Fourth Novatek Hammer Field Test

Department of Energy Well PM-2-31
Garfield County, Colorado

September, 1995

Report Prepared for Mud Hammer Development Project Partners Mobil Oil Novatek

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Dallas, Texas
September 1995

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EXECUTIVE SUMMARY

Objectives

The primary objective of the fourth field test was to establish if the threshold level of power required to increase rock bit penetration rates with hammering in the moderately hard formations expected at 5,000 to 6,000 ft in DOE well PM-2-31 is within the range of power output possible with the current Novatek hammer design. One of the prototype Novatek mud hammers (tool N3) was modified for the fourth field test by reducing the length and OD of the bottom connection and re-cutting it to a box to accept a bit directly below the hammer. In this way the efficiency of delivering blow energy to the bit was increased compared with the previous field tests. To maximize the blow energy produced by the hammer the bit and hammer pressure drop planned was 800 to 1,000 psi, based on, the maximum available surface pump pressure.

A secondary objective was to evaluate the effectiveness of using stellite hard metal sleeve seals in place of the elastomer seals used in the Novatek hammers supplied for previous field tests. Achieving 24 - 48 hours of hammer operation downhole without appreciable erosion from the 9.3 ppg low solids waterbased mud was anticipated.

Results of Fourth Field Test

'Me fourth mud hammer field test was performed in well PM-2-31 from 5,316 ft to 5,495 ft using an 8 -3/4" Reed HP5 I A bit (IADC code 517). Due to pump problems the bit and hammer pressure drop achieved was only 750 psi, so hammer blow energy was slightly lower than planned. Drilling rate, including connection time, averaged 16.3 ft/hr with the hammer. Instantaneous drilling rates ranged from 15 ft/hr in the silty sands to 30 ft/hr in the interbeded shales of the Mesa Verde. These drilling rates are comparable to drilling rates routinely achieved under similar drilling conditions without the hammer (e.g. the same bit averaged 15 ft/hr when re-run after pulling the hammer). Hence, the blow energy delivered by the Novatek hammer in this field test was not high enough to exceed the threshold level required to improve the drilling rate.

The test was stopped after only I I circulating hours due to falling surface pump pressure that indicated a washout. A pumping test with the hammer at surface indicated the washout was in the hammer and examination of the internals confirmed that significant fluid erosion had occurred across one of the stellite seal areas and the test was therefore terminated.

Next Steps

Novatek is reevaluating the stellite hard metal used for the seal areas of the hammer and the configuration of the seals, primarily the clearances used. In the upcoming testing planned at Reeds drilling test laboratory in Houston the primary objective will be to establish the effectiveness of the current prototype hammer design for improving penetration rate under a range of simulated downhole drilling conditions, including those of the fourth field test.

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CONCLUSIONS

1. The 16.3 ft/hr performance of the hammer and HP5 I A insert bit combination in the Mesa Verde was only 8% better than with the same bit re-run after pulling the hammer. This small performance improvement is not enough to conclude that the hammer was operating above the threshold energy level required in the Mesa Verde formation at this depth.

2. Satisfactory evidence of the hammer operating downhole was obtained from monitoring the surface pump pressure and flow rate during the fourth field test. Pump pressure was used as the primary indicator of hammer operation, as surface vibration monitoring equipment was not available. However, with the hammer acting just like a fourth bit nozzle (11.5/32") that was approximately the same as the three bit nozzles (10/32") it was impossible to distinguish between plugging a bit nozzle and the hammer not operating. When a higher pressure than expected was observed, indicating the hammer was not working or a bit nozzle was plugged, efforts to re-start the hammer by bumping the bit on bottom were successful and pump pressure returned to normal.

3. In order to reliably detect hammer operation, future Novatek hammer field tests need to be conducted using surface vibration monitoring equipment. Such equipment was investigated for the fourth field test but was not available at the time of the test.

4. Further development of the hard metal seal systems used in the prototype Novatek hammer run in the fourth field test is required to achieve a target life of 100 hrs. After only I I hrs. with a bit and hammer pressure drop of 750 psi using 9.3 ppg waterbased mud there was significant washing in the stellite seal areas.

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RECOMMENDATIONS

1. Re-evaluate stellite seal system design used in the N3 prototype Novatek hammer run in the fourth field test. Longer life is required.

2. Proceed with planned testing of current prototype Novatek hammer design at Reed's drilling test laboratory in Houston to establish range of conditions under which it can provide enough energy to exceed the threshold required to improve penetration rates with roller cone bits.

3. Consider designing a Novatek hammer with a design operating pressure of no more than 750 psi for operation with smaller land rigs.

4. Consider designing all Novatek hammers with a re-set mechanism that will provide ideal conditions for re-starting after connections.

5. Consider boring the top sub of the Novatek hammers for a float sub and using plastic plugs to temporarily plug the exhaust ports during running in the hole. This could further improve the reliability of getting the hammer to bottom in deeper wells where solids build-up from back-flow through the hammer can be a problem. In the fourth test a dump sub was successfully run above the hammer to prevent back-flow through the hammer but a float sub would have been a better choice from a safety standpoint as the well was being drilled somewhat under balanced.

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Field Test Procedure and Results

1. **Assemble modified Novatek hammer (tool N3) with stellite sleeves for seals (see drawing in Appendix 3) and torque up service connections. Deliver tool N3 to wellsite.**

2. **Install three 10/32 nozzles in the 8-3/4 " Reed HP51A 8-3/4 " bit Nozzle sizes based on expectation of getting a bit + hammer pressure drop downhole of 994 psi at 60 strokes (360 gpm); as per hammer hydraulics spreadsheet with hammer behaving like a 10.4/32 nozzle (as it did in previous field tests) and pumping 9.1 ppg mud.**

3. **Conduct safety meeting with rig crew to explain what to expect Make up the hammer in the BHA with only the bit below it and with dump valve above. Torque's 25,000 ftlbs for bottom connection, 30,000 ftlbs for top connection.**

   Two cross-overs were required to make up the dump valve, one on top of the hammer and one on top of the dump sub. A non-ported float and crows foot for landing the survey instrument had been run on the previous bit. There was no way the float could be run above the hammer as none of the box connections was bored for it. Running either the dump sub or the float above the hammer would have ensured that mud would not be forced to back-flow into the hammer through the exhuast ports. Running the float would be a safer alternative for wells like PM-2-31 being drilled under balanced.

4. **Pick up the kelly and pump through the hammer and bit at surface (in the well) to verify back pressure at three rates. Use hammer hydraulics spreadsheet to determine equivalent nozzle size of hammer.**

   Checked that piston was following extending bit sub as tool picked up by observing the end of the piston through the exhaust ports. Hammer started immediately when pumping started. Following data obtained from pumping test and calculated using the hammer nozzle spreadsheet:

Pump #1 SPM	Flow	Pressure	Calc.Hammer nozzle
43	258 gpm	540 psi	10.4/32”
57	342 gpm	830 psi	11.7/32”
66	400 gpm	1060 psi	12.4/32”

5. **Place the bit and hammer assembly into the rat hole and set bit down. Pump through assembly at three rates and verify hammer operation.**

   Hammer faithfully started when placed into the rathole. Essentially the same pressures recorded with hammer in the rathole, hammering on the bit. May have been slight change in operating frequency based on simple vibrating reed sensors.

Target flowrate for drilling set at 360 gpm (60 SPM) to achieve a downhole bit and hammer pressure drop of 840 psi and a surface operating pressure of 1,650 psi at 5316 ft. (Well within the 1,850 psi limit that rigsite supervisor advised was available.)

6. **If the measured pressure drop with the hammer operating at surface is significantly different from the predicted values then use the hammer hydraulics spreadsheet to select alternate bit nozzles to obtain the required downhole bit + hammer pressure drop of 800 to 1,000 psi.**

   No change needed.

7. **Pick up remainder of BRA. Note survey instrument crows foot position above bit Run in the hole breaking circulation as required.**

   Broke circulation at 2,543 ft and first pressure indication was that hammer was not functioning (or one bit nozzle plugged). After bouncing the string following pump pressure indicated hammer was operating:

Pump #1 SPM	Flow	Pressure	Calc.Hammer nozzle
63	382 gpm	1580 psi	1583 psi

8. **Wash/ream to bottom as necessary. With bit near bottom (5316 ft) record pressure to confirm hammer operating. Break in bit to establish new bottom hole pattern as per manufacturers recommendations for normal rotary drilling using appropriate weight and rpm.**

   Lower than expected pump pressure indicated dump sub was not closed. Bounced string and dump valve closed, as indicated by sudden increase in pressure. Increase in pressure caused problems running pump #1 (6" liners) so pump #2 (5-1/2" liners) was tried. It was thought that the hammer was not operating so attempts were made to shift the shuttle valve to the fully down position by bouncing the string. No change in pump pressure was seen so it was concluded that either the hammer was not operating, due to a fouled shuttle valve, or one of the bit nozzles was partially plugged. However, pump pressure was not stable but falling so it was concluded that whatever was fouled was clearing itself.

9. **Break in bit to establish new bottom hole pattern as per manufacturers recommendations for normal rotary drilling using appropriate weight and rpm. Once drilling conditions stabilize record all the following parameters every 30 minutes and at any time that the average drilling rate changes significantly:**

   Hole depth
   WOB
   rpm
   ROP (30 min. ave. from geolograph chart)
   Pump strokes
   Pump pressure
   Mud density
   Mud viscosity
   Take directional survey as required.

As can be seen from the annotated drilling recorder carts in Appendix 2 a WOB of 40,000 lbs and an rpm of 65 was held essentially constant for drilling. An initial drop off in pump pressure was observed to stabilize after an hour of drilling. Despite plans to use pump #1 the surface pressure was too high for it to handle (it was then that it came to light that the engine driving it was under powered) so drilling continued at a lower flow rate than planned with pump #2 (equipped with 5-1/2" liners) as follows:

Pump #2	SPM Flow	Pressure	Calc. Pressure
66	336 gpm	1400 psi	1433 psi

No inclination surveys were run during the bit run with the hammer but surveys taken before and after the hammer run indicated no unusual change in inclination had occurred:

10. Terminate test if:

a) Hammer stops working (drop in ROP and increase in pump pressure) and hammer cannot be restarted by spudding bit to move piston to the bottom of it's travel.

b) Pump pressure change indicates plugging or wash-out.

c) Hammer operates for 48 hrs. downhole.

Test terminated at 5,495 ft due to a rapid fall off in pump pressure from 1,300 to 1, 100 psi indicating a wash out.

11. Pull out hammer assembly. Run surface test to determine if hammer still operational. Record bit condition.

In the initial surface pumping test the hammer was not operating but the results showed it was acting like a significant size additional bit nozzle so the wash was confirmed as being within the hammer:

Pump #1	SPM Flow	Pressure	Calc. Hammer nozzle
56	340 gpm	1010 psi	10.2/32"
65	394 gpm	1200 psi	11.2/3211

Spudding the bit on the non-slip flooring adjacent to the rotary table moved the piston to the full down position and then the hammer started up with pumping. Surface pumping test results with hammer operating was as follows:

Pump #1	SPM Flow	Pressure	Calc. Hammer nozzle
57	342 gpm	580 psi	15.5/3211
65	394 gpm	730 psi	15.5/32"

Disassembly of the hammer confirmed significant washing of the stellite sleeve on the inner housing seal area. Most significant washing was concentrated in one longitudinal strip that may have been associated with a known crack in the stellite sleeve than ran from the center of the sleeve to the downstream edge. Wash also extended into but not through the inner housing sleeve at the downstream edge of the washed stellite sleeve. Bit was *in* gauge with *no* teeth wear and bearings estimated as only 1/8 worn. (Bit was re-run after changing out nozzles for three 16's.)

12. Return hammer to Novatek for cleaning and inspection.

Erosion had caused significant metal loss as follows: Loss of 5 to 15 thou. (tapered erosion) from stellite sleeve on OD of inner cannister.

Hammer operation had caused coining of impact surfaces on the piston and shuttle valve as follows:

Increase in length of the shuttle valve stops of 10 to 15 thou.

APPENDIX 1 - Well Data

Mesa Verde Drilling Prognosis, prepared by Flour Daniel (NPOSR) Inc.

Annotated Totco Drilling Data Records; 5316 - 5495 ft

Photographs of Bit Pulled at 5316 ft and Bit Run at 5316 ft

Fluor Daniel (NPOSR) Inc.

U.S. Naval Oil Shale Reserve No. 3
Garfield County, Colorado
Rulison Field

MESAVERDE DRILLING PROGNOSIS

WELL NUMBER DOE RM-2-8 JOB ORDER: #543201 (6637)

LOCATION: 1,770’FSL and 463' FEL SE/SE, Sec. 8, T6S-494W

ELEVATIONS: 5,935' GL 5,947'KB

H: 12' KB

EST. TD 8700' TMD

OBJECTIVE PAYS: Cameo Coal & Upper Mesaverde Formation

FORMATION TOPS:

Formation	Measured Depth	S.L. Datum (TYD)
Wasatch “G”	2,427'	3,525'
Williams Fork	5,043'	909’
Fluvial Zone	6,204'	-252’
Costal Zone	7,081’	-1,129’
Cameo Coals	8,700'	-2,748’

DRILLING, CASING AND CEMENTING PROGRAM

PROCEDURE:

1. Provide safety orientation to all subcontracts personnel before accessing the well location.

2. Survey and stake location.

3. Construct location, pits and access road.

4. Move in and rig up drilling rig.

5. Drill a 13-1/2' hole to approximately 800, KB using native mud w/sufficient gel to ensure a clean hole. The surface hole will be drilled to a depth to match the length of casing delivered to the location.

6. Run 9-5/8 0, K-55, 36#/ft casing and cement to surface. Land casing 1 below ground level. Cement with 320 sx 50150 Poz Mix containing 5 % Gel, 2 % CaC12, with 1/4#/sk celloflake and 1/4#/sk kwikseal. Tail with 120 sx Class "0' containing 2% CaCl2, and 1/4#/sk celloflake; utilize top and bottom

rubber plugs. Displace with water. With I * pipe, pump 35 sx Class "G" containing 3% CaCI2 between the conductor and the surface casing.

Casing string will be run as follows:

a. Guide Shoe

b. Insert float valve one joint off bottom.

c. One centralizer 5' off bottom, centralizer on. next collar centralizers on every other collar thereafter.

7. WOC 6 hours. Tea to ensure casing does not move and nipple up BOP including rotating Nod and choke manifold.

8. Test BOP, choke manifold, and all safety valves using a qualified BOP Tester. Trip in hole and test suface casing to 200 psi and follow with 3,000 psi with water.

9. Drill 8-3/4" hole with drilling mud. The mud must ham a water loss at or below 8cc prior to drilling into the Wasatch “G”.

10. At TD, circulate the hole clean, make a short trip, circulate the time required to ensure a clean hole and TOOH for logs.

11. Log the interval of interest in the open hole with DEL, FDC, CNL, GR and Caliper, or as directed by the wellsite Geologist.

12. Trip in the bole and circulate clean to run 5-1120 cuing. Up out of the hole laying down the drill string. Condition hole to minimize drag and torque before LDDP.

13. a) Make sure 5-1/2* pipe rams have been installed a BOP and tested. Reduce ft annular closing pressure to below the 5-1/2" casing collapse rating.

b) Run 5-1/2", N-80, 17#/ft, LT&C to T.D. Casing crew is to supply and use environmentally safe API approved pipe dope. Rig is to supply landing joint only if threads are LT; if not, use extra jt. of N-80 Casing lowering speed is not be faster than 20 seconds/joint unless determined differently by Fluor Daniel on-site supervisor

Casing string will consist of a differential fill &hot, a differential fill float collar two joints, above bottom, one centralizer 5' above bottom, centralizers on the next three collars, then one centralizer on every other collar through zones of interest If a stage collar is used it will be placed at approximately 4,300', with one basket placed on the joint above and one on the joint below the stage collar.

c) 1) Pressure test all cement lines, manifold and head to 3,000 psi minimum prior to cementing.

2) Circulate hole, working casing on 20' stroke if possible, for 30 minutes; when returns am full and drag is stabilized, proceed with cementing.

3) NOTE: The following cement design is preliminary and will be altered depending on mud wt., pump time, placement of stage collar and further engineering review.

1st Stage: Pump 20 bbls mud flush; followed by I ,300 sks of 50150 Poz containing 2 % gel, appropriate fluid loss, retarder, and gas migration control additives, IAN celloflake and 1/4#/sk kwikseal Yield - 1.19 ft3/sk weight 14. 1#/gal.

2nd Stage: Pump 20 bbls mud flush; followed by 1, 100 sks of 65-35 Poz w/6% gel at 13.3-13.1 ppg and 1.69 ft3/sk; followed with 290 sx 50150 Poz containing 2% gel, appropriate fluid loss, retarder and gas migration control additives and 1/4#/sk celloflake.

The actual cement volume is to determined from the caliper. The cement top will be 500' above the upper productive Mesaverde zone or into the base of the surface casing, depending an Wasatch results and whichever is most advantageous. Top and bottom rubber plugs arc to be used.

4). Displace cement with fresh water.

14. Upon completion of the cementing operation, raise the BOP, set the slips and release the drilling rig

NOTE:

a) Logs are to be run as directed by the wellsite Geologist.
b) On trips, connections and running casing, pull and lower the pipe slowly to reduce to possibility of damaging the well bore.
c) Caliper the O.D. and I.D. and record the dimensions of everything that goes in the hole.
d) The drill string must be strapped on the final trip out of ft hole, before any logging, coring, or testing and at any other time as deemed necessary by the Geologist or Supervisor on site. All corrections must be made, prior to continuing Operations.

MUD PROGRAM

1. 13-1/2" Surface Hole: Native mud w/gel.

2. 8-3/4" Hole, Low Solid Non-dispersed System with fluid loss below 8cc prior to penetrating the Wasatch and then below 7cc prior to penetrating the Mesaverde. Maintain viscosity at or below 40 sec *for* drilling and as low a mud weight as safely possible and still maintain well control

3. The following mud maintenance equipment will be installed and used to maintain optimum mud properties: centrifuge and gas buster.

SAMPLES

Samples will be taken by drilling personnel or mud loggers, as requested by ft wellsite Geologist and at the intervals listed below:

a. Surface Hole: NO SAMPLES
b. 8-3/4' Hole: 30' samples zone of interest begin 10' samples

CORING: None anticipated.

DRILL STEM TESTING None anticipated.

LOGGING DIL/SP/GR, CNL/FDC/GR/CAL, or as outlined and directed by the Geologist

BLOWOUT PREVENTERS

1. Use 3,000 psi wp, double gate 10" preventer - blind rams on bottom. A 3,000 psi wp annular, 4 rotating head and hydraulic choke w/stroke counter are also required.

2. When nippling up on surface casing, test BOP and *manifold* and casing to 200 psi, then to 3,000 psi and record on IADC-API Daily Drilling Report (to be furnished by Contractor).

3. Preventers must be checked for operation every 24 hours and recorded on the IACD-API Dally Drilling Report. BOP's will be tested every 30 days.

4. Manifolds located at base of substructure.

5. Accumulators will. be located 50' from substructure.
NOTE: The casing head will be a 3,000 psi wp, flanged, 9-5/8" x 5-1/2".

DRILL PIPE MEASUREMENTS

1. Drill pipe will be tallied at all coring, testing, logging and casing points.

2. At other points as directed by company representative.

HOLE DEVIATION

1. In 13-1/2" hole, deviation surveys shall be taken every 90'. Deviation surveys shall be taken every 500' in the 8-3/4' hole and at other times as requested by company representative .

2. Maximum deviation shall be according to contract

   a. Maximum of 2° on surface hole with the maximum angle change of 1/2° between any two surveys.

b. Maximum rate of change below surface casing of 2° per 1,000’ with maximum change of angle of 1° between any two surveys.

3. Total of 6° at TD.

4. Record each survey on IADC-API Daily Drilling Report.

RECORDING:

1. Use a mechanical recorder with rate of penetration, hook load, rotary torque and pump pressure.

2. Original log shall be given to designated representative daily, along with other forms herein included.

REPORTS

1. All pertinent data and operations such as DST, coring and casing shall be recorded on ft IADC-API Daily Drilling Report and yellow copy given to or mailed daily to the designated representative along with invoices signed and received.

2. As of 6:00 A.M. each morning, a report, shall be given to a designated representative or called into the company office and include all pertinent data on operations such as:

Depth (MD&TVD)	Time Distribution	Rotary Speed	Stand-PipePressure
Formation	Well Tests or Shows	Coring	Drilling Fluid Prop.
Bit Record	New Casing Data	Weight on Bit	Mud LoggersReport
Deviation Surveys			

MAILING LIST

A. Department of Energy
Director
Naval Petroleum Reserve No. 3
907 N. Poplar, Ste. 150
Casper, WY 82601

B. Fluor Daniel (NPOSR), Inc
Technical Services Dept.
907 N. Poplar, Ste 100
Casper, WY 82601

DISTRIBUTION OF LOGS REPORTS

		Field Prints	Final Prints	Original or Film
1.	Government	2	2	
2.	FD Rifle Office	1	1	
3.	FD Casper Files	1	1	All
4.	Geologist	2	2	
5.	Engineer	2	2	
6.	Miscellaneous	2	2	
		10	11	

INVENTORY RIG NO. 3

Drawworks - Brewster N-46 with 3 0" Hydromatic Brake

Engines -(2) Caterpillar 3408 DITA Engines, 400 H.P. each (320 HP @ 10,000 feet elevation)

Pump and Power -Ideco MM-700 Compound Driven with 6" liners, maximum operating pressure 1900 psi at 68 spm

Auxiliary Pump ad Power - D-500 Emsco with 5-1/2" liners powered by Cat D379TA engine 375 RP (400HP @ 10,000 feet elevation), maximum operating pressure 1500 psi at 64 spm

Mast and Substructure – Butler-Parks 131', 600,000# GNC, 460,000# Maximum Hook Load on 8 lines. 10' Substructure with 8.0' Rotary Beam clearance.

Traveling Mock - Brewster Hook-Block, 250 Ton

Swivel - National N-69, 3 00 Ton

Rotary Table - Brewster RSH, 22'

BOP - Schaffer I 1"- 3000 psi Type LWS Double Gate Preventer, Schaffer II" - 3000 psi Shorty Annular. Washington 11" - 3000# Rotating Head, 3" - 3000# HCR Valve to Choke Manifold, Hydraulic Preventer with Koomey Type 80, 5 Station Closing Unit with Remote on Floor, 280 Gaon Accumulator and National 2" x 3" - 3000 psi Choke Manifold

Mud System - Two Steel Tanks, 550 Barrel total capacity with Swaco linear motion shaker Geograph Pioneer Desilter 12 Cone

Fuel Tanks.- 5,000 Gallon with additional 10,000 gallon available

Pre-Mix Tank - 280 Barrel Premix with Hopper and 75 KW Light Plant with Caterpillar 3304 Engine

Generator - 2-265 KW Kato 2401120 Volt Generators powered by Caterpillar 3406 Engines'

Drill Pipe - 8000 ft-4-1/2", 16.60#, Grade E, 2500ft 4-1/2", 20#, grade E

Drill Collars - (21) 6-1/4" OD

Water Storage - 500 Barrel Steel Tank

Supervisor and Crew Quarters - Comb Skid Mounted 35 x 10 ft Trailer for Toolpusher Comb 50 x 10 ft for crews

Additional Equipment

1. Drilling Time Recorder - Eastman 2-pen
2. Automatic Driller - Satelite
3. Straight Hole Instrument -Eastman 12°
4. Communications - Mobile Phone
5. Boiler - 100 H.P.

APPENDIX 2 - AP Calculations

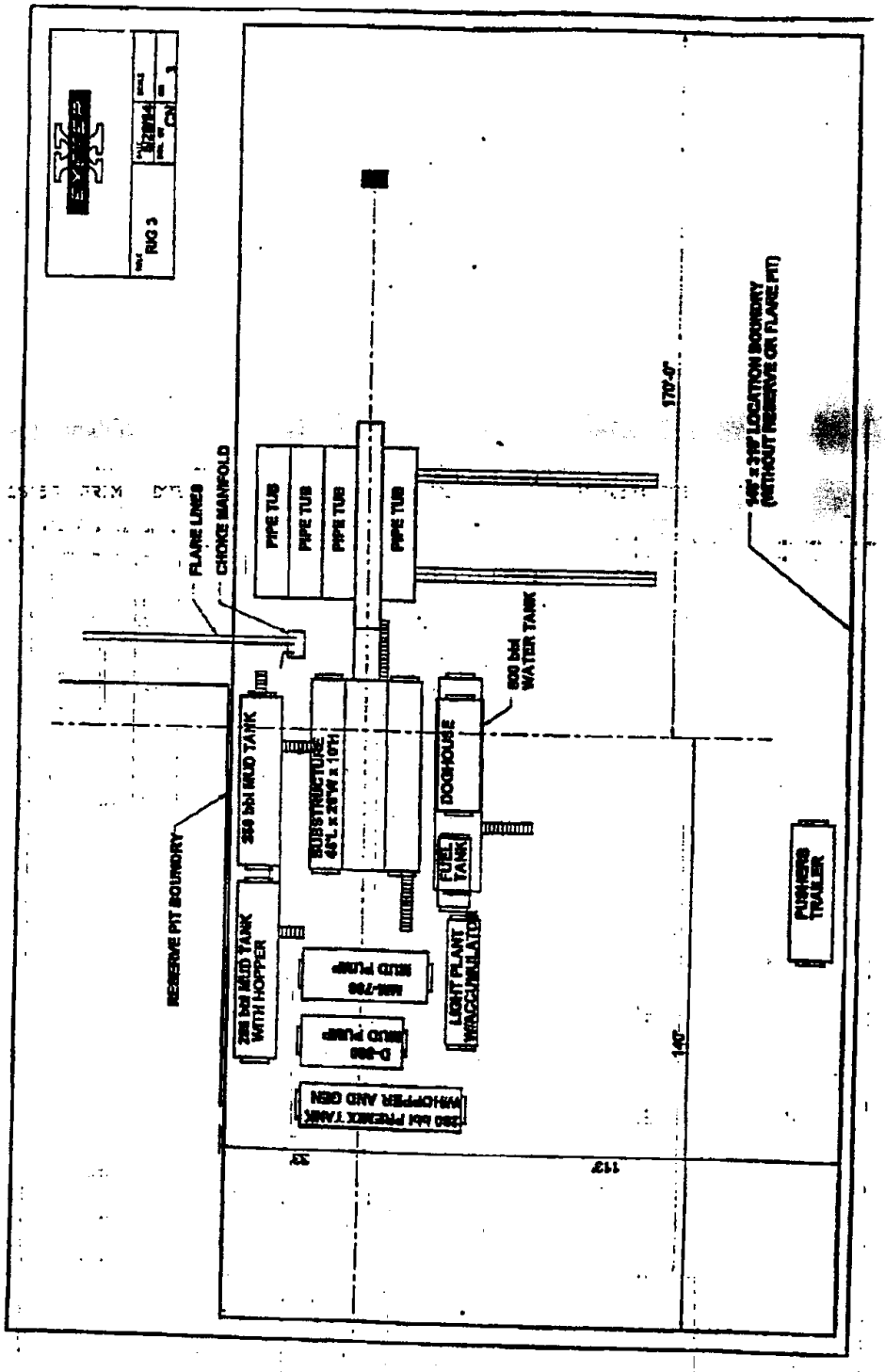
Hammer Hydraulics Spreadsheet for surface pump tests before RIH at 5316 ft: 258 gpm, 9.1 ppg mud, hammer operating 342 gpm, 9.1 ppg mud, hammer operating 400 gpm, 9.1 ppg mud, hammer operating

Hammer Hydraulics Spreadsheet for target and actual drilling conditions: 360 gpm, 9.1 ppg mud, hammer operating 336 gpm, 9.3 ppg mud, hammer operating

(5.0) hydraulics calculations: Circulation at 2543 ft, 382 gpm, 9.1 ppg mud, hammer operating Drilling at 5316 ft, 336 gpm, 9.2 ppg mud, hammer operating Drilling at 5495 ft, 336 gpm, 9.3 ppg mud, hammer operating

Hammer Hydraulics Spreadsheet for surface pump tests after POH at 5495 ft: 340 gpm, 9.3 ppg mud, no hammer operation 394 gpm, 9.3 ppg mud, no hammer operation 342 gpm, 9.3 ppg mud, hammer operating 394 gpm, 9.3 ppg mud, hammer operating

Note: see second hammer field test report for explanation of hammer hydraulics calculations.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PIPE TUB
PIPE TUB
PIPE TUB
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CHOKE MANIFOLD
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LOCATION BOUNDRY
(WITHOUT RESERVE OR FLARE PIT)
WATER TANK
DOGHOUSE
FUEL TANK
LIGHT PLANT
WACCUMULATOR
MUD PUMP
MUD PUMP
WITH HOPPER
RESERVE PIT BOUNDRY
PUSHERS
TRAILER
140'
33'
113'

TOTAL P.08

CHANGE CHART AT 8 A.M. & 8 P.M. PART NO. 260124 PRINTED IN U.S.A.

DRILLING RECORDER

12 HOUR — TOTCO — 12 HOUR

OPERATOR: DOE NO: PM-2-31

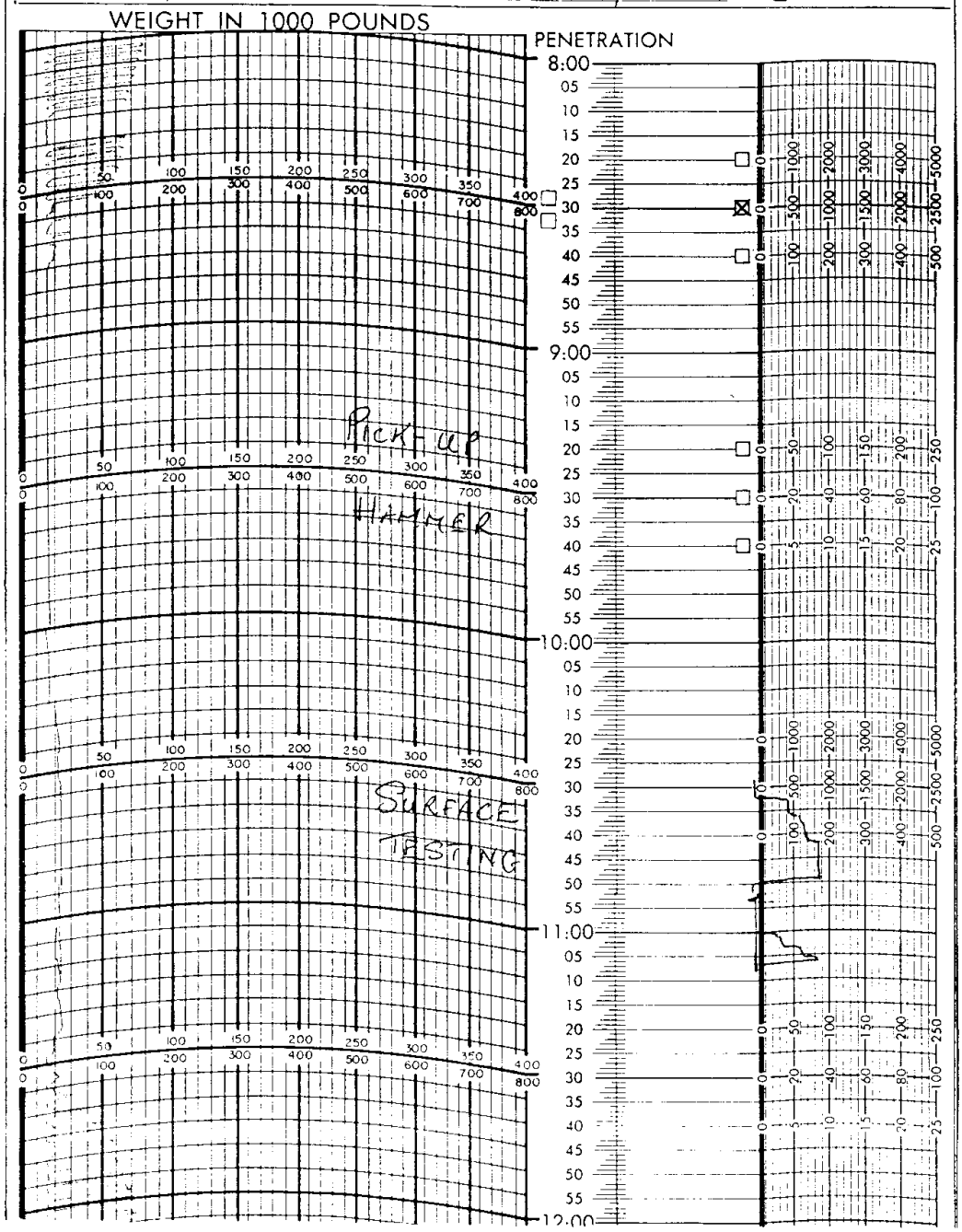
LOCATION: DOE STATE: Co

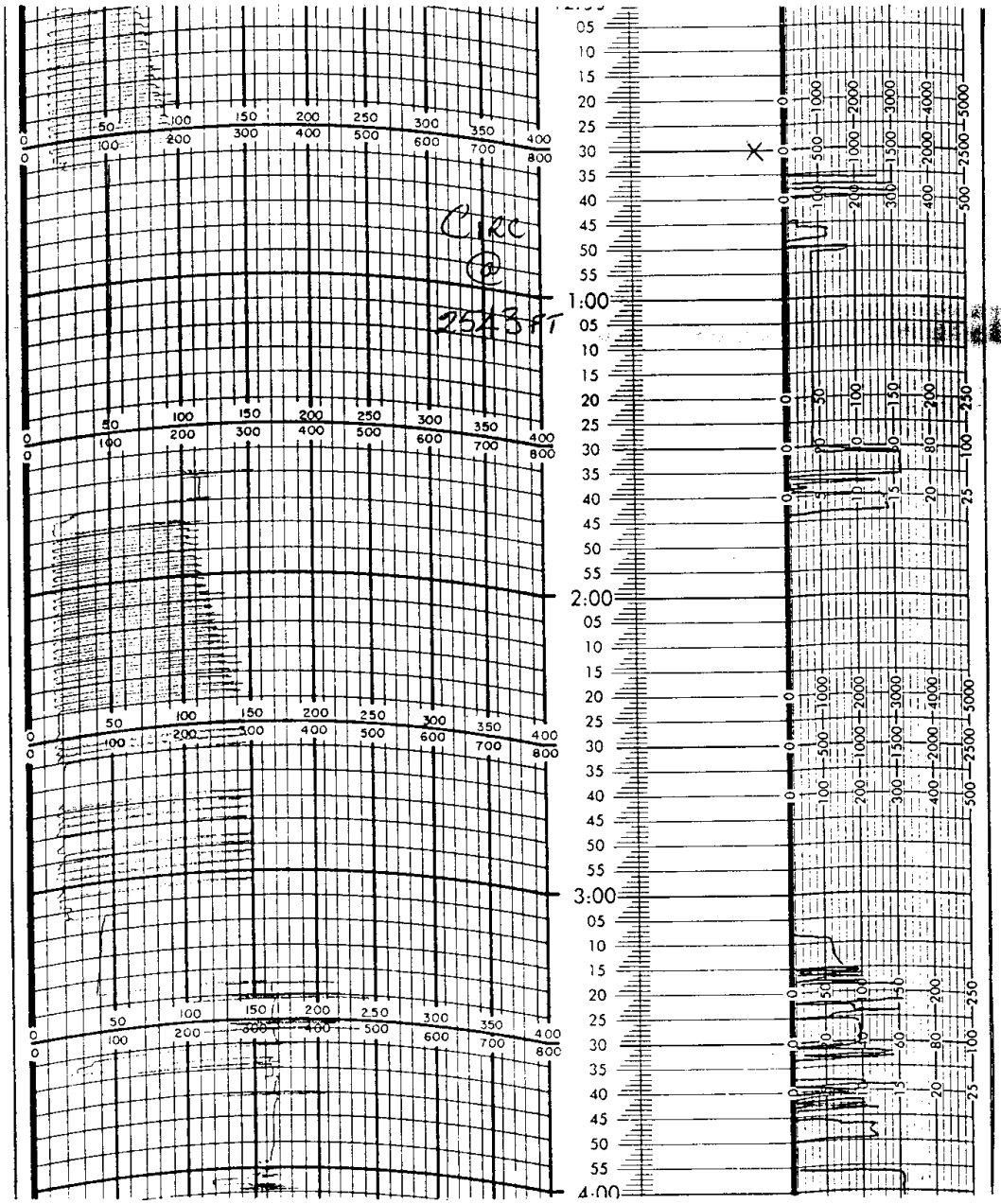
COUNTY: GARFIELD T.D. OFF: 5359

DATE ON: 9-19-95 T.D. ON: 5316

TIME ON: ☒ 8:00 A. M. ☐ 8:00 P. M. FT. DRLD 43

☒ FLUID PRESSURE
☐ PUMP STROKES
☐ TORQUE
☐ RPM
☐ % MUD FLOW
☐ % PIT LEVEL

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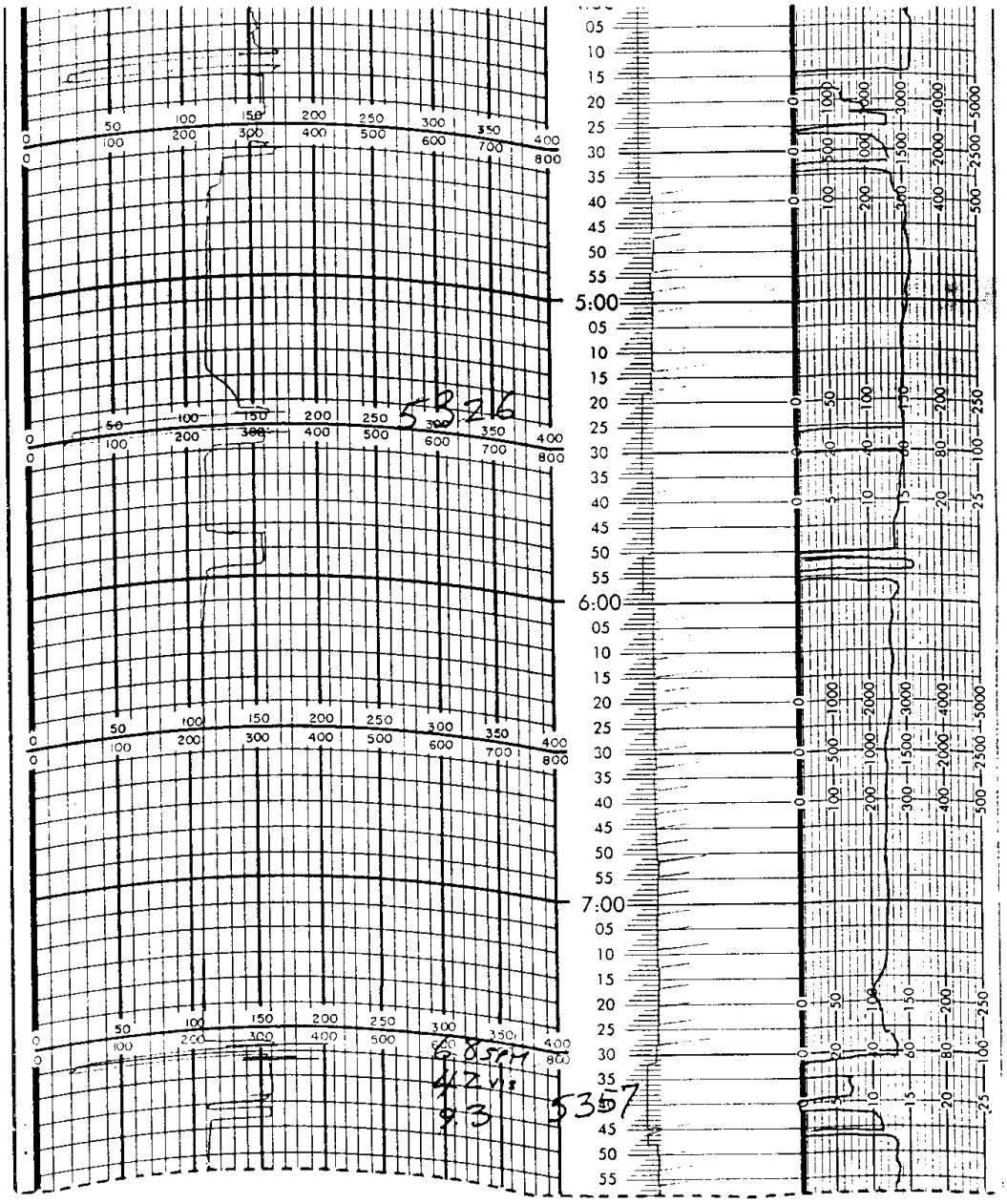

5:00
6:00
7:00
5326
5357

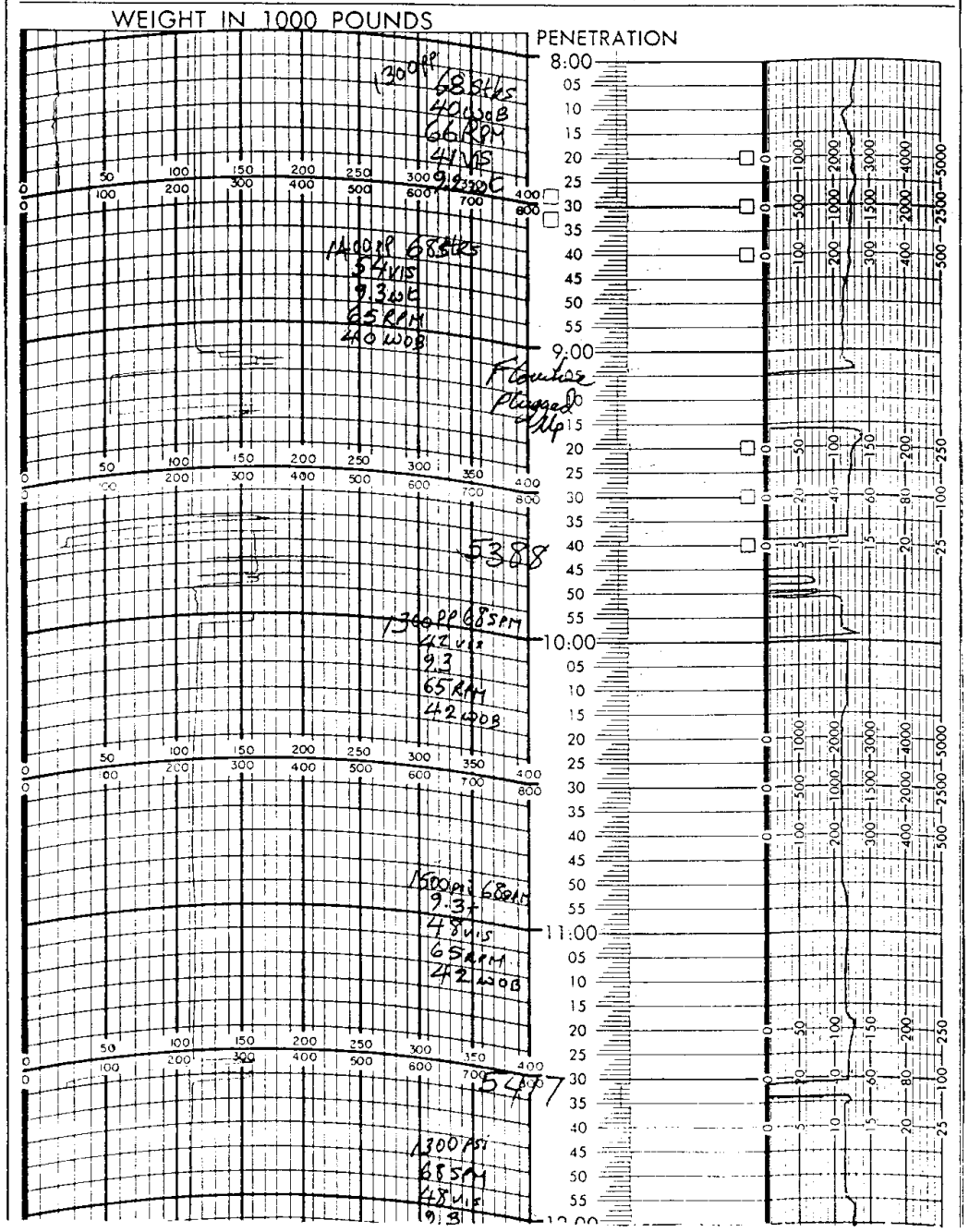
CHANGE CHART AT 8 A.M. & 8 P.M. PART NO. 260124 PRINTED IN U.S.A.

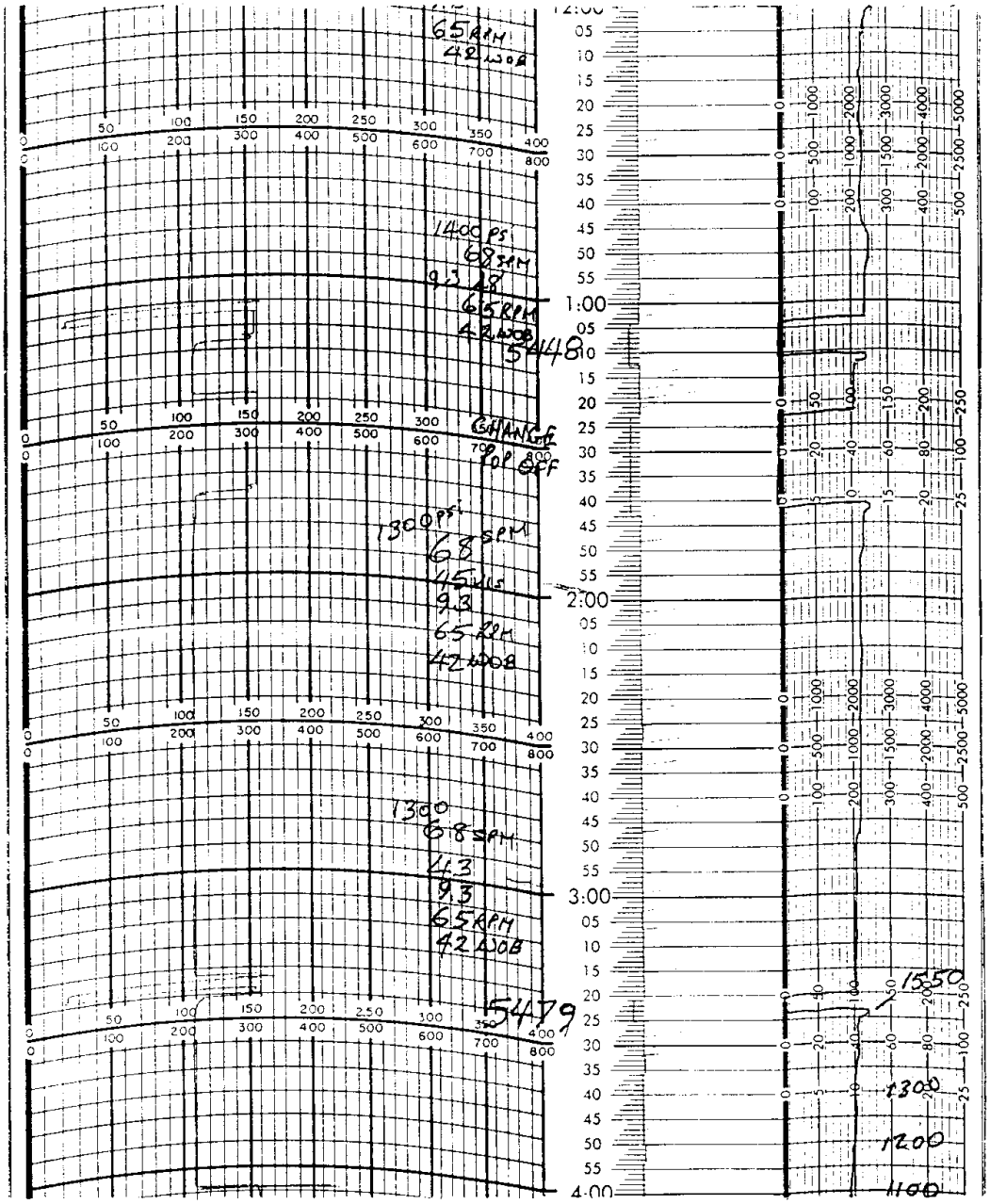
DRILLING RECORDER

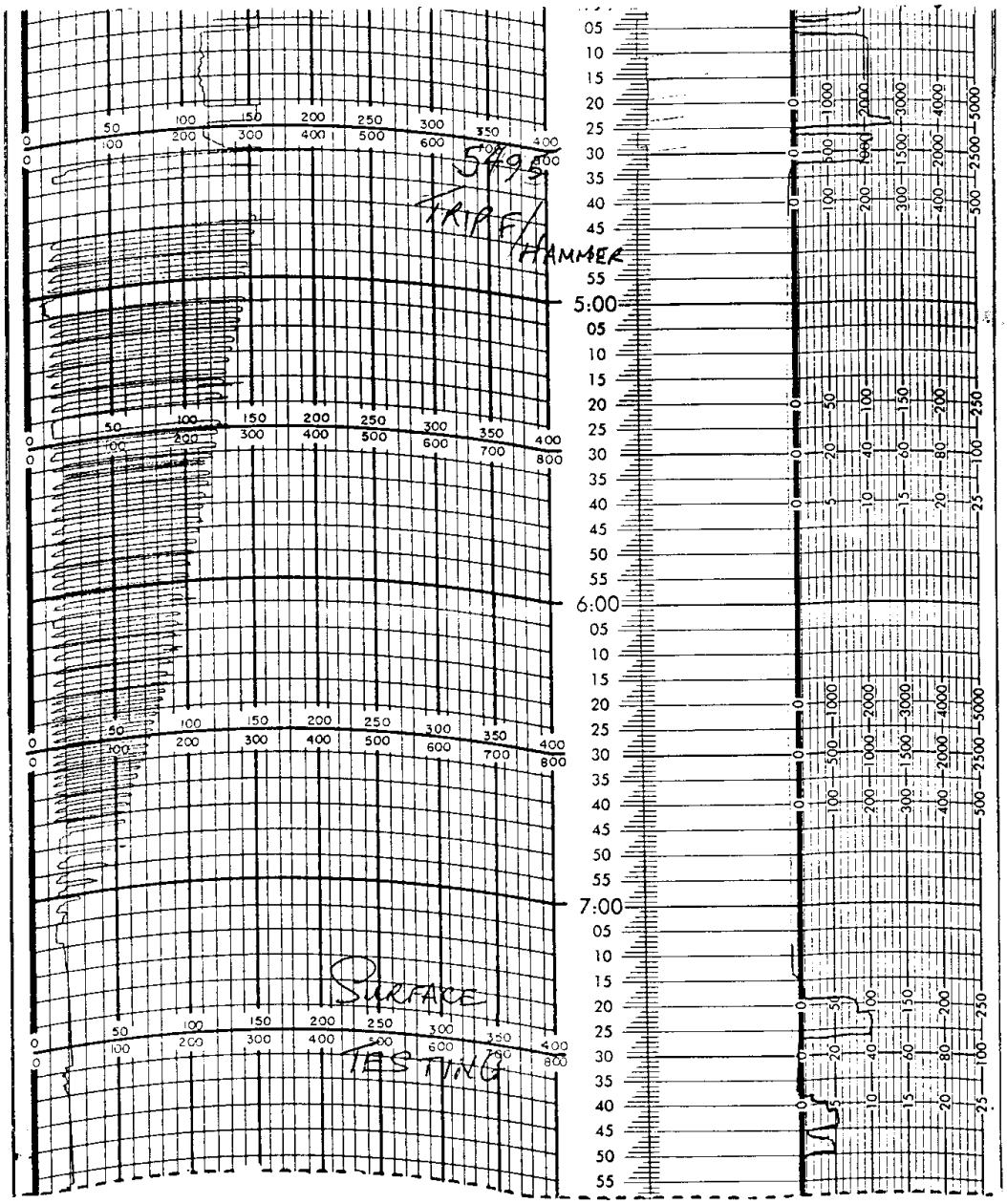
12 HOUR — TOTCO — 12 HOUR

OPERATOR: DOE NO: PM-2-31
LOCATION: DOE STATE: Co
COUNTY: GARFIELD T.D. OFF: 5495
DATE ON: 9-19-95 T.D. ON: 5359
TIME ON: ☐ 8:00 A.M. ☒ 8:00 P.M. FT. DRLD. 136

☒ FLUID PRESSURE
☐ PUMP STROKES
☐ TORQUE
☐ RPM
☐ % MUD FLOW
☐ % PIT LEVEL




65 RPM
42 WOB
1400 psi
68 SPM
9.3 #
65 RPM
42 WOB
5448
CHANGE
POP OFF
1300 psi
68 SPM
45 WOB
9.3
65 RPM
42 WOB
1300
68 SPM
45
9.3
65 RPM
42 WOB
5479
1550
1300
1200
1100


5:00
6:00
7:00
TRIP F/ HAMMER
SURFACE TESTING

Hughes GT09 (IADC code 517) Bit Pulled at 5316 ft

Large percentage of broken teeth in outer rows.

New Reed HP51A (IADC 517) Bit Run at 5316 ft

Bit cutting structure as new when pulled at 5495 ft

APPENDIX 2 - ΔP Calculations

Hammer Hydraulics Spreadsheet for surface pump tests before RIH at 5316 ft:

258 gpm, 9.1 ppg mud, hammer operating
342 gpm, 9.1 ppg mud, hammer operating
400 gpm, 9.1 ppg mud, hammer operating

Hammer Hydraulics Spreadsheet for target and actual drilling conditions:

360 gpm, 9.1 ppg mud, hammer operating
336 gpm, 9.3 ppg mud, hammer operating

MacIDEAS (5.0) hydraulics calculations:

Circulation at 2543 ft, 382 gpm, 9.1 ppg mud, hammer operating
Drilling at 5316 ft, 336 gpm, 9.2 ppg mud, hammer operating
Drilling at 5495 ft, 336 gpm, 9.3 ppg mud, hammer operating

Hammer Hydraulics Spreadsheet for surface pump tests after POH at 5495 ft:

340 gpm, 9.3 ppg mud, no hammer operation
394 gpm, 9.3 ppg mud, no hammer operation
342 gpm, 9.3 ppg mud, hammer operating
394 gpm, 9.3 ppg mud, hammer operating

Note: see second hammer field test report for explanation of hammer hydraulics calculations.

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 10.40 /32" bit nozzle

Mud Weight	9.10	lbs/gal	1.09 kg/m^3
Pump Rate	258	gal/min	975 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	**187**	**gal/min**	**707 ltr/min**
Hammer Exhaust	71	gal/min	268 ltr/min
ΔP Bit	**550**	**psi**	**37.39 bar**
ΔP Hammer	550	psi	37.39 bar
Actual ΔP	540	psi	

Hammer Operating Test at Surface

Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	190	gal/min	716 ltr/min
Hammer Exhaust	68	gal/min	258 ltr/min
ΔP Bit	510	psi	34.71 bar
ΔP Hammer	510	psi	34.71 bar
Actual ΔP		psi	

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 11.70 /32" bit nozzle

Mud Weight	9.10	lbs/gal	1.09 kg/m^3
Pump Rate	342	gal/min	1292 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	**231**	**gal/min**	**873 ltr/min**
Hammer Exhaust	111	gal/min	419 ltr/min
ΔP Bit	**839**	**psi**	**57.06 bar**
ΔP Hammer	**839**	**psi**	**57.05 bar**
Actual ΔP	830	psi	

Hammer Operating Test at Surface

Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	235	gal/min	887 ltr/min
Hammer Exhaust	107	gal/min	405 ltr/min
ΔP Bit	783	psi	53.24 bar
ΔP Hammer	783	psi	53.24 bar
Actual ΔP		psi	

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 12.40 /32" bit nozzle

Mud Weight	9.10	lbs/gal	1.09 kg/m^3
Pump Rate	400	gal/min	1511 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	**260**	**gal/min**	**982 ltr/min**
Hammer Exhaust	140	gal/min	529 ltr/min
ΔP Bit	**1061**	**psi**	**72.17 bar**
ΔP Hammer	1061	psi	72.16 bar
Actual ΔP	1060	psi	

Hammer Operating Test at Surface

Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	264	gal/min	999 ltr/min
Hammer Exhaust	136	gal/min	512 ltr/min
ΔP Bit	992	psi	67.51 bar
ΔP Hammer	992	psi	67.51 bar
Actual ΔP		psi	

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 12.00 /32" bit nozzle

Mud Weight	9.10	lbs/gal	1.09 kg/m^3
Pump Rate	360	gal/min	1360 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	239 gal/min	904 ltr/min
Hammer Exhaust	121 gal/min	456 ltr/min
ΔP Bit	899 psi	61.15 bar
ΔP Hammer	899 psi	61.14 bar
Actual ΔP	psi	

Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	243 gal/min	919 ltr/min
Hammer Exhaust	117 gal/min	441 ltr/min
ΔP Bit	840 psi	57.11 bar
ΔP Hammer	840 psi	57.11 bar
Actual ΔP	psi	

Target Drilling Conditions 800 - 1,000 psi

Hydraulic Case: 8-3/4" at 2543 Report

Input Data

Flow Rate gpm	Mud Weight ppg	Bit Depth ft	ROP ft/hr
382	9.10	2543	0

Pressure Drops (psi) & Horse Power (HP)

	Pressure Drop	% Pressure Drop	Horse Power	% Horse Power
Surface Elm	40	2.50	9	2.50
Drill Str	567	35.80	126	35.80
Bit	942	59.51	210	59.51
Annulus	35	2.19	8	2.19
Total	1583	100.00	353	100.00

ECD's (ppg)

Shoe ECD	Bottom ECD
9.23	9.36

Bit Impact Force: 646 lbf

Drill String Pressure Drop Breakdown (psi)

Surface	Pipe	MWD	Mud Motor	Tool Joint
40	535	0	0	32

Annulus Pressure Drop Breakdown (psi)

Friction	Cuttings
35	0

Total Volume (bbl)

Annulus	Drill String
131	30

Time (minutes)

Bottoms Up	Circulation
14	18

Drill String Data

Component	ID in	Length ft	n-Index	Velocity ft/min	Rey No.	ΔP psi	Adj. MW ppg
Drill Pipe	3.826	1794	0.7370	639.6	9096	122	9.10
HW drill pipe	2.750	332	0.7370	1238.1	16422	101	9.10
Collar	2.250	417	0.7370	1849.4	23515	312	9.10
Bit	0.000	1	0.0000	21537.3	0	942	9.10

Annulus Data (Concentric)

No.	ID in	OD in	Length ft	n-Index	Velocity ft/min	Slip Vel. ft/min	Rey No.	ΔP psi	Adj. MW ppg
1	4.500	8.921	730	0.7370	157.8	36.1	1266	5	9.10
2	4.500	8.750	1396	0.7370	166.3	36.4	1313	11	9.10
3	6.750	8.750	417	0.7370	302.0	40.9	1591	19	9.10

Detail Report

Element #1: Pipe
ID = 0.00 in.; OD = 3.83 in.
Length = 1794.00 ft
Volume = 25.53 bbl

Hydraulic Case: 8-3/4" at 5316 Report

Input Data

Flow Rate gpm	Mud Weight ppg	Bit Depth ft	ROP ft/hr
336	9.20	5316	16

Pressure Drops (psi) & Horse Power (HP)

	Pressure Drop	% Pressure Drop	Horse Power	% Horse Power
Surface Elm	32	2.20	6	2.20
Drill Str	642	44.77	126	44.77
Bit	698	48.69	137	48.69
Annulus	62	4.34	12	4.34
Total	1433	100.00	281	100.00

ECD's (ppg)

Shoe ECD	Bottom ECD
9.36	9.42

Bit Impact Force: 492 lbf

Drill String Pressure Drop Breakdown (psi)

Surface	Pipe	MWD	Mud Motor	Tool Joint
32	589	0	0	53

Annulus Pressure Drop Breakdown (psi)

Friction	Cuttings
51	11

Total Volume (bbl)

Annulus	Drill String
283	69

Time (minutes)

Bottoms Up	Circulation
35	44

Drill String Data

Component	ID in	Length ft	n-Index	Velocity ft/min	Rey No.	ΔP psi	Adj. MW ppg
Drill Pipe	3.826	4567	0.7370	562.6	7820	253	9.20
HW drill pipe	2.750	332	0.7370	1089.0	14119	82	9.20
Collar	2.250	417	0.7370	1626.7	20217	254	9.20
Bit	0.000	1	0.0000	18435.2	0	698	9.20

Annulus Data (Concentric)

No.	ID in	OD in	Length ft	n-Index	Velocity ft/min	Slip Vel. ft/min	Rey No.	ΔP psi	Adj. MW ppg
1	4.500	8.921	730	0.7370	138.8	35.4	1093	5	9.24
2	4.500	8.750	4169	0.7370	146.2	35.7	1134	29	9.24
3	6.750	8.750	417	0.7370	265.7	40.1	1373	17	9.24

Detail Report

Element #1: Pipe
ID = 0.00 in.; OD = 3.83 in.
Length = 4567.00 ft
Volume = 65.00 bbl

Hydraulic Case: 8-3/4" at 5495 Report

Input Data

Flow Rate gpm	Mud Weight ppg	Bit Depth ft	ROP ft/hr
336	9.30	5495	16

Pressure Drops (psi) & Horse Power (HP)

	Pressure Drop	% Pressure Drop	Horse Power	% Horse Power
Surface Elm	32	2.54	6	2.54
Drill Str	656	52.13	129	52.13
Bit	503	40.00	99	40.00
Annulus	67	5.33	13	5.33
Total	1258	100.00	247	100.00

ECD's (ppg)

Shoe ECD	Bottom ECD
9.47	9.53

Bit Impact Force: 420 lbf

Drill String Pressure Drop Breakdown (psi)

Surface	Pipe	MWD	Mud Motor	Tool Joint
32	601	0	0	55

Annulus Pressure Drop Breakdown (psi)

Friction	Cuttings
56	11

Total Volume (bbl)

Annulus	Drill String
293	72

Time (minutes)

Bottoms Up	Circulation
37	46

Drill String Data

Component	ID in	Length ft	n-Index	Velocity ft/min	Rey No.	ΔP psi	Adj. MW ppg
Drill Pipe	3.826	4746	0.7182	562.6	7508	265	9.30
HW drill pipe	2.750	332	0.7182	1089.0	13809	82	9.30
Collar	2.250	417	0.7182	1626.7	19998	254	9.30
Bit	0.000	1	0.0000	15568.8	0	503	9.30

Annulus Data (Concentric)

No.	ID in	OD in	Length ft	n-Index	Velocity ft/min	Slip Vel. ft/min	Rey No.	ΔP psi	Adj. MW ppg
1	4.500	8.921	730	0.7182	138.8	34.2	1026	5	9.34
2	4.500	8.750	4348	0.7182	146.2	34.5	1066	33	9.34
3	6.750	8.750	417	0.7182	265.7	39.1	1324	18	9.34

Detail Report

Element #1: Pipe
ID = 0.00 in.; OD = 3.83 in.
Length = 4746.00 ft
Volume = 67.54 bbl

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 10.20 /32" bit nozzle

Mud Weight	9.30	lbs/gal	1.12 kg/m^3
Pump Rate	340	gal/min	1285 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	249	gal/min	941 ltr/min
Hammer Exhaust	91	gal/min	343 ltr/min
ΔP Bit	996	psi	67.78 bar
ΔP Hammer	996	psi	67.77 bar
Actual ΔP	1010	psi	**Hammer Not Operating at Surface after POH**

Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	252	gal/min	954 ltr/min
Hammer Exhaust	88	gal/min	331 ltr/min
ΔP Bit	924	psi	62.87 bar
ΔP Hammer	924	psi	62.87 bar
Actual ΔP		psi	

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 11.20 /32" bit nozzle

Mud Weight	9.30	lbs/gal	1.12 kg/m^3
Pump Rate	394	gal/min	1489 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	274	gal/min	1034 ltr/min
Hammer Exhaust	120	gal/min	455 ltr/min
ΔP Bit	1202	psi	81.77 bar
ΔP Hammer	1202	psi	81.76 bar
Actual ΔP	1200	psi	**Hammer Not Operating at Surface after POH**

Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	278	gal/min	1050 ltr/min
Hammer Exhaust	116	gal/min	439 ltr/min
ΔP Bit	1119	psi	76.15 bar
ΔP Hammer	1119	psi	76.15 bar
Actual ΔP		psi	

NOVATEC MUD HAMMER AND BIT HYDRAULICS CALCULATOR

Note: Novatec mud hammer behaves like a 15.50 /32" bit nozzle

Mud Weight	9.30	lbs/gal	1.12 kg/m^3
Pump Rate	342	gal/min	1292 ltr/min
Bit Noz. 1	10	1/32`s	
Bit Noz. 2	10	1/32`s	
Bit Noz. 3	10	1/32`s	
Bit Noz. 4	0	1/32`s	
Bit Noz. 5	0	1/32`s	

Surface Test Conditions:

Bit Flow Rate	**186**	**gal/min**	**701 ltr/min**
Hammer Exhaust	156	gal/min	591 ltr/min
ΔP Bit	**553**	**psi**	**37.63 bar**
ΔP Hammer	**553**	**psi**	**37.62 bar**
Actual ΔP	580	psi	**Hammer Operating at Surface after POH**

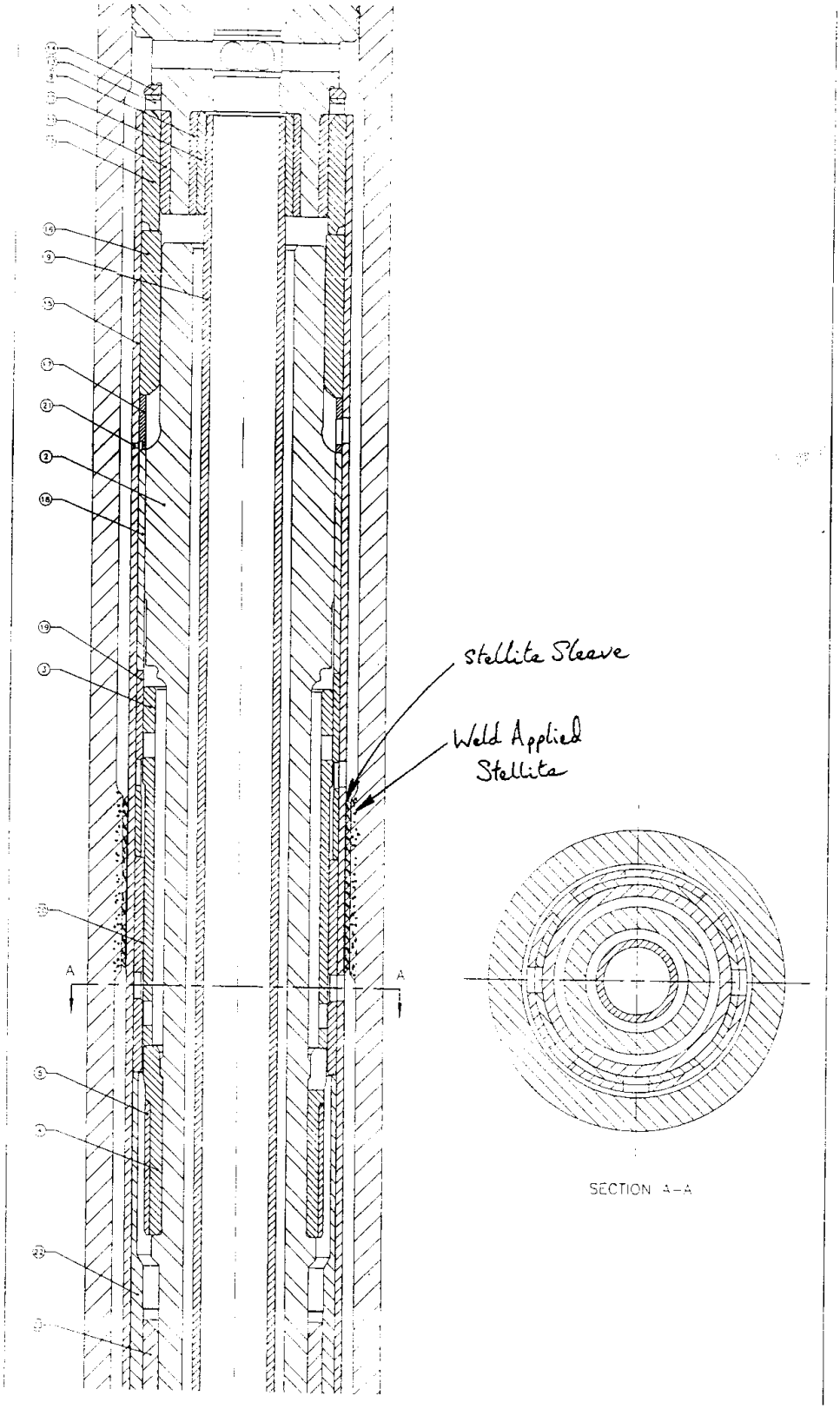
Downhole Conditions (bit nozzle ΔP 10% lower):

Bit Flow Rate	190	gal/min	717 ltr/min
Hammer Exhaust	152	gal/min	575 ltr/min
ΔP Bit	523	psi	35.58 bar
ΔP Hammer	523	psi	35.58 bar
Actual ΔP		psi	

APPENDIX 3 - Novatek hammer drawings and photo.'s

Modified Hammer Drawing with Stellite Seals

Photographs of Novatek Mud Hammer


Stellite Sleeve
Weld Applied Stellite
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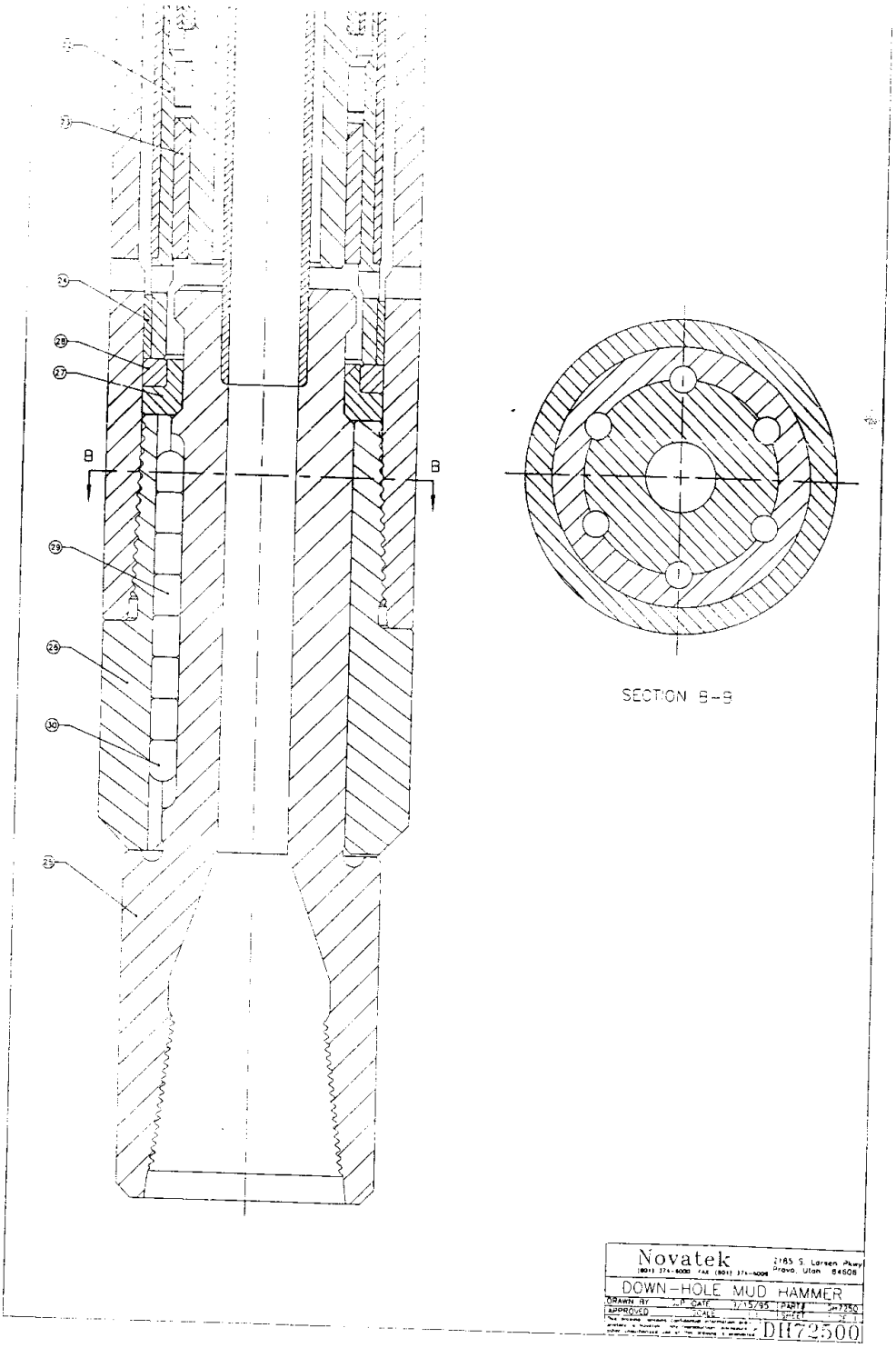
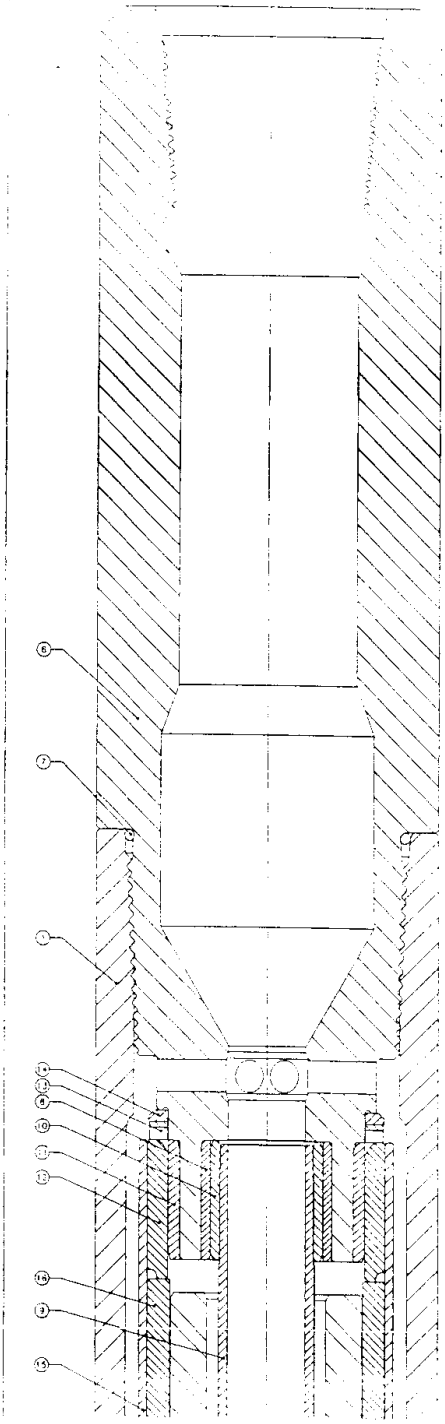
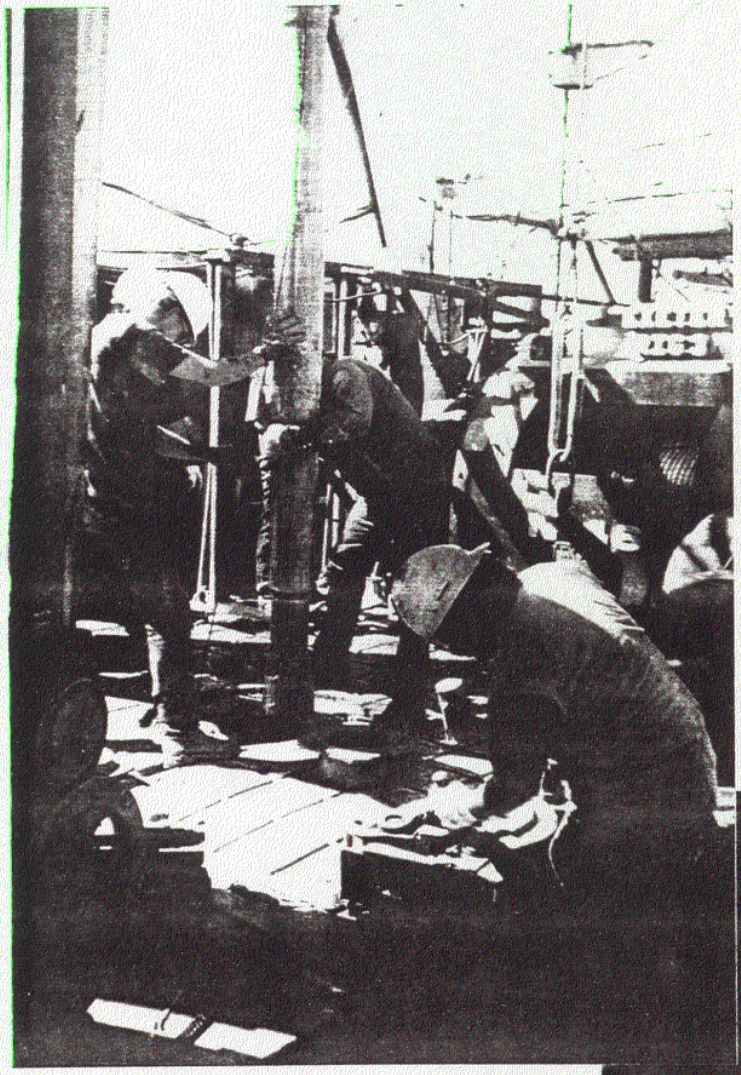
SECTION A-A


B
B
SECTION B-B
Novatek
2165 S. Larsen Pkwy
Provo, Utah 84606
DOWN-HOLE MUD HAMMER
DRAWN BY
DATE
7/15/95
PART
SCALE
SHEET
DH72500



KEY	PART NAME	PART #	QTY	MATERIAL
1	HOUSING	DH7101	1	4140 STEEL
2	PISTON	DH7201	1	C250 VASCOMAX CONFORMACLAD
3	SHUTTLE VALVE	DH7202	1	C250 VASCOMAX CONFORMACLAD
4	VALVE STOP	DH7205	1	4340 STEEL SURFACE HARD
5	VALVE STOP RETAINER	DH7206	1	17-4 PH STAINLESS
6	BACKHEAD	DH7301	1	4340 STEEL
7	BACKHEAD SEAL	DH7313	1	4FLAS 80 DURO
8	THROAT BUSHING	DH7306	1	TUNGSTEN CARBIDE 15%
9	THROAT	DH7304	1	4140 STEEL
10	THROAT BEARING SLEEVE	DH7312	1	4140 STEEL & HVOF WC
11	BACKHEAD BEARING SLEEVE	DH7809	1	4140 STEEL & HVOF WC
12	BACKHEAD SEAL SLEEVE	DH7808	1	TUNGSTEN CARBIDE 15%
13	PRELOAD SPRING	DH7310	1	17-4 PH STAINLESS
14	SPRING SHIM	DH7311	1	4340 STEEL
15	INNER HOUSING	DH7801	1	4140 STEEL
16	UPPER BEARING	DH7802	1	TUNGSTEN CARBIDE 15%
17	PORT SPACER	DH7803	1	17-4 PH STAINLESS
18	MIDDLE BEARING	DH7804	1	TUNGSTEN CARBIDE 15%
19	VALVE SUPPLY SLEEVE	DH7805	1	TUNGSTEN CARBIDE 15%
20	VALVE EXHAUST SLEEVE	DH7806	1	TUNGSTEN CARBIDE 15%
21	INNER HOUSING LOCATING PIN	DH7813	2	SPRING STEEL
22	EXHAUST SLEEVE	DH7601	1	17-4 PH STAINLESS
23	EXHAUST SLEEVE BEARING	DH7604	1	TUNGSTEN CARBIDE 15%
24	EXHAUST SLEEVE STANDOFF	DH7602	1	BEARING BRONZE
25	BIT SHANK	DH7701	1	4340 STEEL SURFACE HARD
26	SHANK SUB	DH7702	1	4140 STEEL NITRIDED
27	SPLIT SHANK RETAINER	DH7703	1	4140 STEEL
28	SHANK RETAINER SLEEVE	DH7704	1	4140 STEEL
29	SHANK KEYS	DH7706	36	TUNGSTEN CARBIDE 10%
30	ROUNDED SHANK KEYS	DH7707	12	TUNGSTEN CARBIDE 10%



Hammer Assembly Ready
to RIH after Surface Testing

Hammer Disassembled After POH
Stellite Sleeve Washed