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Geothermal Drill Pipe Corrosion Test Plan

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Billy C. Caskey, Kathleen Sue Copass

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185
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GEOTHERMAL DRILL PIPE CORROSION TEST PLAN

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ABSTRACT

Plans are presented for conducting a field test of drill pipe corrosion, comparing air and nitrogen as drilling fluids. This test will provide data for evaluating the potential of reducing geothermal well drilling costs by extending drill pipe life and reducing corrosion control costs. Union Geothermal Company of New Mexico, a subsidiary of Union Oil Company of California, is participating by providing the drill rig, the well, and other support. Sandia National Laboratories is providing the nitrogen, recording the data, and assessing the results. The 10-day test will take place during fall 1980 at the Baca Location in Sandoval County, New Mexico.

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EXECUTIVE SUMMARY

Reducing drill pipe corrosion is one way to reduce the cost of geothermal well drilling, which is the goal of Sandia National Laboratories' Geothermal Drilling and Completion Technology Development Program. When aerated water is used as a drilling fluid (typically, geothermal reservoirs are underpressured and fractured, requiring a low-density drilling fluid), corrosion of the drill pipe is a serious problem. Drill pipe life can be reduced to weeks instead of years, even when expensive corrosion control chemicals are added to the water.

An inert gas can be used instead of air as the principal component of the drilling fluid, thereby reducing the corrosion problem. Data are needed to properly assess the effectiveness and economics of inert gas usage.

A field test is planned in conjunction with a Union geothermal well to be drilled in Redondo Creek Field at the Baca Location in New Mexico. The deeper part of the well will be alternately drilled with air and with nitrogen as the primary component of the drilling fluid. Measurements of the resulting corrosion rates will be made.

Air will be supplied, using Magcobar/Dresser compressors, and liquid nitrogen will be trucked to the site, pumped, and vaporized, using NOWSCO Services.

New drill pipe (used at the top and bottom of the hole) will be inspected before and after the test, using PA Incorporated Services.

EG&G will instrument the fluid flow streams, collect fluid samples, and record test data on digital tape.

The test is presently scheduled for early fall 1980.

GEOHERMAL DRILL PIPE CORROSION TEST PLAN

I. INTRODUCTION

Background

Sandia National Laboratories (SNL) manages the Geothermal Drilling and Completion Technology Development Program for the Division of Geothermal Energy (DGE) in the U.S. Department of Energy (DOE). The near-term goal of the program is to demonstrate the technical capability to reduce the cost of drilling and completing geothermal wells by 25% by 1983. Since drill pipe corrosion and corrosion control are significant cost contributors, the Geothermal Drilling and Completion Advisory Panel for this program has recommended that SNL investigate the use of inert, low-density drilling fluids. Nitrogen gas generated cryogenically and diesel exhaust gases treated with a catalytic converter have been suggested as possible drilling fluid candidates. SNL has separate efforts addressing these generation schemes.

Purpose

Data are sparse to nonexistent for corrosion rates of steel drill pipe when the drilling fluid in a geothermal well is air or nitrogen. The purpose of the test outlined in this report is to obtain these data.

Participants

The names, addresses, and telephone numbers of the individuals participating in this test are given in Appendix A. The organizations and their involvement are as follows:

Union Geothermal Company of New Mexico, a subsidiary of Union Oil Company of California -- Union is participating in this test on a cost-sharing basis. It is providing the well and the drill rig and assuming all costs associated with normal geothermal well drilling, such as the air compression costs and corrosion chemical costs. In addition, the company is providing new drill pipe (24 joints), corrosion coupons, corrosion probes and meters, and corrosion expertise. Union has also agreed to contract for the well services (nitrogen, pipe inspection, etc.) required for the test and to bill SNL for the actual costs incurred. SNL contract 62-2529 has been placed with Union for this purpose.

Sandia National Laboratories -- SNL is responsible for planning and conducting the test and assessing the results. SNL is providing essentially all the funding for costs over and above normal drilling operations through Union (Contract 62-2529) to service suppliers (NOWSCO, PA, Brinkerhoff, etc.). SNL is contracting separately to EG&G for instrumentation services as outlined in Section IV. DATA REQUIREMENTS. SNL will report the test results and also incorporate them in a study of low-density, inert drilling fluid/drill pipe corrosion.

EG&G -- EG&G/Las Vegas is providing the instrumentation (sensors, signal conditioning, displays, and recording) required and will provide the necessary personnel to acquire the data. EG&G/Kirtland is designing the hardware to allow fluid samples to be drawn for subsequent analysis in the laboratory and will provide the personnel to acquire the samples.

Loffland Brothers -- Loffland has provided helpful advice on planning and conducting the test and is continuing to provide consulting services. In particular, the drill pipe inspections will be made to Loffland standards.

NOWSCO Services -- NOWSCO will be used to provide the nitrogen required. Most equipment and manpower will be supplied from Farmington, New Mexico, and the liquid nitrogen will be transported from a plant in Albuquerque. The costs associated with NOWSCO Services are outlined in Appendix C.

PA Incorporated -- PA will be used to inspect the test drill pipe (24 joints) before and after the test at their Odessa, Texas, facility. They will inspect to the Loffland standard and will provide their most experienced personnel. Also, an engineer from their research laboratory in Houston will be on hand during the inspections. PA costs are listed in Appendix D.

Magcobar Division of Dresser Industries -- Magcobar will be used to provide and operate the air compressors during the air drilling phases of the test. They have also assisted in planning the test.

Brinkerhoff Signal -- Brinkerhoff has been contracted by Union to drill the well. Standby rig time needed for the test will be billed to SNL through Union. Rig modifications to accommodate instrumentation will be arranged by Union.

Test Details

Details on the test procedure, setup, data, and costs are provided in subsequent sections of this report.

II. TEST PROCEDURE

The geothermal drill pipe corrosion test will begin when a low-density drilling fluid is required for drilling ahead on a development well. This point is typically reached at about 3500 feet in the Redondo Creek Field at the Baca Location. The test will consist of four phases; each phase is depicted pictorially with its associated depth and drilling fluid in Figure 1. A general description of each phase follows:

Phase	Drilling Fluid	Approx. Depth (ft)	Estimated Elapsed Time (days)	Approx. Circulating Time (hours)	Remarks
I	Air	3500 - 4250	3	50	Customary chemicals
II	Nitrogen	4250 - 5000	3	50	No chemicals
IIA	Nitrogen	4500	0.02	0.5	During Phase II
III	Air	5001 - T.D.	2	30	Customary chemicals
IV	Nitrogen	On bottom	2	30	No chemicals

Phase IIA has been included to obtain corrosion rate data when small amounts of oxygen are injected with the nitrogen. The liquid nitrogen is expected to contain less than 5 parts per million (ppm) oxygen; oxygen content will be increased to 100 ppm for a short time as data are collected from a fast-responding corrosion rate probe (corrater). Since both the amount and the time of oxygen injection are small, the effect of Phase IIA on the long-term corrosion measurements (coupons and drill pipe) is estimated to be unmeasurable (less than 1%).

The following description of each test phase is included to provide more detail and a better chronology:

Phase I -- Install three joints of new drill pipe at the bottom and at the top of the string, install corrosion coupons in the crossover subs at the bottom and at the top of the string (also install a ring coupon about the middle of the string), and ensure that all instrumentation and sampling hardware are functional. Drill, using customary air drilling practices, for about 50 hours. This phase is expected to take about 3 days and deepen the hole to about 4250 feet. Record data and acquire samples as specified in Section IV of this report. Recover the coupons, lay down (set aside) the six joints of test drill pipe, and drain all water in the mud tank to clean out treated water.

Phase II -- Fill the mud tank with untreated water from the reserve pit, install new drill pipe (six joints) and new corrosion coupons in the same locations as in Phase I, and ensure that instrumentation, sampling hardware,

Figure 1. Pictorial Description of Test Phases

and nitrogen supply are proper. Drill ahead, using nitrogen and untreated water as required by the driller, for about 50 hours. Acquire data and samples as specified. Recover the coupons and lay down the six joints of test drill pipe. It is anticipated that this phase will take about 3 days; the hole depth will be about 5000 feet at completion.

Phase IIA -- At a convenient time during Phase II, inject oxygen into the nitrogen line to increase the oxygen content to 10, 20, 50, and 100 ppm in 5-minute-long steps. Data from the standpipe corraters will be taken to correlate with the oxygen concentrations. No samples will be drawn during this 20-minute period, and the short time is not expected to change the coupon or drill pipe corrosion measurements taken after a 50-hour exposure.

Phase III -- Treat the water as needed for air drilling, install new drill pipe (six joints) and coupons as before, and drill ahead for 50 hours or until total depth (T.D.), whichever is first. Based on previous experience, T.D. will be reached in about 30 hours at a depth of about 5500 feet. Acquire data and samples as specified. Recover coupons and lay down the six joints of drill pipe. Drain all water from the mud tank.

Phase IV -- After Union has performed necessary completion activities and the mud tank is filled with untreated water, the fourth phase will begin. Install six joints of new drill pipe and coupons as before and circulate nitrogen (without drilling) for a period comparable to Phase III (about 30 hours). Acquire data and samples as specified. Lay down the drill pipe and recover the coupons.

It is expected to take about 10 days to complete all four phases of this test. An instrumentation installation and checkout period has been provided on Baca 20 well earlier, in August 1980. This activity and the present schedule are shown in Figure 2. In Figure 2, the black triangles represent activities completed. All other dates should be considered tentative since they depend on field problems and conditions.

Figure 2. Test Schedule

III. TEST SETUP

At the present time, the detailed site layout for Baca 21 is not available. For information on a typical layout, Figure 3 is included. It was taken from the Final Environmental Impact Statement for the Geothermal Demonstration Program for a 50-MW power plant at the Baca Ranch (DOE/EIS-0049). In addition to the equipment shown, the following will be installed on or near the site to support this test.

<u>Item</u>	<u>Supplied by</u>	<u>Approx. Size</u>
Instrumentation trailer	EG&G	8 ft by 20 ft
Diesel electric generator	EG&G	8 ft by 15 ft
Sampling/chemical analysis trailer	EG&G	8 ft by 20 ft
Office/lab trailer	SNL	8 ft by 30 ft
Office trailer	NOWSCO	8 ft by 22 ft
Pump truck/transport	NOWSCO	8 ft by 120 ft
Standby pump truck	NOWSCO	8 ft by 40 ft

Additional detail on the NOWSCO space requirements may be found in Appendix C.

Service interconnections necessary for this test include

<u>Service</u>	<u>Supplied from</u>	<u>Supplied to</u>
Diesel fuel	Rig fuel tank	NOWSCO pump truck
Diesel fuel	Rig fuel tank	EG&G electric generator
Electricity	Rig generators	NOWSCO trailer
Electricity	EG&G generator	SNL trailer
Electricity	EG&G generator	EG&G trailer
Nitrogen	NOWSCO pump truck	Rig "air" line

SNL will also install a radio frequency repeater station at a location that will assure reliable radio communications between the SNL trailer and SNL in Albuquerque. An existing SNL frequency will be used that will not interfere with Union's radio equipment.

Figure 3. Typical Equipment Layout of a Geothermal Well

IV. DATA REQUIREMENTS

Data are required to realize the test objectives of determining drill pipe corrosion rates (for both air and nitrogen drilling fluids) and attempting to understand corrosion related field chemistry. The basic data sources are

1. Flow Lines
 - a. Instrumentation -- data obtained from sensors in or on the flow lines and recorded on magnetic tape in a digital format.
 - b. Physical Samples -- samples taken from various points in the flow lines for subsequent analysis.
2. Coupons -- steel corrosion coupons installed in the drill string for each test phase.
3. Drill Pipe -- new drill pipe installed at the top and bottom of the drill string for each test phase.

The following subsections describe in detail each of these data sources.

Flow Lines

Instrumentation

A block diagram of the instrumentation system is provided in Figure 4, and data to be obtained from flow line sensors are listed in Table 1. A plan view of the drill site is shown in Figure 5. It defines the approximate location of the instrumentation/sampling points in relation to the drill rig.

EG&G/Las Vegas will provide the support required to install, check out, and record these data. The basic data storage medium is digital magnetic tape (cassettes) although some information may be manually recorded in log books. The final test configuration will be determined jointly.

In addition to the digital tape, all data will be printed out periodically, and some will be displayed continuously on digital displays or on a strip chart recorder. Table 2 summarizes these parameters.

SNL will reduce and analyze these data in conjunction with the sample analyses (see next subsection).

Samples

Physical samples will be taken from the various flow lines, as indicated in Table 3. EG&G/Kirtland has designed the sampling hardware and will assist in obtaining the samples and performing some analyses.

Figure 4. Instrumentation System Block Diagram

Table 1
Flow Lines Instrumentation

ID	Type	Location	Range	Accuracy	Recording Rate	Remarks
P-Z	Pressure	Air/Nitrogen Line (point Z)	0 to 2000 psia	+20 psi	12 per hour	for sample indication
T-Z	Temperature		32 to 212°F	+2°F	12 per hour	
F-Z	Flow Rate		0 to 4600 ft ³ /min	+20 ft ³ /min	12 per hour	
S-ZS	Switch Closure		0 to 5 V	--		
P-B	Pressure	Standpipe (point B)	0 to 2000 psia	+20 psi	12 per hour	corroding wire probe galvanic probe
T-B	Temperature		32 to 212°F	+2°F	12 per hour	
Cl-B	Corrosometer		0.1 to 100 lb/ft ² ·yr	+5%	see note	
C2-B	Corrater		0.1 to 100 lb/ft ² ·yr	+5%	12 per hour	
P-C	Pressure	Blooie Line (point C)	0 to 100 psia	+2 psi	12 per hour	galvanic probe corroding wire probe for sample indication
T-C	Temperature		32 to 250°F	+3°F	12 per hour	
C2-C	Corrater		0.1 to 100 lb/ft ² ·yr	+5%	12 per hour	
Cl-C	Corrosometer		0.1 to 100 lb/ft ² ·yr	+5%	see note	
T-CS	Temperature	Water Line (point D)	32° to 250°F	+3°F	12 per hour	for sample indication
S-CS	Switch Closure		0 to 5 V	--	--	
P-D	Pressure		0 to 2000 psia	+20 psi	12 per hour	
T-D	Temperature		32° to 212°F	+2°F	12 per hour	
F-D	Flow Rate	Water Line (point D)	100 to 300 gpm	+5 gpm	12 per hour	for sample indication desired, not required
S-DS	Switch Closure		0 to 5 V	--		
PH-D	pH		5 to 14	+0.1	12 per hour	
F-A	Mass Flow Rate	Ammonia Line (point A)	0 to 10 gpm	+0.5 gpm	12 per hour	only active when using air
P-A	Pressure		0 to 2000 psia	+20 psi	12 per hour	
T-A	Temperature		32° to 212°F	+3°F	12 per hour	
F1-E	Flow Rate	Oxygen Line (point E)	0 to 1 ft ³ /min	+0.05 ft ³ /min	12 per hour	only active when injecting oxygen
F2-E	Flow Rate		0 to 0.4 ft ³ /min	+0.02 ft ³ /min	12 per hour	

Note: Channels Cl-B and Cl-C are read with a portable instrument approximately every hour.

Figure 5. Instrumentation/Sampling Points

Table 2
Data Displays

<u>ID</u>	<u>Location</u>	<u>Digital Display Parameters</u>	<u>Strip Chart Recorder Parameters</u>
F-Z	Air/nitrogen line	Flow rate	Flow rate
P-ZS	Air/nitrogen line	--	Switch Closure (sample indication)
C2-B	Standpipe	Corrosion rate (corrater)	Corrosion rate (corrater)
C2-C	Blooie line	Corrosion rate (corrater)	Corrosion rate (corrater)
P-CS	Blooie line	--	Switch closure (sample indication)
F-D	Water line	--	Flow rate
P-DS	Water line	--	Switch closure (sample indication)
PH-D	Water line	pH*	--

* Desired, not required.

The gas samples will be collected in special, SNL-fabricated, glass vessels for subsequent analysis by SNL (or a contractor).

Liquid samples will be collected in polyethylene bottles purged with argon. On-site pH and oxygen content determinations will be made as soon as possible after collection and cooling because some changes are expected in these parameters as the samples age. Other analyses will be performed by SNL (or a contractor) in the laboratory.

Solid samples will be collected in a filter assembly designed for this test by EG&G. SNL will perform the laboratory analyses.

Coupons

Corrosion coupons will be installed inside and outside the drill pipe, as specified in Table 4. A total of 12 rings and 8 disks will be supplied by Union and analyzed as shown in Table 5. The resulting data will be summarized and published by SNL. For reference, the API-recommended coupon test procedure is included as Appendix B.

Drill Pipe

Twenty-four joints of new drill pipe, provided by Union, will be used for this test.* Three new joints will be placed at the top of the drill string, and three more will be placed in the bottom portion of the string for each phase of the

* During the 8 July 1980 inspection, one joint of pipe was rejected; only 23 joints are available for the test.

Table 3
Sampling Plan

Sampling Point	Scheduled Timing	Estimated Quantity	Analyses Required
Blooie Line Instrumentation Spool (point C)	When drilling nears the end of every pipe joint, approx. every 90 minutes	100	Gas Sample -- O ₂ , CO ₂ , N ₂
		100	Liquid Sample* -- pH, Cl ⁻ , Ca ⁺⁺ , SO ₄ ⁻⁻ , CO ₂ , O ₂ , NH ₃ , total dissolved solids, Na, K, Ca, Mg, Li, F, Si, Ru, Cs, U, Fe, Sr, Al, S, As, B, Pb, Ag, Cu, W, Sb, Hg, Tl, Ba, H ₂ S (100 to 250 cm ³ size)
		100	Solid Sample -- X-ray diffraction, X-ray fluorescence
Water Line Instrumentation Spool (point D)	When drilling nears the end of every second joint of drill pipe, approx. every 3 hours	50	Liquid Sample* -- pH, O ₂ , Na, K, Ca, Mg, Li, F, Si, Ru, Cs, U, Fe, Sr, Al, S, As, B, Pb, Ag, Cu, W, Sb, Hg, Tl, Ba (100 to 250 cm ³ size)
Nitrogen Line Instrumentation Spool (point Z)	When drilling nears the end of every 8th to 10th joint of drill pipe, approx. every 12 to 15 hours	10 to 12	Gas Sample -- O ₂

* The pH and O₂ concentration will be measured as soon as possible after collection (on site). A separate sample and/or rapid cooling provisions will be provided as needed to make these measurements.

Table 4
Corrosion Coupon Plan

<u>Location in String</u>	<u>Location in Pipe, Shape</u>	<u>Installation Schedule</u>	<u>Total Required</u>
Top of drill string in Kelly saver sub	Internal, ring	New coupon at beginning of each of four test phases	4
	External, disk	New coupon at beginning of each of four test phases	4
Approximate center of drill string	Internal, ring	Same as above	4
Bottom of drill string in pipe/ collar crossover sub	Internal, ring	Same as above	4
	External, disk	Same as above	4

Table 5
Corrosion Coupon Analyses

<u>Measurement</u>	<u>Analysis</u>
Weight	Weigh coupons before and after exposure to within 1 mg per API RP13B.
Corrosion Rate	Provide time history plot of corrosion rates measured in the standpipe and blooie line, corresponding to the exposure of each coupon.
Metallographic	Provide metallographic examination, including annotated photomicrographs.
Scale Examination	Provide X-ray diffraction and X-ray fluorescence analysis (including annotated photographs) of coupon or drill pipe scale.
Photographic	Photograph each coupon before and after exposure.

test. PA Incorporated will perform drill pipe inspection services. An inspection report on each joint of pipe was completed on 8 July 1980, and an identical inspection will be performed after test completion. Each joint was die-stamped with an identifying number at the base of the pin tool joint prior to the first inspection. PA's Scanalog 400 system will be utilized in this study, and the procedures are as follows:

1. Transverse inspection -- electromagnetic inspection of the tube body for internal and external fatigue cracks, cuts, gouges, and corrosion pitting.
2. Longitudinal inspection -- electromagnetic inspection of the tube body for internal and external seams, slip area cracks, and wireline cuts.
3. Scanawall -- full-length tube body wall measurement, utilizing gamma-ray. This inspection records wall reduction, o.d., wear, general corrosion, and eccentricity.
4. Average wall -- recorded full-length continuous gamma-ray wall measurement readout of the average tube wall.
5. Magnetic particle of external surface of tool joints, excluding thread.
6. O.d. gauge full length.

In addition to the above services, PA will also perform the following procedures.

1. The used drill pipe worksheet form P-155 or P-155-1 will be used and provided to SNL as part of the inspection report.
2. The minimum wall thickness found anywhere along the length of each tube will be recorded in the column headed "Minimum Wall-Scanalog Inches." This value will not be at the base of isolated pitting.
3. The maximum wall thickness, at the same areas where item 2 is found, will also be recorded under the column headed "Maximum Wall Inches."
4. The lowest average wall thickness determination made anywhere along the length of the tube will be recorded in the column headed "Average Wall Inches." This value may not necessarily be of the same location as item 2 or item 3.
5. The tool joint flash date and pipe manufacture will be recorded for each joint on the full worksheet.
6. Measurement of the average o.d. at the area where the lowest average wall thickness is determined will be made with an o.d. tape. This measurement reads the outside diameter directly and will be recorded on the field worksheet.
7. Ultrasonic readings will be made at the base of isolated pitting areas and recorded.
8. Inspection tapes will be numbered in relation to the joint being inspected. Tapes from the original inspection will be provided for comparison with those from the second inspection.

Each time the pipe is inspected, the same inspection unit will be used, along with the same operator. Correspondence from PA detailing their participation in this test is included in Appendix D.

General Operational Data

In addition to the data recorded specifically for this test, operational data that may bear on economics or chemistry will be recorded. Some of these parameters are

1. Drilling log -- depth versus time.
2. Formation characteristics.
3. Ambient weather conditions.
4. Quantity of diesel fuel supplied to NOWSCO.
5. Corrosion control chemical records -- kind, quantity, time.
6. Water tank records -- time of chemical additions and flushing/filling operations.

V. RESOURCE ESTIMATES

SNL is funding the bulk of the costs (over and above normal drilling costs) necessary to perform this test. Anticipated expenditures include

<u>Item</u>	<u>Performed by</u>	<u>Estimated Cost</u>	<u>Remarks</u>
Liquid nitrogen	NOWSCO	\$304,000	See Appendix C
Diesel fuel for nitrogen vaporizer	Union contractor	1,500	300 gal/day
Drill pipe--inspection	PA Incorporated	4,800	See Appendix D
Instrumentation plumbing/rig mods	Union contractors	5,000	
Standby rig time (5d)	Union contractor	60,000	
Circulating rig time (3d)	Union contractor	36,000	
Miscellaneous	--	<u>1,200</u>	
	Total	\$412,500	

These services will be billed to Union for subsequent billing to SNL under contract 62-2529.

SNL will also provide instrumentation through a subcontract with EG&G, a DOE-integrated contractor. This contract is expected to result in a funds transfer of \$85,000 from SNL to EG&G.

SNL is committing two staff personnel to the test full time for approximately 3 months and approximately five other individuals on a part-time basis. The manpower to be expended on this test is valued at approximately \$45,000.

In addition to these government-derived resources, Union is providing the following:

1. New drill pipe (24 joints),
2. Corrosion coupons,
3. Corrosion probes and meters,
4. Technical support (including travel), and
5. Some drilling delay costs.

Union estimates that their investment will amount to approximately \$38,000 in direct costs. In addition, Union is contributing the use of a geothermal well worth over \$1,000,000 and is assuming all risks of damage to the well.

In summary, the total cost of this test is expected to be

SNL	\$542,500
Union	<u>38,000</u>
Total	\$580,500

APPENDIX A
Participants and Contacts

APPENDIX A

Participants and Contacts

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APPENDIX B

API Drill Pipe Corrosion Ring Coupon
Test Procedure

DRILL PIPE CORROSION RING COUPON TEST PROCEDURE (Tentative)

A.1 The placement of corrosion test rings in the drill string is one of the more common techniques used to evaluate the corrosiveness of drilling fluid environments on the drill string and other steel goods. Removal and examination of these rings after a period of exposure downhole can be highly informative as to the corrosiveness of the drilling fluid as well as to the type of corrosion encountered. An examination of scales and pits on the exposed rings gives clues as to the cause of the corrosion, thus aiding in choosing proper remedial action.

A.2 The ring technique is specifically designed for detection of the type of corrosion characterized by metal loss whether it be localized (pitting) or generalized attack. The test ring is not designed to give information relating to hydrogen embrittlement, stress corrosion cracking, or other forms of fracture except in the manner in which pitting may relate to these failures.

A.3 Ring Composition and Construction. The ring-type drill string corrosion coupon, or corrosion ring, should be machined to fit in the tool joint box recess, at the end of the pin, and should have a bore the same as that of the tool joint to minimize turbulence. Ideally, to avoid galvanic corrosion, the ring should be made from steel identical to that of the tool joint in which it is placed. Such a requirement is impractical and use of a steel that is similar in chemical composition, such as AISI 4130, is recommended.

NOTE: *If steel other than AISI 4130 is used, it should be identified on the report form.*

The rings are normally cut from tubes that have not been quenched and tempered. The similarity in composition of the 4130 steel and the tool joint should be adequate to minimize galvanic effects and provide useful data.

A.4 Marking and Preparation. The rings should be stenciled with a serial number for permanent identification. They should then be scrubbed with a stiff fiber bristle brush and detergent solution, rinsed with clean water, and then with anhydrous acetone or methanol. Allow to dry, weigh to one milligram, and record this weight on the report form. Store the ring in a dry container, such as a desiccator, to prevent corrosion. The corrosion rings should be shipped to the field in sealed envelopes or wrappers to minimize atmospheric corrosion.

A.5 Procedure.

- a. Drill pipe corrosion rings should be kept in the drill string for a minimum of 40 hours. Exposure periods of less than 40 hours should not be used because initial corrosion rates are unusually high and can give misleading data. The ring is usually placed in the tool joint at the top of the first stand above the drill collars and can be left in the drill string for more than one bit run. An additional ring can be placed in the kelly saver sub to monitor corrosion at that point. Care should be taken to insure that the box recess is clean to prevent interference with proper make-up of the joint and to avoid damage to the ring. In some instances specially manufactured subs have been used for the ring placement in the string. During installation the ring should be handled with clean, dry gloves only.
- b. The drill pipe corrosion coupon form should be filled out completely. Each form should have a space for ring material, drilling fluid properties, type of corrosion, location of ring in drill string, initial weight, time, depth in, depth out, ring number, color of scale, and any other information of significance in the specific test. The form may be printed on a mailing envelope for the ring or on a separate form to be enclosed with the ring.
- c. The drilling fluid residue should be removed from the coupon by wiping with a cloth when the ring is pulled from the drill string. The ring should be examined for severity of corrosion or mechanical damage. If severe corrosion is evident, the cause of the corrosion should be determined promptly so remedial action can be taken. Following visual observation, immediately coat the coupon with oil or other available grease. (Do not use thread compound for this purpose.) Place in a plastic bag and then in the mailing envelope.
- d. Before proceeding with a quantitative evaluation of corrosion of the ring, the ring should be rinsed with a suitable solvent, such as acetone or petroleum ether to remove the oil applied to the ring on location. Prior to cleaning for weighing, a spot test should be made for corrosion by-products and mineral scale. For example, the surface can be examined qualitatively for sul-

fides by the acid arsenite test.⁽¹⁾ The rings should be cleaned with a detergent solution and a stiff fiber bristle brush. It may be necessary to dip the ring for 5 to 10 seconds in *inhibited* 10 to 15% hydrochloric acid one or more times to remove corrosion products. The ring should be scrubbed with detergent solution after each acid dip. Rinse thoroughly with clean water and then with anhydrous acetone or methanol. Allow to dry prior to weighing. Harsh, abrasive materials or strong, uninhibited acids should not be used. An ultrasonic bath can be useful in cleaning the rings.

- c. After the preweighed drill pipe corrosion coupon has been properly cleaned and the corrosion film and type of attack noted, the ring should be reweighed to 1 milligram and the weight loss determined. If significant loss of metal due to mechanical damage is evident, it should be noted and taken into consideration in evaluating the ring. The corrosion rate may be reported as grams per square decimeter per year, lb per sq ft per year, or mils per year. Formulas for calculating the corrosion rate are given in Par. A.7.

A.6 Comments on Visual Examination. If visual corrosion is evident, it will normally be detectable as pitting corrosion. Uniform attack or general corrosion can best be determined by a weight loss measurement. Mechanical damage to the ring will most often be evidenced by cuts or dents on the outer surfaces of the ring. In some cases, the ring will exhibit a series of dents and worn spots, indicating considerable movement of the ring in the box recess.

In assessing the magnitude of the corrosion rate as calculated from weight loss measurements, it should be remembered that the rate is also influenced by the erosive effects of the drilling fluid. Since the bore of the ring is exposed to the mud pumped down the drill pipe, the loss of metal includes that removed by erosion as well as from corrosion. Loss from erosion can be substantial when the drilling fluid contains a high concentration of sand.

Examination of the ring may reveal a few deep pits with a relatively low weight loss. This condition would indicate a rather severe corrosion problem even though the calculated corrosion rate would be considered low.

⁽¹⁾ *Corrosion of Oil- and Gas-Well Equipment*, API, Dallas (1958)

A.7 Calculation of Corrosion Rates.

- a. The corrosion rate in kilograms per square meter per year may be calculated by the following formula:

$$\begin{aligned} \text{kg/m}^2/\text{yr} &= \frac{\text{wt. loss, mg}}{1,000,000} \times \frac{10,000}{\text{*area, cm}^2} \times \frac{365}{\text{days exposure}} \\ &= \frac{\text{wt. loss, mg} \times 87.60}{\text{*area, cm}^2 \times \text{hours exposed**}} \\ &= \frac{\text{wt. loss, mg} \times 13.58}{\text{*area, in.}^2 \times \text{hours exposed**}} \end{aligned}$$

- b. The corrosion rate in pounds per square foot per year may be calculated by the following formula:

$$\begin{aligned} \text{lb/ft}^2/\text{yr} &= \frac{\text{wt. loss, mg}}{453,600} \times \frac{144}{\text{*area, in.}^2} \times \frac{365}{\text{days exposure}} \\ &= \frac{\text{wt. loss, mg} \times 2.781}{\text{*area, in.}^2 \times \text{hours exposed**}} \end{aligned}$$

- c. The corrosion rate in mils per year may be calculated by the following formula:

$$\text{mpy} = \frac{\text{wt. loss, mg}}{\text{specific gravity} \times 16.387 \times \text{*area} \times \text{yr}} \\ \left(\frac{\text{g/cm}^3}{(\text{cm}^3/\text{in.}^3)} \right) \left(\frac{\text{in.}^2}{(\text{in.}^2)} \right) \left(\frac{\text{days/365}}{(\text{days/365})} \right)$$

For steel coupons with a specific gravity of 7.86, the formula can be reduced to:

$$\text{mpy} = \frac{\text{wt. loss, mg} \times 68.33}{\text{*area, in.}^2 \times \text{hours exposed**}}$$

- d. Following are the conversion rates between the various units for steel coupons (specific gravity 7.86):

$$\text{mpy} = 24.62 \times \text{lb/ft}^2/\text{yr}$$

$$\text{mpy} = 5.03 \times \text{kg/m}^2/\text{yr}$$

$$\text{lb/ft}^2/\text{yr} = 0.04 \times \text{mpy}$$

$$\text{lb/ft}^2/\text{yr} = 0.20 \times \text{kg/m}^2/\text{yr}$$

$$\text{kg/m}^2/\text{yr} = 0.20 \times \text{mpy}$$

$$\text{kg/m}^2/\text{yr} = 4.90 \times \text{lb/ft}^2/\text{yr}$$

- e. Corrosion rings available from drilling fluid service companies or corrosion test laboratories are generally supplied with a multiplication factor which includes the metal density and surface area of the ring. Thus, the weight loss divided by the exposure time need only be multiplied by the supplied factor to obtain the corrosion rate.

*The total surface area of the ring is used in these calculations.

**Time used based on total time in drill string.

APPENDIX C
NOWSCO Services Costs

NOWSCO SERVICES

A Big Three Industry
P.O. Box 1574 • Houston, Texas 77001 • Phone 713/861-4111

April 15, 1980

Frank Corbin
Union Geothermal of New Mexico
4100 Southern Blvd., S. E.
Rio Rancho, New Mexico 87124

Dear Mr. Corbin:

As requested in the letter from Bill Caskey, the costs for our services for the nitrogen test at Jemez Springs are as follows:

Set up charges \$625.00 includes first 25,000 SCF of nitrogen, one 3000 SCF/min. pump truck, and one operator.

Nitrogen charges in access of first 25,000 SCF will be \$1.65 per hundred SCF.

Pump truck hourly charges will be \$55.00 per hour.

Second pump truck and all unmanned standby charges for both pump trucks will be \$40.00 per hour.

Transport truck for on site storage will be \$50.00 per hour.

Additional transports, as needed, will be charged at \$50.00 per hour, while on location.

Pump trucks mileage will be charged round trip from Farmington, N.M. at \$1.50 per mile per truck.

Transports will originate and refill at Albuquerque, N.M. and round trip mileage charged for transports at \$1.50 per mile per truck.

Additional supervision will be charged at \$175.00 per day.

Remote location subsistence will be charged at \$80.00 per man per day.

The travel trailer will need 110 volts, 30 amps for electrical power.

Included in this letter is a sketch showing the approximate space needed for equipment.

As stated in the previous letter to Sandia Laboratories, dated March 20, 1980, we will need a two (2) inch connection with valve.

Approximately 300 gallons of #2 diesel fuel per day will be needed for pump trucks.

I hope this information will be sufficient, if not, feel free to write or call me.

NOWSCO SERVICES

A Big Three Industry
P.O. Box 1574 • Houston, Texas 77001 • Phone 713/861-4111

NOWSCO Services at Farmington, N.M. will require a minimum of forty-eight (48) hours notice before beginning the job.

All prices are subject to change without notice.

Sincerely,

Robert Fette

Robert Fette
District Manager

cc: Dr. Steven Pye
Union Oil of California
Union Geothermal Division
2099 Range Avenue
Santa Rosa, CA 95406

Bill C. Caskey
Sandia National Laboratories
Division 4744
Albuquerque, N.M. 87185

APPENDIX D
PA Incorporated Services and Costs

April 22, 1980

Mr. Bill Caskey
System Analysis
Division 4716
Sandia Laboratories
Albuquerque, New Mexico 87185

Dear Bill,

This letter is to confirm my visit with you and Kathy Copas on April 17, 1980 and our discussion concerning used drill pipe inspection methods in relation to your corrosion rate study. You will be performing this study for Union Oil of California Geothermal Division on a geothermal well to be drilled by Brinkerhoff Drilling. The well site is located in Northern New Mexico.

As I understand it, the purpose of this study is to measure the corrosion rates in used drill pipe in both air and nitrogen drilling environments. The pipe will be inspected prior to and during your evaluation as follows:

6 joints	after	50 hours	Air Drilling
6 joints	after	50 hours	Nitrogen Drilling
6 joints	after	100 hours	Air Drilling
6 joints	after	100 hours	Nitrogen Drilling

PA Incorporated will participate in this study utilizing our Scanalog 400 inspection service. The standard procedures for this service are as follows:

1. Transverse inspection - electromagnetic inspection of tube body for internal and external fatigue cracks, cuts, gouges, and corrosion pitting.
2. Longitudinal inspection - electromagnetic of tube body for internal and external seams, slip area cracks, and wireline cuts.
3. Scanawall - Full length tube body wall measurement utilizing gamma ray. This inspection records wall reduction, O.D. wear, general corrosion, and eccentricity.
4. Average Wall - Recorded full length continuous gamma ray wall measurement readout of the average tube wall.
5. Magnetic particle of external surface of tool joints excluding thread.

PA Incorporated
P.O. Box 7631, Houston, Texas 77007, Telephone: (713) 524-9141, TWX: 910-881-2585

ANESL COMPANY

6. O.D. guage full length.

In addition to our standard procedures, we will also perform the following services:

1. The used drill pipe worksheet form P-155 or P-155-1 will be used and provided Sandia Laboratories or part of the inspection report.
2. The minimum wall thickness found anywhere along the length of each tube will be recorded in column titled "Minimum Wall-Scanawall Inches." This value will not be at the base of isolated pitting.
3. The maximum wall thickness, at the same ares #2 is found, will also be recorded under column titled "Maximum Wall Inches".
4. The lowest average wall thickness determination made anywhere along the length of the tube will be recorded in the column titled "Average Wall Inches". This value may not necessarily be of the same location as #2 or #3.
5. Joint number will be die stamped at the base of the pin tool joint prior to the first inspection.
6. The tool joint flash date and pipe manufacture will be recorded for each joint on the full worksheet.
7. Measurement of the average O.D. at the area where the lowest average wall thickness is determined, will be made with an O.D. tape. This measurement reads the outside diameter directly and will be recorded on the field worksheet.
8. Ultrasonic reading will be made at the base of isolated pitting and recorded.
9. Inspection tapes will be numbered in relation to the joint being inspected. Tapes from the original inspection will be provided for comparison purposes of second inspection.

Location of our inspection to be performed will be at PA Incorporated yard located at either Casper, Wyoming or Odessa, Texas. Inspection location site will be determined by Sandia Laboratories. Each time the pipe is inspected, the same unit will be used along with the same operator.

We would appreciate as much lead time as possible. As you indicated, this inspection should take place near the end of May or first of June 1980. We would also appreciate a complete description of the pipe prior to inspection time.

We will notify you as to when the inspection will take place, as you and Kathy Copas indicated you will want to be present during actual inspection. Estimated time for performing this service will be about one day per each time the pipe is inspected. Due to the nature of the inspection procedures and services to be performed, we will charge \$2,400.00 per day.

PA Incorporated is looking forward to participating in this study with Sandia Laboratories and Union Oil of California Geothermal Division. Please notify me when and where you will have the planning meeting involving all the companies participating in this study, as I would like to attend.

If you have any further questions, please feel free to call me at our Houston, Texas office 713-524-9141.

Sincerely,

Bill Anderson
Corporate Sales Manager

cc: Union Oil of California
Dr. Steven Pye
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