021	0038	0518	496	0000	000000	038	
13:57	01015.9	000	00.3	180.5	000.0-401	059	034	022	0035	0569	456	0000	000000	095	
13:57	01015.9	000	00.2	180.5	000.0-401	059	034	022	0035	0544	464	0000	000000	097	
13:57	01015.9	000	00.2	180.5	000.0-401	059	034	022	0029	0527	448	0000	000000	097	
13:57	01015.9	000	00.2	180.5	000.0-401	059	034	022	0032	0571	536	0000	000000	097	
13:58	01015.9	000	00.0	180.5	000.0-400	059	034	021	0035	0542	472	0000	000000	097	
13:58	01015.9	000	00.0	180.5	000.0-401	059	034	022	0029	0530	416	0000	000000	098	
13:58	01015.9	000	00.1	180.5	000.0-401	059	034	023	0029	0537	504	0000	000000	129	
13:58	01015.9	000	00.2	180.5	000.0-401	059	034	024	0035	0552	512	0000	000000	173	
13:59	01015.9	000	00.2	180.5	000.0-401	059	034	024	0035	0513	528	0000	000000	137	
13:59	01015.9	000	00.0	180.5	000.0-400	059	034	024	0041	0564	560	0000	000000	203	
13:59	01015.9	000	00.1	180.5	000.0-400	059	034	024	0041	0540	528	0000	000000	203	
13:59	01015.9	000	00.2	180.5	000.0-401	059	034	024	0032	0520	456	0000	000000	205	
13:00	01015.9	000	00.1	180.5	000.0-400	059	034	024	0035	0520	512	0000	000000	205	
13:00	01015.9	000	00.0	180.5	000.0-400	059	034	024	0035	0505	480	0000	000000	205	
13:00	01015.9	000	00.2	180.5	000.0-401	059	034	024	0038	0522	448	0000	000000	205	
13:00	01015.9	000	00.0	180.5	000.0-400	059	034	022	0035	0515	488	0000	000000	166	
13:01	01015.9	000	00.1	180.5	000.0-400	059	034	021	0041	0508	472	0000	000000	121	
13:01	01015.9	000	00.1	180.5	000.0-400	059	034	022	0041	0515	392	0000	000000	105	
13:01	01015.9	000	00.0	180.5	000.0-400	059	034	021	0035	0554	456	0000	000000	101	
13:01	01015.9	000	00.2	180.5	000.0-401	059	034	022	0032	0530	488	0000	000000	099	
13:02	01015.9	000	00.1	180.5	000.0-400	059	034	022	0041	0510	416	0000	000000	099	
13:02	01015.9	000	00.2	180.5	000.0-401	059	034	020	0035	0557	480	0000	000000	087	
13:02	01015.9	000	00.3	180.5	000.0-401	059	034	020	0032	0500	528	0000	000000	059	
13:02	01015.9	000	00.2	180.5	000.0-401	059	034	020	0035	0520	512	0000	000000	050	
13:03	01015.9	000	00.1	180.5	000.0-400	059	034	000	0035	0549	528	0000	000000	026	
13:03	01015.9	000	00.2	180.5	000.0-401	059	034	000	0032	0554	456	0000	000000	003	
13:03	01015.9	000	00.2	180.5	000.0-401	059	034	000	0032	0518	456	0000	000000	002	
13:03	01015.9	000	00.0	180.5	000.0-400	059	034	000	0035	0515	440	0000	000000	002	
13:04	01015.9	000	00.2	180.5	000.0-401	059	034	000	0032	0562	472	0000	000000	002	
13:04	01015.9	000	00.2	180.5	000.0-401	059	034	000	0032	0515	424	0000	000000	002	
13:04	01015.9	000	00.1	180.5	000.0-400	059	034	000	0035	0515	424	0000	000000	002	

Table 3

TYPICAL ELECTRODRIL STRIP RECORDER TRACES

Table 4

4.0 MEASURES OF EFFECTIVENESS

Several means of obtaining data have been implemented in the Electrodril Instrumentation Subsystem design to assure that the information obtained during the test program will permit meaningful performance evaluation of the Electrodril System. The measures of system effectiveness have been grouped into three categories: Economic, Functional and Safety.

The most important economic yardstick will be cost per foot drilled. The cost aspect is made up of the cost of amortizing the Electrodril System, cost of operations at site and cost of maintenance. There are other direct measures of functional effectiveness which include penetration rate, hole quality (straight, smooth hole), percent time spent drilling, rig up and rig down time, deployment time, and trip time.

In addition, there are less tangible measures that are still important factors in considering drilling system performance.

- Reduction or elimination of blowouts by downhole sensing while drilling.
- Demonstration of the drilling systems' ability to adapt to changing conditions such as different type bits, variations in formations, mud type/density/flow rate.
- Reduction of tripping frequency by optimizing bit life through carefully controlling mud flow, mud type, RPM, and bit torque as downhole condition changes are noted via the telemetry system, and by eliminating the need for position and formation logging.

- Demonstration that the Electrodril System is safe.
- Reduction of damage to hole wall casing and drill pipe by slower rotation of pipe, resulting in longer drill pipe life.
- Reduction of need for fishing jobs by monitoring changes in downhole vibration characteristics to predict bit failure.
- Reduction in likelihood of sticking and twistoff.

The less tangible measures will be evaluated through a comparison of historical data on drilling performance with conventional methods in each drill site area.

Data sheets and detailed instructions for obtaining the directly measured data have been generated and will be used during each drilling demonstration.

SITE I TEST

REPORT ON

ELECTRODRIL DEEP DRILLING SYSTEM
DEMONSTRATION

AT

EXXON I.C.H. MATTHEWS WELL NO. 1 FIELD SITE
BEAUMONT, TEXAS

April 1979

GENERAL ELECTRIC

Houston, Texas

1.0 INTRODUCTION

This report documents the major events of the Electrodril Deep Drilling System deployment at the Exxon I.C.H. Matthews Well No. 1 drill site south of Beaumont, Texas, April 4-15, 1979. The report includes a chronology of the deployment/demonstration effort, an analysis of the anomalies encountered and a summary of the lessons learned in this initial operational demonstration.

2.0 DEPLOYMENT/DEMONSTRATION CHRONOLOGY

April 4

Electrodril equipment loaded on transporters to be held overnight at freight yard prior to delivery at well site. Exxon drilling at 40 ft/hr and at a total depth of 2553 ft.

April 5

Electrodril surface equipment delivered and deployed at well site, cabled up and exercised using diesel APU. Instrument trailer, power inverter and control unit check OK. Exxon is continuing drilling and projecting reaching Electrodril deployment target depth (5876 ft) by some time 4/8/79.

April 6

Electrodril drill pipe, motors and instrument assembly delivered to drill site. Prepared to exercise both motors and instrument assembly to assure their functional readiness. Remeasured length of kelly and saver sub to assure total length is correct length for cable. No modifications necessary. Exxon projecting coming out of hole for bit change and hole logging some time 4/7/79.

April 7

With the string inside the casing, Electrodril kelly crossover sub installed on top of rig kelly, preparatory to laying it down and installing cable. Crossover sub experienced pin end twist-off during torque-up. Post-failure analysis indicated thread root relief incorrectly machined at shoulder. Crossover sub returned to Drilco at Houston for rework.

Exxon uses open hole time to survey and to check BOP. BOP ram failure discovered (4:30 pm). Trip out of hole and await parts for BOP. BOP repaired (3:30 am), trip pipe in hole to test BOP.

April 8

Electrodril kelly crossover sub returned to well site (9:00 am) after overnight rework by Drilco. Test of Electrodril motor, instrument and power subsystem over 2000' of cable proved unsuccessful. Technical support requested from Houston to help diagnose problem.

Exxon continues drilling (8:00 am). Drilling progress slow due to problems with plugged flow lines and standpipe problems.

April 9

Electrodril voltage control system problem isolated in instrument sub, necessitating assembly return to Houston for repairs. Exxon requested to drill ahead without Electrodril to new target depth of 6973 ft.

Exxon proceeds with drilling program, pulls out of hole (4:00 am) lays down kelly and installs kelly cable. Crossover sub and cable removed until Electrodril motor is deployed. Successfully makes up Electrodril crossover sub (6:00 am).

April 10

Electrodril instrument assembly returned from Houston after successful repair. Assembly successfully exercised over 7000' of cable with motor and power generator.

Exxon pulling out of hole after reaching 6973 ft., drill string hits BOP rams and three drill collars with drill bit are dropped to the bottom (10:30 am). BOP pipe ram connecting rod broken. BOP changeout begun.

April 11

Electrodril instrument assembly successfully exercised over 5000' of cable with motor and power generator.

Exxon effects repairs on BOP and proceeds with fishing for downhole drill collars. First attempt succeeds in latching collars but drop out on trip out of hole (7:00 pm). Trip back in hole (11:30 pm) with overshot and second fishing attempt succeeds (6:00 am 4/12/79). Kelly saver sub threads damaged - sub replaced.

April 12

Primary activity of the day was to recondition the hole and to test BOP

and casing string. Final trip in the hole for reconditioning (6:00 pm)
the GE dedicated 90' stands are made up so that they can be stood back in the
rig when the drill string is tripped out to receive Electrodril.

April 13

Trip into hole with Electrodril began 6:00 am. Bottom hole assembly lowered
to bottom of surface casing (1984') and circulated (11:00 am). Crossover sub
added and kelly laid down and wired for Electrodril (4:00 pm). Drill string
lowered into hole to 4700' (11:00 pm). First 5000' Electrodril cable lowered
into hole - successful mate but unacceptable electrical parameters. Cable
removal from hole (3:30 am) started. Cable reel problems experienced, fixed
by 5:30 am. Cable clear of hole at 6:00 am.

April 14

Drill pipe added to a total depth of 5125'.	(7:00 am)
Second 5000' Electrodril cable deployed to 5027'	(8:00 am)
Drill pipe added to total depth of 6183'	(8:30 am)
Deploy 1000' Electrodril cable	(9:30 am)
Complete drill string with 8 dedicated 90' stands	(11:00 am)
Slip Ring added to top of crossover sub and power cable added	(1:00 pm)
Circulate and test motor through slip ring, kelly with 6870' of dedi- cated pipe and cables. Five successful motor starts were made (no drilling).	(2:30 pm)
Failure to start motor realized (failure isolated at approx 7000' level).	(3:00 pm)
Decision to pull out of hole	(3:30 pm)
Lay down dedicated pipe	(7:00 pm)

Pulled out 1000' and 5000' cables	(9:00 pm)
Pulled drill string in surface casing	(11:00 pm)
Lay down kelly and remove subs and cable	(2:00 am)
Complete removal of Electrodril string	(5:30 am)

April 15

Electrodril equipment prepared for loading and return to Houston. No trucks available, decision to remove equipment from drill site early April 16.

Exxon makes up drill string and goes to hole bottom (6:00 am) continues own drilling program.

3.0 FAILURE ANALYSIS

Early in the afternoon on April 14, 1979, the Electrodril system was fully deployed to approximately 7000 feet, all subsystems were functional and drilling operations were about to be initiated. After five consecutive motor starts for system calibration purposes, an electrical short was experienced and the drilling demonstration was aborted. This prime failure is discussed below.

During the process of removing the Electrodril equipment from the hole, a series of tests were made to isolate the power conductor failure and to identify its location. Immediately upon recognition of a "no start" situation with the motor, the power cable from the output transformer to the top of the kelly slip ring assembly was disconnected and a Time Domain Reflectometer was used, which indicated the failure cause was located approximately 6800 feet downhole. This information indicated the failure location was close to the instrument sub.

Upon completing the withdrawal of the 5000-foot and 1000-foot cables, together with the associated drill pipe, tests were again made at the top of the instrument sub, which indicated that the instrument was functioning correctly but the power leads had been shorted to ground. The instrument sub was then removed from the string, separated from the motor and laid down, and for the first time the failure was determined to be somewhere in the instrument sub rather than in the motor.

The instrument sub was disassembled in the Houston shop, and the failure cause was isolated in the lower power connector assembly (Figures 1 and 2). The

Figure 1
LOWER INSTRUMENT SUB POWER CONNECTOR

Figure 2
POWER CONNECTOR SHOWING FAILURE MODE

female connector was not damaged but its adaptor had been shorted to ground and the power conductors had failed. The absolute cause is not discernible as there is little left for failure analysis. The most probable cause, however, appears to be a mechanical malfunction in the mating of the connector adaptor, which caused shorting of the power conductors.

This particular failure was most disappointing as the instrument harness assembly had been exhaustively tested at the manufacturer and during our own assembly process (Figures 3 and 4). In addition, the complete assembly was hydrostatically and electrically tested prior to closeout for shipment to the well site (Figures 5 and 6). A reassessment of the design approach taken at this connector interface is in progress now. Particular attention is being paid to methods of motor servo loop isolation to permit drilling with Electrodrill to continue in the event of instrumentation sub failure.

Figure 3
USING REMOTE DISPLAY UNIT TO MONITOR
ASSEMBLY PROGRESS OF INSTRUMENT UNIT

Figure 4
FINAL ASSEMBLY AND TEST OF INSTRUMENT SUB

Figure 5
HYDROSTATIC TESTING OF ASSEMBLED INSTRUMENT SUB

Figure 6
HYDROSTATIC TESTING OF ASSEMBLED INSTRUMENT SUB

4.0 OTHER PROBLEMS

Other equipment failures were experienced during the deployment period at the well site. These malfunctions, however, did not contribute to the primary cause for removing the Electrodril system from the hole. These anomalies are discussed below.

Kelly Cross Over Sub

During preparations for the first "test assembly" of the electrified kelly (April 7) the pin end of the kelly crossover sub was twisted off (Figures 7 and 8). Investigation of the failed parts by Drilco (Houston) revealed the twist off occurred at the thread root near the pin shoulder. A crack had propagated from a tool mark (in the thread relief groove) and caused the failure.

Drilco faced the end off the crossover sub and made a female thread in the end. A pin-by-pin saver sub was then used to make up the assembly. Prior to delivery, the reworked sub was magnafluxed to assure no additional failure/corrosion cracks existed and the sub was also tested for correct metallurgy and heat treatment.

Motor Servo Loop

Prior to going into the hole with Electrodril, the motor voltage servo loop was being exercised on the surface when it exhibited a failure which was isolated in the instrument sub at the formation sensor sub assembly. This failure required the instrument sub to be returned to Houston for rework. This rework was completed overnight and returned to the well site. The

Figure 7
TWIST-OFF OF KELLY CROSSOVER PIN END

Figure 8
TWIST-OFF OF KELLY CROSSOVER PIN END

failure was caused by an integrated circuit which had come loose from its mother board but had caused no subsequent electrical failure. Reinsertion of the I.C. chip into its mother board and soldering the pins to assure good mechanical attachment, was the solution. This servo loop failure, which occurred April 8, caused Exxon to continue drilling ahead. A new deployment target depth (6973 feet) was established.

5000-foot Cable

At the completion of the first 5000-foot cable deployment in the drill pipe, the cable length did not coincide with the preplanned pipe tally (i.e., cable too long by 30 feet). At the same time it was noticed that the core of the cable connector had receded from its housing by approximately 3/8 inch. This cable was retrieved from the drill string and a second 5000-foot cable was successfully deployed.

It appears that the core of the cable connector was "milked down" by the hanging weight of the cable (10,000 lbs.). A more positive retainer was installed to correct this problem.

Cable Reel Skid

During the second deployment of a 5000 foot-cable into the hole, the cable reel skid began to make clanking and squealing noises in the drive bearing located near the operator console. The reeling-in process was temporarily terminated and upon investigation, it was found that six of eight bushing re-

tainer bolts had come loose and dropped between the rotating and non-rotating members. These bolts were wedged in this area and had to be driven free using a cold chisel. Upon clearing the bolts, the reeling process was begun and successfully concluded without further event. It appears that these bushing drive bolts had worked loose under stress. No mechanical means of retention had been provided. New bolts were installed and lock wired to prevent recurrence.

Sinker Bars

There appears to be a tolerance stackup problem with male to female sinker bar connections. Not all male adaptors will mate with all female adaptors even though the gages provided by the vendor do mate on any sinker bars. A reassessment of the worst case tolerance stackup has been made (by the vendor) and appropriate rework has been accomplished.

During the process of going in the hole with the second 5000 foot cable, the decision was made to use two sinker bars. The sinker bar mating process was difficult because of the tolerance stackup problem previously identified. The sinker bars were laid down and mated on the drill pipe ramp. In the process of picking up the mated pair, the two sinker bars were picked up by their ends and they folded in the middle (total weight 750 lbs.). Clearly the sinker bar connector nuts were not intended to withstand a bending moment of 21,000

1b-ft. The use of a second sinker bar as a means to compensate for errors in cable deployment is to be discouraged. The need for two sinker bars to facilitate cable deployment (i.e., to overcome mud bouyancy effect) does not exist, even for mud weights up to 17-lb.

Connectors

Aside from the lower instrument harness connector adaptor failure, one other connector-related failure was experienced. The male connector located at the top of the 5000-foot cable lost its tip during the process of mating. At the time the first 5000-ft. cable was deployed, a manual mate of a female connector was made with the male connector at the top of the 5000-foot cable to check its electrical characteristics. This process was physically awkward, and in mating the female, very severe bending loads were inadvertently forced on the male. Normal downhole mating would never result in such loading. The male was simply not designed to withstand these bending forces and the tip broke away from the connector.

Sprague Clutch

At the time motor start failure was established, Exxon was advised to proceed drilling in the conventional way using the kelly and rotary table but drilling ahead with Electrodril. This process was designed into the Electrodril System by means of an overrunning clutch.

There appears to have been a drilling anomaly during the period when Electrodril was used as part of the conventional drill string. The penetration rate immediately prior to the deployment of Electrodril was in the order of 20 ft./hr. While drilling with Electrodril in the conventional string, however, the penetration rate had dropped to 10 ft./hr. Upon removal of Electrodril and resumption of conventional drilling, and penetration rate was approximately 35 ft./hr.

The inference given by this data alone is that the Electrodril string had a negative influence on the drilling rate. Checks made on the overrunning clutch indicated that it was in operational condition. Discussions with the driller indicate a significantly lower weight on bit was used with Electrodril during this drilling process. An appropriate reduction in penetration would normally be expected, but the magnitude of reduction is not completely supported by the reduction in weight on bit. This drilling anomaly remains a mystery.

SITE II TEST

REPORT ON

ELECTRODRIL DEEP DRILLING SYSTEM

DEMONSTRATION

AT

SHELL, MARTINEZ STATE NO.4 FIELD SITE

McCOOK, TEXAS

June 1979

GENERAL ELECTRIC

Houston, Texas

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SUMMARY

Transport of the Deep Drilling System to the McCook site began June 25, 1979. Initial plans called for deployment of Electrodril at 5180 feet. A thorough surface checkout of the system was successfully conducted after delivery and assembly of the system was completed. At this time, June 27, the driller's prognosis for Electrodril deployment was June 29. Refinement of knowledge of cable lengths caused the target depth for Electrodril deployment to be revised to 5220 feet.

Electrodril was subsequently deployed with 5099 feet of cable to hole bottom at 5220 feet. The drill string with the Electrodril downhole system was checked electrically and found to be operationally ready. The motor was started and shut down twice to calibrate the motor voltage control feedback loop. The motor subsequently was started and 20 feet of hole was drilled to the top of the kelly. All aspects of the downhole instrumentation system functioned properly during the drilling operation with real time data received, displayed, and recorded in the instrumentation trailer. Some examples of the McCook data collected are shown in Figure 1 and Table 1.

In order to drill ahead, a dedicated joint of drill pipe was added but it was laid back down because of poor electrical continuity and leakage. After three dedicated joints were deemed unusable (one was damaged by rig hands), it was decided to conventionally drill an additional 60 feet with the rotary.

At this point, a 90-foot dedicated stand of pipe was added and the system was powered up. Drilling continued until a short developed in the string.

Figure 1
EXAMPLES OF MCCOOK BRUSH RECORDER DATA
D-2

COMPANY: GE FIELD: LACOPITO LEASE: MARTINEZ1
WELL NO: HARKINSITY: STARR STATE: TX DATE: 07/01/79

TIME HR:MM	DEPTH FEET	PEN F/H	DRAFT DEG	AZMTH DEG	TFACE DEG	MTR DGF	INS DGF	ANN DGF	MTR AMP	DPRS PSI	SURF PSI	VOL GPM	GMAA CNT	HANGWT POUNDS	SPD RPM
00:32	05203.3	000	00.3	219.0	000.0	151	131	147	000	1417	1862	465	0043	000000	000
00:32	05203.3	000	00.0	338.0	000.0	152	130	147	000	1409	1858	465	0042	000000	000
00:32	05203.3	000	00.4	230.6	000.0	152	130	147	000	1259	1683	370	0042	000000	000
00:32	05203.3	000	00.3	073.3	000.0	152	130	147	001	1418	1853	412	0044	000000	000
00:33	05203.3	000	00.9	034.6	331.7	152	130	147	000	1413	1855	423	0043	000000	000
00:33	05203.3	000	00.3	309.5	000.0	152	130	147	001	1413	1841	402	0041	000000	000
00:33	05203.3	000	00.9	303.9	000.0	152	130	147	022	1428	1849	402	0047	000000	000
00:33	05203.3	000	00.7	306.9	000.0	152	131	147	021	1417	1840	455	0045	000000	000
00:34	05203.3	000	01.6	263.4	234.5	151	131	147	021	1407	1836	455	0047	000000	000
00:34	05203.3	000	00.5	104.0	000.0	151	130	147	000	1418	1824	412	0047	000000	000
00:34	05203.3	000	01.0	354.2	349.4	151	130	147	000	1428	1841	423	0048	000000	000
00:34	05203.3	000	00.5	360.0	000.0	151	130	147	000	1423	1818	423	0048	000000	000
00:35	05203.3	000	00.5	124.3	000.0	151	130	147	000	1428	1825	391	0048	000000	000
00:35	05203.3	000	00.4	109.4	000.0	151	130	147	000	1428	1831	370	0043	000000	000
00:35	05203.3	000	01.6	295.2	053.1	151	130	147	000	1428	1814	370	0044	000000	000
00:35	05203.3	000	00.3	360.0	000.0	151	130	147	000	1423	1824	423	0044	000000	000
00:36	05203.3	000	00.2	130.0	000.0	151	131	147	000	1445	1823	412	0043	000000	000
00:36	05203.3	000	01.0	176.2	301.6	150	130	147	000	1428	1816	370	0040	000000	000
00:36	05203.3	000	00.3	360.0	000.0	151	131	147	000	1445	1814	349	0042	000000	000
00:36	05203.3	000	01.0	162.9	142.4	150	130	147	000	1423	1807	402	0046	000000	000
00:37	05203.3	000	00.1	291.3	000.0	150	130	147	000	1437	1812	331	0047	000000	000
00:37	05203.3	000	00.7	102.1	000.0	151	131	147	000	1445	1815	402	0046	000000	000
00:37	05203.3	000	00.3	031.2	000.0	150	130	147	000	1423	1801	391	0046	000000	000
00:37	05203.3	000	00.9	169.3	113.3	150	130	147	000	1447	1797	402	0050	000000	000
00:38	05203.3	000	00.7	273.0	000.0	150	130	147	000	1437	1805	423	0048	000000	000
00:38	05203.3	000	00.4	076.7	000.0	150	131	147	000	1445	1797	434	0044	000000	000
00:38	05203.3	000	00.4	041.3	000.0	150	130	147	000	1437	1779	434	0042	000000	000
00:38	05203.3	000	00.6	237.0	000.0	150	130	147	000	1437	1796	455	0044	000000	000
00:39	05203.3	000	00.0	136.0	000.0	150	130	147	000	1437	1775	465	0046	000000	000
00:39	05203.3	000	00.8	017.1	000.0	150	130	147	000	1437	1738	423	0045	000000	000
00:39	05203.3	000	00.4	360.0	000.0	150	130	147	000	1447	1805	331	0043	000000	000
00:39	05203.3	000	00.6	125.5	000.0	150	130	147	000	1447	1813	370	0045	000000	000
00:40	05203.3	000	00.3	076.3	000.0	150	130	146	000	1456	1808	391	0041	000000	000
00:40	05203.3	000	00.4	032.3	000.0	150	130	146	000	1456	1826	370	0041	000000	000
00:40	05203.3	000	00.3	229.1	000.0	150	130	146	000	1456	1824	444	0045	000000	000
00:40	05203.3	000	00.4	130.0	000.0	150	130	146	000	1456	1818	455	0045	000000	000
00:41	05203.3	000	00.3	360.0	000.0	150	130	146	000	1456	1814	402	0045	000000	000
00:41	05203.3	000	00.7	304.4	000.0	150	130	146	000	1447	1816	391	0044	000000	000
00:41	05203.3	000	00.1	102.6	000.0	150	130	146	000	1447	1815	370	0044	000000	000
00:41	05203.3	000	00.0	073.1	000.0	150	130	146	000	1447	1809	370	0046	000000	000
00:42	05203.3	000	00.3	276.8	000.0	149	130	147	000	1454	1809	402	0046	000000	000
00:42	05203.3	000	00.4	220.9	000.0	149	130	146	000	1447	1804	434	0044	000000	000
00:42	05203.3	000	00.2	032.5	000.0	149	130	146	000	1437	1813	436	0044	000000	000
00:42	05203.3	000	00.9	360.0	000.0	149	130	146	000	1437	1804	402	0041	000000	000

Table 1

EXAMPLE OF SILENT 700 McCOOK DATA

Analysis showed the problem to be in the 90 foot stand. It was replaced and the remainder of the Kelly was successfully drilled down with the Electrodril complemented by complete real time instrumentation.

An additional 60 feet were drilled ahead conventionally and, while attempting to add another 90-foot prewired pipe, it was determined that the resistance to ground below the top of the 5000-foot cable had degraded to the point where equipment damage could result if power was applied. The Electrodril demonstration was, consequently, discontinued on July 1.

Despite the power cable/connector failures and the resulting demonstration shutdown, a number of significant accomplishments were achieved as shown below:

- ° The motor voltage feedback loop successfully controlled the motor voltage during some 20 motor stops and starts, under varying loads and frequencies.
- ° The operation of the motor while drilling ahead approximately 60 feet at rates up to 120 feet per hour was a major accomplishment.
- ° All channels of the instrumentation system functioned before, during, and after drilling with Electrodril. Real time downhole position data, gamma log data, mud temperature inside and outside the drill string, motor temperature, differential mud pressure (inside drill pipe pressure minus annulus pressure), vibration spectrum, motor voltage and instrument voltage were received and recorded on the surface. In addition, several surface parameters were monitored, processed and recorded. Included was depth, penetration rate, mud flow rate, mud pressure, motor current, and motor voltage.

- ° Downhole pressure zones indicated that pressure drop across bit nozzles was close to surface test reading. While pulling up to make connection, pressure reading decreased, showing suction effect of bit.
- ° Downhole temperature readings showed effect of circulating mud on motor temperature.
- ° The static inverter allowed the driller to control the bit speed. The motor was run at 60 rpm, 120 rpm and 200 rpm.

Subsequent post-test analyses indicated that the primary cause of failure at the McCook site was due to water ingress to the female connectors. In reviewing the manufacturer's product test data, there appears to have been some laxity in the Quality Control process resulting in the receipt and use of connectors that would not have normally passed the acceptance test program. This problem has been identified to the manufacturer, and positive steps have been taken to tighten the production quality control process.

INTRODUCTION

This report documents the major events of the Electrodril Deep Drilling System deployment at the Shell, Martinez State No. 4 drill site west of McCook, Texas, from June 25-July 1, 1979. The report includes a chronology of the deployment/demonstration effort, an analysis of the anomalies encountered and a summary of the lessons learned in this operational demonstration.

DEPLOYMENT/DEMONSTRATION CHRONOLOGY

June 25

The Electrodril equipment was loaded on transporters and held overnight at a freight yard prior to delivery at the McCook well site. Shell set the casing and nipples up.

June 26

The Electrodril surface equipment was delivered and deployed at the well site. It was cabled up and exercised using the diesel auxiliary power unit. The instrument trailer, power inverter and control unit checked OK. Shell was drilling ahead and projected reaching Electrodril deployment target depth (5180 feet) by some time 6/29/79.

June 27

The Electrodril drill pipe, motors and instrument assembly were delivered to the McCook drill site. Both motors and instrument assembly were exercised to assure their functional readiness. The length of the kelly and saver sub were remeasured to assure the length was compatible with that of the cable. No modifications were necessary. Shell decided to come out of the hole for a bit change and survey. While out of the hole, packing of the swivel and cutting of the drill line was accomplished.

June 28

The Baroid logging trailer and depth monitor were moved in and hooked up. Shell drilled ahead, dropped the survey tool, tripped out (laying down 37 joints of pipe) and picked up 33 joints of GE pipe.

June 29

Shell drilled ahead, reached 5180 feet, circulated and dropped the survey tool. Eleven 90-foot stands of GE dedicated pipe were wired during the tripping out process. Shell ran in the Electrodrill motor with bit and conducted a motor hydraulic test.

June 30

Laid the kelly down with the crossover and slip ring subs on top, and wired it for Electrodrill. Picked up and placed the kelly in the mousehole. Ran surface power cable from the Hoffman Power Skid panel up the standpipe and mud hose to the slip ring assembly. Picked up 43 joints of pipe to replace the GE and Heviwate pipe in the string and continued to the bottom. Reworked the surface power cable as movement of the mud hose tore the rubber clamps loose and broke the cable connector that mates the cable to slip ring assembly. Set the cable sheaves in the rig, made up the sinker bar and went in the hole with a 5000-foot cable. Found the cable to be 37 feet too long. Removed cable and drilled 40 more feet conventionally. Redeployed the cable and made up kelly. Electrical parameters checked out satisfactorily.

July 1

The motor was started and shut down twice to calibrate the motor voltage control feedback loop and other downhole instrumentation. The motor was subsequently started. All instrumentation was displayed on the driller's console located at the driller's stand. Drilling started at 12:30 am; penetrating slowly at first because the motor voltage gain required adjustment while running motor at 60 rpm with 8000 lb weight on bit. Motor stalled each time power demand was too high. To restart, the Tool Pusher pushed the stop button,

pulled off bottom and restarted the motor. Drilled the kelly down a total of 20 feet with the motor current held to less than 40 amperes. A joint of dedicated pipe was then added, but because of a signal lead discontinuity, it was laid down. Picked up a second joint of dedicated pipe and broke the male connector end off while mating with kelly. Picked up a third joint of dedicated pipe but found no continuity on one power phase.

It was decided to drill ahead conventionally 60 feet with the kelly and rotary table combination using conventional pipe. After this was done, the conventional pipe was laid down and a 90-foot stand of dedicated pipe was picked up and mated to the Kelly. Continuity was established and the system was powered up. Drilling was accomplished with the Electrodril motor operating at 200 rpm with 15,000 lb weight on bit. The motor, at this time, was drawing 40 to 45 amperes while drilling ahead at instantaneous rates varying between 80 and 120 feet per hour. Power to the motor was erratic. An electrical short, while drilling, caused the 90-foot stand of dedicated pipe to be replaced. Drilling then continued until the kelly was once again drilled down. Attempted to drill ahead with two different single joints of reworked dedicated pipe but could not establish necessary electrical parameters. An additional 60 feet were drilled ahead conventionally and while attempting to add a 90-foot prewired joint, it was determined that the resistance to ground below the top of the 5000-foot cable had degraded to the point where equipment damage could result if power was applied. The Electrodril demonstration was, consequently, discontinued at 2:00 p.m. Shell tripped out of the hole, laying down the Electrodril tools.

July 2

Electrodril equipment was prepared for loading and return to Houston. No trucks were available, so it was decided to remove the equipment from the drill site on July 3 and 4.

FAILURE ANALYSIS

There were five basic problems identified as a result of the McCook deployment. These were:

1. Shorted 90 foot stand while drilling.
2. Leakage to ground when adding 30-foot and 90-foot stands.
3. Continuing degradation in downhole leakage to ground.
4. Inability to achieve continuity reliably when male and female connectors were mated.
5. Apparent inability of the power generation subsystem to support the drilling process when using the downhole motor.

Each of these problems was investigated in an attempt to arrive at the "most probable cause".

CABLE/CONNECTOR ANALYSIS

Measurements were made at the Longpoint facility after the equipment returned from McCook to provide a baseline for the failure analysis. In general, the 90-foot cables, the 30-foot dedicated pipes, the kelly cable, the slip ring assembly, the 5000-foot cable, the instrument subsystem and the motor subsystem all checked out satisfactorily after disassembly and cleanup. The absence of any electrical anomaly in the cable string, motor and instrument assemblies indicated that the probable cause for the electrical anomalies would be found in the field replaceable connectors.

Subsequent testing of the male and female bayonet connectors indicated that they were the main source of the McCook problems. This baseline testing can be summarized as follows:

- ° Eight out of 20 female connectors had (electrical) leakage to ground and/or leakage between phases.
- ° Five out of 20 female connectors had one or more conductors "open" (i.e., no electrical continuity) when mated with a known good male.
- ° Four out of 25 male connectors were cracked or broken.
- ° One out of 25 male connectors was electrically shorted.

Prior to these electrical tests, all male and female connectors were inspected for conformity to design dimensions to assure the electrical mating parts were within tolerance. In all instances, the connectors were within tolerance. The results of these tests indicated that the basic design of the connector mating concept was valid and that the probable cause for electrical failure would be found in the manufacturing process and the post-manufacturing test program prior to delivery. The electrical test data sheets are provided for reference purposes in Attachment B of this report. A summary of the male and female connector test results can be found in Tables 2 and 3.

MALE CONNECTOR TEST SUMMARY

	POST MC COOK BASELINE			LOW PRESSURE	HIGH PRESSURE
	VISUAL	DIMENSIONAL ANALYSIS	ELECTRICAL		
PASSED / POPULATION	<u>21</u> 25	<u>21</u> 21	<u>20</u> 21	<u>19</u> 20	<u>18</u> 19
PHASE TO PHASE & PHASE TO GROUND FALLOUT	4	0	1	1	1

TABLE 2

FEMALE CONNECTOR TEST SUMMARY

	POST MC COOK BASELINE				LOW PRESSURE		HIGH PRESSURE		
	VISUAL	DIMENSIONAL ANALYSIS	ELECTRICAL	ELECTRICAL AFTER DRY OUT	MATED NO LOAD	UNMATED	MATED NO LOAD	UNMATED	MATED VAR. LOAD
PASSED/ POPULATION	20/ 20	20/ 20	12/ 20	18/ 20	17/ 18	16/ 17	14/ 16	12/ 14	12/ 12
PHASE TO PHASE AND PHASE TO GROUND FALLOUT				2	1	1	2	2	

TABLE 3

SHORTED 90 FOOT STAND

It was known that the shorted male connector found in the post McCook baseline had been in the drill string atop the 90 foot stand when it shorted. Discoloration of the stainless housing of the connector (Figure 2) indicated that considerable current and heat were generated. The two logical possible causes of the short were water intrusion or a dielectric breakdown under voltage. Temperature was not deemed to be a factor because of the position of the 90 foot stand in the drill string at the time of failure. Removal of the stainless hardware revealed that the four O-rings in the connector body were intact, but a hairline crack was observed at the point that discoloration had occurred as shown in Figure 3. It is possible that a dielectric breakdown caused plastic outgassing which in turn caused the crack. It is much more likely that the crack formed and allowed water in to short out the power conductors.

CONCLUSION:

Most probable cause of the shorted 90-foot stand was a defective male bayonet connector. There is no way of knowing when this defect was caused.

EXCESSIVE LEAKAGE TO GROUND

Excessive electrical leakage to ground was observed all too many times at McCook after making up 30-foot or 90-foot stands. The previously conducted baseline tests suggested that water intrusion into the connectors could be the cause of the problem.

Male and female connectors were subjected to a low-pressure and high-pressure test program using the test equipment shown in Figures 4 and 5, aimed at discovering if and where water was entering the connectors.

Figure 2
SHORTED MALE CONNECTOR HOUSING

Figure 3
HAIRLINE CRACK IN MALE CONNECTOR

Figure 4

Figure 5

CONNECTOR PRESSURE TEST SETUP

The connectors that showed baseline leakage were put into an oven overnight at 55°C. All but two of the female "leakers" recovered. The remaining 18 female and 20 male connectors were used in the pressure test program. It was decided to test connectors until such time as any leakage was detected, at which time testing of that item would cease.

In an effort to learn more about the water ingress path, the 18 female connectors were subjected to low-pressure water immersion (in a mated condition) and rechecked. One exhibited leakage that was attributed to water intrusion external to the bayonet cavity. The 17 remaining connectors were put back in the water bath without male connectors and rechecking showed one additional "leaker" attributed to water intrusion internal to the bayonet mating cavity.

These tests were repeated for a one-hour @ 2000 psi environment and resulted in a fallout of two additional internal and two more external "leakers".

To determine whether a varying load had any effect on the test results, the 12 female connectors surviving the high-pressure test were put back in the pressure chamber (mated) with currents of 20, 40, 60 and 80 amps being passed for a period of 15 minutes each. Checking for leakage both at elevated and at ambient pressures did not uncover any additional phase leakage anomalies.

Twenty male connectors were subjected to low pressure testing with one fallout. Subsequent high-pressure testing dropped out one additional male leaker.

CONCLUSION:

The most probable cause of excessive leakage to ground is water intrusion into female connectors.

CONTINUING DEGRADATION IN DOWNHOLE LEAKAGE

The cables, motor assembly and instrument assembly had already been eliminated as probable causes for this electrical leakage problem by virtue of the post test analyses conducted at the Longpoint facility. Furthermore, subsequent analyses of the connectors, as previously described, tends to eliminate the male connectors as a probable cause for the electrical leakage problem. It must be understood, however, that there may be a latent problem of electrical leakage that can be related to downhole environment exposure time. The Electrodril system has yet to experience this problem, if it exists.

Inasmuch as the post test-analysis of the connectors identified the female connectors as the probable failure cause, they were further investigated for insight into the leakage degradation problem. All the female connectors used in the water intrusion tests previously described were put in an oven at 55°C for two hours to determine the additional effects of temperature. These connectors were then checked for electrical leakage while they were at temperature. The 12 connectors that had originally shown no leakage still checked satisfactorily. In the case of the originally identified eight "leakers", they showed more leakage (i.e., lower resistance) at elevated temperature than at room temperature. This resistance increased as the connectors were allowed to cool.

This data indicates that the higher temperature probably vaporized the trapped moisture in the connector and increased the leakage path to ground. This is especially so when the leakage data relating to the 12 "good" connectors is considered.

CONCLUSION:

Degradation of downhole leakage as experienced at McCook, was most probably caused by water intrusion in the female connectors. Temperature effects may become significant with increasing downhole exposure.

INABILITY TO ACHIEVE RELIABLE CONTINUITY

It was first thought that the electrical "opens" (i.e., no continuity) that were experienced at McCook were caused by female connector rings opening wider than the diameter of a mating male connector. The dimensional inspection that was conducted dispelled this theory.

During baseline testing, four female connectors that had an open conductor were identified, along with one other connector with an intermittently open conductor when mated with a known good male connector. All opens cleared up when the male connector was rotated and reinserted.

Pinpointing a "most probable cause" for this problem was extremely difficult because, in approximately 300 matings of various male/female connector combinations, only two opens could be detected and these were not repeatable. This led to the conclusion that repeated matings tend to clean and slightly scour the mating surfaces and thus minimize chances for opens.

Prior to going to McCook, most of the connectors (both male and female) had not been used for several months and during this period had been exposed to heat and humidity by virtue of their storage at the Longpoint facility. These conditions probably allowed oxides to form on the Amcoloy contact surfaces.

Continuity historically has been verified with the ohmmeter portion of a standard multimeter. Instruments of this type use a 1 1/2 volt battery for their operation. Assuming the open problem is related to a thin, non-conductive film between the connector mating surfaces, the 1 1/2 volt level in the multimeter is probably insufficient to break down the non-conducting film. It appears that a higher test voltage could break down the film and establish satisfactory contact. This theory was successfully tested on the two open connections identified after the baseline tests. It took approximately 120 VAC in both cases to establish continuity.

CONCLUSION:

The "most probable cause" of conductor opens is a combination of smooth, oxidized contacts separated by the extremely thin film of dielectric grease used for lubrication and mud exclusion.

POOR POWER GENERATOR SUPPORT

The Emerson prototype AS4590 AC static inverter was able to start and run the drill motor at a depth of 5220 feet. It was soon apparent, however, that the drill motor was not developing maximum horsepower/torque relationships for the frequency/voltage/horsepower selected on the static inverter. The lack of horsepower/torque manifested itself in the fact that the drill motor would stall each time weight was applied to the bit to increase drill motor current from 40 to an optimum of 75 amperes.

Three parameters or anomalies were visually monitored when drilling, which would indicate the prime 480 VAC voltage was unstable and contributing to the inability of the inverter/drill motor to produce proper horsepower.

The parameters were:

- ° A panel light on the Hoffman control panel is powered directly from the 480 VAC generator. The light output dropped significantly during heavy loading of the drill motor. This indicates a drop in the 480 VAC feeding the inverter.
- ° Visual observation of the panel volt/ammeter mounted on the 480 VAC, 440 KW diesel generator indicated that, as the current tried to exceed 200 amperes during drilling, the voltage output of the generator would significantly diminish. Since the generator voltmeter was highly damped, the actual decrease in voltage is unknown, but is considerably more than indicated on the meter.

- ° The static inverter is protected by instantaneous overcurrent trip circuitry which, when sensing an overcurrent condition, causes the inverter to shut down. We experienced arcing and a dead short in one dedicated 90-foot joint at the surface while trying to drill. When this shorting occurred, the inverter did not trip itself off but had to be shut down manually. Strip chart recordings of the inverter output current showed that the inverter could not produce enough current output to trip itself when the 90 foot dedicated pipe/cable shorted. Since the inverter seemed to be functioning properly in every respect, the only answer to this anomaly is that only a drop in input voltage/power could create this condition.

Prior to leaving Houston, the 480 VAC power unit utilized at McCook had refused to output any power whatsoever and had to be serviced by factory representatives. In addition, just before drilling, the power unit became intermittent and required service again. Even though the generator was outputting power, the question arises about its ability to develop enough power to satisfy the static inverter requirements under heavy pulsating loads. It appeared from the parameters monitored during testing that the generator unit was malfunctioning. To further substantiate our conclusions, the generator was returned to Mustang Power Products, Houston, Texas for load testing and evaluation. Subsequent tests at Mustang Power concluded that there was a problem with the generator unit. A complete test of the unit was not conducted due to the inability of the test facility to simulate high dynamic electrical loads such as would be seen when Electrodril was in operation.

MOTOR AND BIT SHAFT

Post-test inspection of the motor consisted of cleanup, electrical check and check of quantity and quality of oil. Nothing unusual was noted. The quick-look inspection of the bit shaft to check the quantity and quality of the bit shaft lube oil did, unfortunately, find drilling mud in the remaining fluid. Subsequent disassembly of the bit shaft found the following problems:

1. The upper seal insert (stationary part of the seal) had failed. The Tungsten carbide disc spun and was loose in its holder and, and the Tungsten carbide disc had broken into three pieces. Mud erosion of the Tungsten carbide disc holder and the insert housing which align with the cracks in the Tungsten carbide disc indicated much of the erosion took place while drilling conventionally while the bit shaft is not rotating.
2. The lower seal O-ring between the compression ring and Tungsten carbide seal ring had failed. About one-third of the O-ring was gone, and drilling mud had ground away part of the compression unit. There was also mud erosion of the bit shaft at the place where the O-ring failed.
3. Heat checking of the seal faces was also noted.

The seal assemblies were removed from the bit shaft and sent to the manufacturer for failure analysis. Results to date from these analyses indicate that

the upper seal Tungsten carbide disc which spun in its holder caused mud to enter into the bit shaft oil cavity. This combined with the extrusion of the lower rotating seal O-ring and allowed a short circuit of mud flow through the bit shaft bearing section. This also resulted in rupture of the bladder bag and mud erosion of the upper and lower seal areas. The force that broke the upper seal Tungsten carbide disc is not yet fully understood.

The cause of the Tungsten carbide disc spinning in the holder was the result of a design error by the seal manufacturer. The holder is 316 stainless steel which has a functional upper temperature limit of 280° - 300°F rather than the specified 400°F. The corrective action is to use 17-4 PH material for the disc holder or to eliminate the two-piece design and replace with a solid Tungsten carbide insert.

The most likely cause of the lower seal failure was back pressure on the lower seal assembly, which caused the Tungsten carbide insert to move forward in the insert holder until full compression of the springs bottomed on the compression unit. When the back pressure was relieved, the Tungsten carbide insert cocked in the insert holder rather than moving back into proper position. This would have caused high face loading of the seal, and most likely the heat checking observed on the seal faces. This condition or the removal of the Tungsten carbide insert resulted in the broken Tungsten carbide insert. No mud erosion was noted in this area. The pressure that moved the Tungsten carbide insert forward resulted from over filling the lower cavity with grease, or from running the tool into the well.

APPENDIX A
ELECTRICAL TEST
DATA SHEETS

Female Connectors - Post McCook Baseline

Conn.#	Continuity				Leakage			Leakage to Ground			
	Ø1	Ø2	Ø3	Inst.	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst.
1	OK	→			OK	→		OK	→		
2	OK	→	Open	OK	50M	→		20M	→		
3	OK	Int.	Open	OK	100M	→		50M	→		
4	OK	→	Open	OK	inf	→		100K	inf	→	
5	OK	→		Int.	inf	→		100M	→		
6	OK	→			20M	→		10M	10M	6M	20M
7	OK	→			20M	→		20M	→		
8	OK	→			20M	→		12M	10M	7.5M	15M
9	OK	→			inf	→		inf	→		
10	OK	→	Open		inf	→		20M	20M	20M	inf
11	OK	→			inf	→		inf	→		
12	OK	→			inf	→		inf	→		
13	OK	→			inf	→		inf	→		
14	OK	→			inf	→		inf	→		
15	OK	→			inf	→		inf	→		
16	OK	→			inf	→		inf	→		
17	OK	→			inf	→		inf	→		
18	OK	→			inf	→		inf	→		
19	OK	→			inf	→		inf	→		
20	OK	→			inf	→		inf	→		

Female Connectors

Test 1 All female connectors put into water tank, unmated for 16 hours - air dried and checked for leakage. Those showing leakage were oven dried @ 55°C for 24 hours, cooled to room temperature and retested.

dried @ 55°C for 24 hours, cooled to room temperature and retested.														
Conn #	Leakage			Leakage to Ground				After Dryout						
	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst.	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst.
1	inf			inf										
2	2M			2M				1.5M			1.5M			
3	50M			600K	20M	inf	inf	inf			inf			
4	inf	250K	inf	450K	inf	400K	3.5M	inf			inf			
5	2M			2M			inf	inf			inf			
6	50M			20M	20M	50M	50M	50M			30M	30M	12M	100M
7	inf			1M	inf			inf			inf			
8	3M			2.5M	2.5M	3.5M	4M	inf			inf			
9	50M			50M	20M	inf	inf	inf			inf			
10	3M			2M	5M	20M	50M	inf			inf			
11	inf			inf										
12	inf			inf										
13	10M			1M	10M	inf	inf	inf			inf			
14	inf			inf										
15	2M			1.5M	2.8M	inf	inf	inf			inf			
16	inf			inf										
17	inf			7.5M	inf			inf			inf			
18	inf			inf										
19	inf			inf										
20	inf			inf										

Female Connectors

Test 2 Those which could be dried out in Test 1 were subjected to 16 hour water immersion using DC-3 dielectric and mated with a male.

Conn.#	Leakage			Leakage to Ground				Remarks
	p1/p2	p1/p3	p2/p3	p1	p2	p3	Inst.	
3	inf	→		inf	→			External leakage
4	inf	→		inf	→			
5	inf	→		inf	→			
7	inf	→		inf	→			
8	20M	→		20M	→			
9	inf	→		inf	→			
10	inf	→		inf	→			
13	inf	→		inf	→			
15	inf	→		inf	→			
17	inf	→		inf	→			

Female Connectors

Test 3 Those showing no leakage in Test 2 were put back in water bath unmated for 16 hours and retested - DC-3 residue not removed

Conn.#	Leakage			Leakage to Ground				Remarks
	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst	
3	inf	→	→	inf	→	→	→	Internal Leakage
4	inf	→	→	inf	→	→	→	
5	inf	→	→	inf	→	→	→	
7	inf	→	→	inf	→	→	→	
9	inf	→	→	inf	→	→	→	
10	20M	→	→	20M	→	→	→	
13	inf	→	→	inf	→	→	→	
15	inf	→	→	inf	→	→	→	
17	inf	→	→	inf	→	→	→	

Female Connectors

Test 4 All female connectors not culled out from Tests 1, 2 and 3 subjected to 1 hour @ 2000 psi mated - no load and checked after removal from chamber.

Conn. #	Leakage			Leakage to Ground				Remarks
	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst.	
1	inf			inf				External leakage
3	100M			50M				
4	inf	1M	inf	1M	inf	1M	inf	
5	inf			inf				
7	inf			inf				
9	inf			inf				
11	inf			inf				
12	inf			inf				
13	inf			inf				
14	inf			inf				
15	inf			inf				
16	inf			inf				
17	inf			inf				
18	inf			inf				
19	inf			inf				
20	inf			inf				

Female Connectors

Test 5 All female connectors not culled out in Test 4 subjected to 1 hour
@ 2000 psi unmated

Conn.#	Leakage			Leakage to Ground				Remarks
	$\phi 1/\phi 2$	$\phi 1/\phi 3$	$\phi 2/\phi 3$	$\phi 1$	$\phi 2$	$\phi 3$	Inst	
1	inf	→	→	inf	→	→	→	Internal leakage
5	50M	→	→	50M	→	→	→	
7	50M	→	→	50M	→	→	→	
9	inf	→	→	inf	→	→	→	Internal leakage
11	inf	→	→	inf	→	→	→	
12	inf	→	→	inf	→	→	→	
13	inf	→	→	inf	→	→	→	
14	inf	→	→	inf	→	→	→	
15	inf	→	→	inf	→	→	→	
16	inf	→	→	inf	→	→	→	
17	inf	→	→	inf	→	→	→	
18	inf	→	→	inf	→	→	→	
19	inf	→	→	inf	→	→	→	
20	inf	→	→	inf	→	→	→	

Female Connectors

Test 6 All 20 females put in oven @ 55°C for 2 hours and checked for leakage before and immediately after removal

Conn.#	Room Temp							55°C						
	Leakage			Leakage to Ground				Leakage			Leakage to Ground			
	01/02	01/03	02/03	01	02	02	Inst	01/02	01/03	02/03	01	02	03	Inst
1	inf			inf				inf			inf			
2	1.5M			2M				500K			200K			
3	inf			50M				25M			15M			
4	inf	1M	inf	1M	inf	1M		20CK			100K			
5	50M			50M				20M			10M			
6	1.5M			10M				2M			1M			
7	50M			50M				15M			8M			
8	3M			3M				20M			10M			
9	inf			inf				inf			inf			
10	3M			3M				2M			1M			
11	inf			inf				inf			inf			
12	inf			inf				inf			inf			
13	inf			inf				inf			inf			
14	inf			inf				inf			inf			
15	inf			inf				inf			inf			
16	inf			inf				inf			inf			
17	inf			inf				inf			inf			
18	inf			inf				inf			inf			
19	inf			inf				inf			inf			
20	inf			inf				inf			inf			

Female Connectors

Test 7 All females showing no leakage in Test 6 mated with a male connector having shorted phases. Leakage was checked while the mated pair was in water @ 14.7 psi and 2000 psi prior to passing current. Leakage is checked after 15 minutes of passing 20, 40, 60 and 80 amps through two pair of contacts while at 2000 psi and again at 14.7 psi.

Conn.#	Initial Leakage		Leakage to Gnd after 15 minutes @				Final Leakage @
	14.7 psi	2000 psi	20a.	40a.	60a.	80a.	
1	inf						→
9	inf						→
11	inf						→
12	inf						→
13	inf						→
14	inf						→
15	inf						→
16	inf						→
17	inf						→
18	inf						→
19	inf						→
20	inf						→

Male Connectors - Post McCook Baseline

Conn.	Continuity	Leakage				Leakage to Ground				Remarks
		01/02	01/02	01/03	02/03	01	02	02	Inst.	
M1										Cracked shaft @ rig
M2	OK →	inf →				inf →				
M3										
M4										
M5										
M6	OK	inf →				inf →				Cracked plastic Shorted Phases Cracked shaft
M7	OK	inf →				inf →				
M8	OK	inf →				inf →				
M9	OK	inf →				inf →				
M10	OK	inf →				inf →				
M11	OK	inf →				inf →				Broken tip @ rig
M12	OK	inf →				inf →				
M13										
M14	OK	inf →				inf →				
M15	OK	inf →				inf →				
M16	OK	inf →				inf →				
X1	OK	inf →				inf →				
X2	OK	inf →				inf →				
X3	OK	inf →				inf →				
X4	OK	inf →				inf →				
X5	OK	inf →				inf →				
X6	OK	inf →				inf →				
X7	OK	inf →				inf →				
X8	OK	inf →				inf →				
X9	OK	inf →				inf →				

Male Connectors

Test 1 All uncracked non leaky male connectors put in water tank for 16 hours and re-checked.

Conn.	Leakage				Leakage to Ground				Remarks
	Ø1/Ø2	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø2	Inst.	
M2	inf	→	→	→	inf	→	→	→	Chipped wafer @ rig
M3	inf	→	→	→	inf	→	→	→	
M6	inf	→	→	→	inf	→	→	→	
M7	inf	→	→	→	inf	→	→	→	
M8	inf	→	→	→	inf	→	→	→	
M9	inf	→	→	→	inf	→	→	→	
M10	inf	→	→	→	inf	→	→	→	
M11	inf	→	→	→	inf	→	→	→	
M12	inf	→	→	→	inf	→	→	→	
M14	inf	→	→	→	inf	→	→	→	
M15	inf	→	→	→	inf	→	→	→	
M16	inf	→	→	→	inf	→	→	→	
X1	inf	→	→	→	inf	→	→	→	Visual indication of porosity
X2	inf	→	→	→	inf	→	→	→	
X3	inf	→	→	→	inf	→	→	→	
X4	inf	→	→	→	inf	→	→	→	
X5	inf	→	→	→	inf	→	→	→	
X6	100M	→	→	→	75M	→	→	→	
X7	inf	→	→	→	inf	→	→	→	
X8	inf	→	→	→	inf	→	→	→	
X9	inf	→	→	→	inf	→	→	→	

Male Connectors

Test 2 All male connectors passing Test #1 subjected to 3000 psi for one hour and rechecked.

Conn. #	Leakage				Leakage to Ground				Remarks
	Ø1/Ø2	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø2	Inst.	
M2	inf	→	→	→	inf	→	→	→	Signal leakage only
M6	inf	→	→	→	inf	→	→	→	
M7	inf	→	→	→	inf	→	→	→	
M8	inf	→	→	→	inf	→	→	→	
M9	inf	→	→	→	inf	→	→	→	
M10	inf	→	→	→	inf	→	50M	→	
M11	inf	→	→	→	inf	→	→	→	
M12	inf	→	→	→	inf	→	→	→	
M14	inf	→	→	→	inf	→	→	→	
M15	inf	→	→	→	inf	→	→	→	
M16	inf	→	→	→	inf	→	→	→	
X1	inf	→	→	→	inf	→	→	→	
X2	inf	→	→	→	inf	→	→	→	
X3	inf	→	→	→	inf	→	→	→	
X4	inf	→	→	→	inf	→	→	→	
X5	inf	→	→	→	inf	→	→	→	
X7	inf	→	→	→	inf	→	→	→	
X8	inf	→	→	→	inf	→	→	→	
X9	inf	→	→	→	inf	→	→	→	