BOOTS & COOTS
CT WELL CONTROL EQUIPMENT AUDIT

PERFORMANCE TESTING AND CERTIFICATION OF BOOTS & COOTS COILED TUBING ES56 SHEAR-BLIND RAM

DUAL COMBI RAM STACK TOT 123-37672

API RP 16ST 180 Day PM Program
(March 20, 2014 through September 16, 2014)

System Evaluation Based on the B&C 11939830 Stand-Alone Closing Unit With the 77-Gallon Accumulator Circuit

March 24, 2014

Prepared By:

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TABLE OF CONTENTS

SUMMARY OF SHEAR-BLIND RAM PERFORMANCE EVALUATION 2

Table 1 - List of Well Control Equipment Performance Tested 2

RESULTS OF CT SHEAR-BLIND RAM TEST CERTIFICATION 3

Table 2 - Coiled Tubing Test Specimen – Material Properties 3
Table 3 - Coiled Tubing Test Specimen – Dimensional Measurements 3
Table 4 - Mechanical Component Tests - Shear-Blind Rams 3
Table 5 - Design of CT Unit Accumulator System 5
Table 6 - Closing and Opening Volumes for Rams in Stack 5
Table 7 - Accumulator Circuit Performance - Predicted vs Actual 5
Figure 1 - Shear-Blind Ram Critical Pressure Evaluation 5
Table 8 - Well Control Stack Performance Qualification for MASP 6
Table 9 - Well Control Stack Performance Qualification for Additional Workstring . . 6

STATEMENT FOR CERTIFICATION AND SIGNATURE 6

DISCLAIMER 6

ATTACHMENT A 7

Texas Oil Tool Theoretical Shear-Blind Ram Performance Calculations 7

ATTACHMENT B 8

Shear-Blind Ram Performance Chart 8

Shear-Blind Ram Pressure Test Charts 9

SAS Industries, Inc. Audit of Coiled Tubing Well Control Equipment
Boots & Coots - Coiled Tubing Division - New Iberia, Louisiana

Boots & Coots (B&C) requested SAS Industries, Inc. (SAS) to conduct a performance audit of the B&C coiled tubing (CT) well control equipment and systems identified in this Report. The SAS Audit was conducted to evaluate condition and performance capability of the B&C coiled tubing well control equipment listed below to certify compliance with the Recommended Practices and performance expectations outlined in **API RP 16ST** ***Coiled Tubing Well Control Equipment Systems*** and to meet or exceed the intent of **30 CFR 250.615** for Shear-Blind Ram (SBR) "Performance Test" qualification.

The SAS well control and support equipment certification program is conducted to ensure conformance with **API RP 16ST** standards, **30 CFR 250.615** and **30 CFR 250.616** regulations, SAS Asset Integrity and Lifting Equipment Standards, OSHA Guidelines, DOT regulations (where applicable) and established "Industry Best Practice" performance requirements.

The location and time period for the CT equipment performance testing audit are shown below:

Location	Start Date	End Date
Boots & Coots Coiled Tubing - New Iberia, Louisiana	March 20, 2014	March 21, 2014

I. SUMMARY OF CT SHEAR-BLIND RAM PERFORMANCE EVALUATION

The B&C well control equipment components subjected to performance testing are shown below.

Table 1 - List of Well Control Equipment Performance Tested

B&C Coiled Tubing Well Control Equipment and System					
Met Requirements as Found	MET	Required Repairs/Adjustments	RR/A	Did Not Meet Requirements	DNM
Item	**Well Control Equipment Components**	**Size / Rating**	**ID No.**	**Status**	
1.	Dual Combi Well Control Stack	5-1/8", 15M TOT ES56	TOT 123-37672	MET	
2.	Well Control Closing Unit	77-Gallon Circuit Volume	B&C 11939830	MET	

*Note: The ES56 Shear-Blind Ram and Pipe-Slip Ram were the only ram assemblies used in the accumulator system volume qualification tests.

Coiled Tubing Test Specimen:	1.750" OD, 0.203" wall, CT – 130 grade
Shear-Blind Ram Performance Test Pressure:	1,947 psig (at atmospheric pressure)
Post-Shear Sealing Pressure Test:	15,400 Psig (with 1,800 psig closing pressure)
Calculated Shear-Blind Ram Pressure:	2,124 psig (at atmospheric pressure) (with **Blade Factor** of **0.91**)
Minimum CT Unit Accumulator Volume:	77 Gallons
Accumulator Precharge Pressure:	1,200 psig at 69° F (average temperature)
30-Minute Stabilized Accumulator Pressure:	2,920 psig at 83° F (average temperature)
Expected Accumulator Pressure at Shear:	2,465 psig

Based on the performance testing of the Texas Oil Tools (TOT) ES56 Dual Combi Ram assembly 123–37672, the SBR demonstrated the capability of shearing the referenced CT size wall thickness and grade to a ***MASP of 15,000 psig*** and is qualified for service when used with the ***B&C 11939830 Closing Unit equipped with a 77-Gallon accumulator system***.

II. RESULTS OF CT SHEAR-BLIND RAM TEST CERTIFICATION

At the request of B&C, SAS prepared this abbreviated Report which is intended to focus exclusively on the Test Documentation and Performance Evaluation of the Shear-Blind Rams included in the captioned Dual-Combi Ram well control stack assembly. The coiled tubing well control equipment performance expectation review conducted by SAS is based on the design capabilities recommended in API RP 16ST Coiled Tubing Well Control Equipment Systems (1st Edition, March 2009) as seen in the SAS Formal Audit Report.

SAS advises the User to review the Formal Audit Report to confirm that all well control stack components in the stack assembly meet the performance expectations stipulated in API RP 16ST.

B&C selected 1.750" OD, CT-130 grade coiled tubing as the workstring design to be qualified for the designated well control equipment. For this CT workstring design, the heaviest wall thickness selected was 0.203" wall thickness. Based on the aforementioned CT workstring design, the size, wall thickness and grade of the ***Quality Tubing, Inc.*** CT test specimen specified for the certification testing observed in this report are shown in **Table 2** below.

Table 2 - Coiled Tubing Test Specimen – Material Properties

Coiled Tube OD	Wall Thickness	CT Grade	QTI Strip No.	Minimum Yield	Ultimate Tensile
1.750 Inches	0.203 Inch	CT – 130	1500057097	146,000 psi	150,000 psi

Table 3 - Coiled Tubing Test Specimen – Dimensional Measurements

Tube OD Measurements		Wall Thickness Measurements			
Vertical Axis	Horizontal Axis	0 Degrees	90 Degrees	180 Degrees	270 Degrees
1.7515 Inches	1.7515 Inches	0.21100 Inch	0.20985 Inch	0.20120 Inch	0.20995 Inch

The results of the **API RP 16ST** Shear-Blind Ram performance tests conducted on the ES56 Dual Combi Ram Assembly (SN: 123-37672) by SAS on March 20, 2014, are listed in **Table 4** below.

Table 4. Mechanical Component Tests - Shear-Blind Rams (API RP 16ST 12.2.3)

Component	Serial Number	Shear Pressure 1	Shear Pressure 2	Shear Pressure 3
Shear-Blind Ram	TOT 123-37672	1,947 Psig*	2,014 psig	2,016 psig

*Shear-Blind Test No.1 was performed with the CT specimen secured within the Pipe-Slip Rams and serves as the ***test of record***. Note that the "post-shear" SBR pressure sealing test was conducted immediately after SBR Test No. 1.

B&C requested that SAS perform theoretical Shear-Blind Ram calculations to meet the BSEE approval requirement. SAS obtained the Shear-Blind Ram performance calculation method recommended by Texas Oil Tools (manufacturers of the ES56 Dual Combi Ram).

The TOT calculation method is based on the Distortion Energy Theory (see Worksheet in **Attachment A** of this Report) and yielded a theoretical Shear-Blind Ram pressure (P_{shear}) of **2,334 psig** (at atmospheric conditions). In comparison to the theoretical calculations offered by TOT, the "Actual" SBR pressure of **1,947 psig** is found to be **83.4%** of the "theoretical" shear value. For purposes of providing sensitivity to the theoretical shear value, the TOT **Blade Factor** of **0.91** is shown in **Figure 1** and **Attachment A** of this Report, yielding an adjusted theoretical shear value of **2,124 psig**.

To the extent that there are differences between the Shear-Blind Ram performance tests observed by SAS and the TOT Calculations, SAS bases the Report findings on observed physical performance testing and does not rely on the TOT Calculations as a means for determining "fitness-for-purpose". ***SAS makes no representation or warranties regarding the accuracy of the TOT Calculations and provides them for comparative analysis only.***

SAS conducted the aforementioned well control equipment performance tests and evaluated the performance as it relates to the ***B&C 11939830 Closing Unit*** equipped with a ***77-gallon Accumulator system*** to be used with this equipment as seen in **Tables 5, 6** and **7** and **Figure 1**.

Table 5 shows the design and configuration of the accumulator system used with the captioned well control equipment, along with the "As-Found" precharge pressure (and temperature) and "30-Minute Stabilized Operating Pressure". The accumulator operating parameters seen in **Table 5** are required for determining the performance capability of the accumulator circuit (Usable Volume and Critical Pressure) with respect to the well control equipment to be used.

Table 6 shows the volumes for closing and opening the Texas Oil Tools ES56 rams installed within the Dual Combi-Ram well control stack. This information was obtained from the TOT 1449 Technical Manual provided to B&C with the well control equipment. Based on the "Usable" power fluid volume (**31.1056** gallons) available at the accumulator conditions stated above, the B&C accumulator circuit has more than sufficient "Usable" volume to complete the required ES56 SBR "close-open-close" functions with a remaining system pressure at least 200 psig above precharge.

Table 7 is taken from the SAS ***Accumulator Performance Evaluation Spreadsheet***, which illustrates the comparison of the predicted accumulator pressure response to the response observed during the physical "close-open-close" ram tests conducted by SAS. The pressure values seen in **Table 7** reflect the pressure in the accumulator circuit immediately after closure of the PSR (first ram to close) and then closure of the SBR (second ram to close). Note that the predicted responses are based on empirical relationships that reflect changes in accumulator pressure due to changes in nitrogen temperature as the bladders expand.

For this application, the B&C ES56 PSR and SBR are the only ram assemblies to be operated from the **B&C 11939830 Closing Unit**. For the accumulator operating parameters identified above, the maximum accumulator circuit pressure to be expected upon initial closure of the ES56 SBR is approximately **2,465 psig**. ***As a result, SAS uses the projected accumulator circuit pressure of 2,465 psig as the limit for determining the capability of shearing the respective size of coiled tubing across the range of wellbore pressures using the 77-gallon accumulator system.***

Figure 1 represents the graphical representation of the Shear-Blind Ram pressure to be expected when shearing the respective size of coiled tubing with wellbore pressure present. The "red" line represents the expected shear pressure using the observed shear test data. The "green" line represents the Shear-Blind Ram pressure projected using the theoretical calculations (see **Attachment A**). The "blue" dashed line across the graph represents the accumulator pressure recommended to be used in determining the wellbore pressure working limits for the Shear-Blind Ram with the captioned coiled tubing string.

TABLE 5 B&C 11939830 CLOSING UNIT WITH 77-GALLON ACCUMULATOR BOTTLE PACKAGE

Accumulator System Design			Precharge Conditions		Stabilized Conditions	
Number	Gallons	Orientation	Pressure	Temperature	Pressure	Temperature
1	11	Vertical	1,200 Psig	70.0 F	2,920 Psig	83.0 F
2	11	Vertical	1,200 Psig	69.0 F	2,920 Psig	83.0 F
3	11	Vertical	1,200 Psig	69.0 F	2,920 Psig	83.0 F
4	11	Vertical	1,200 Psig	68.0 F	2,920 Psig	83.0 F
5	11	Vertical	1,200 Psig	68.0 F	2,920 Psig	83.0 F
6	11	Vertical	1,200 Psig	68.0 F	2,920 Psig	83.0 F
7	11	Vertical	1,200 Psig	72.0 F	2,920 Psig	83.0 F
TOTAL	77	Gallons	(Accumulator Performance Test Conducted on 03.19.14)			

TABLE 6 BOOTS & COOTS ES56 CT STACK CLOSING AND OPENING OPERATING VOLUMES

	Blind Rams	Shear Rams	Slip Rams	Pipe Rams	Pipe Slips	Shear Blinds	Total
	Gallons	Gallons	Gallons	Gallons	Gallons	Gallons	Gallons
Close					1.06494	1.83550	2.90044
Open					1.06494	1.93939	3.00433

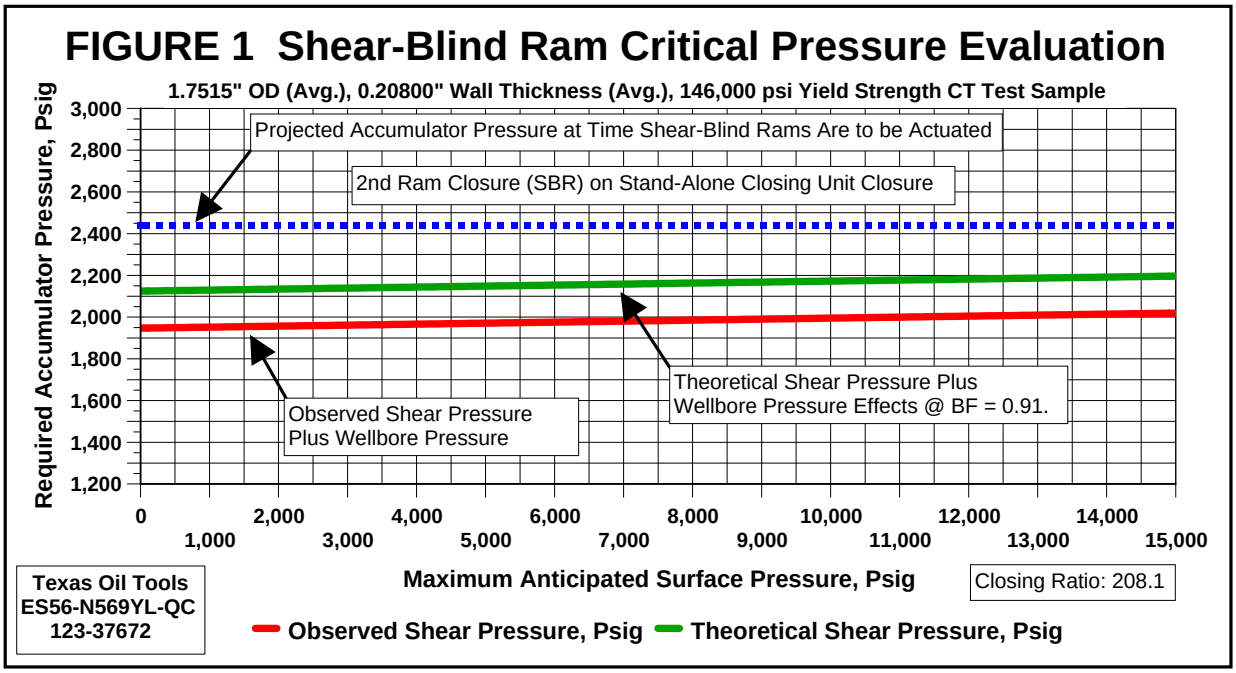
Volume for "Close - Open - Close" of CT Rams in Stack : 8.80521 Gallons

API RP16ST Accumulator Usable Volume Calculation : 31.1056 Gallons MET

(Note: Vacc Calculations Based on the Accumulator Pressures and Temperatures Noted Above)

TABLE 7 ACCUMULATOR CIRCUIT PERFORMANCE - Predicted Versus Actual

Adiabatic Cd:	0.76	Accumulator Pressure		Usable	Closing	Pressure /
Ram	Function	Calculated	Observed	Volume	Time	Rate Ratio
		(psig)	(psig)	(gallons)	(sec.)	(gpm/psig)
Initial Status	Open Valve	2,910	2,910	31.106	(Through 3/4" ID Hoses)	
Pipe-Slips	Close	2,772	2,720	30.041	3.00	0.007830
Shear-Blinds	Close	2,553	2,465	28.205	5.00	0.008935
Pipe-Slips	Open	2,434	2,350	27.140	3.00	0.009063
Shear-Blinds	Open	2,246	2,165	25.201	5.00	0.010750
Pipe-Slips	Close	2,150	2,095	24.136	3.00	0.010166
Shear-Blinds	Close	2,004	1,965	22.300	5.00	0.011209



Observed Shear-Blind Ram Test Pressure : 1,947 Psig (at atmospheric conditions)
Theoretical Shear-Blind Ram Pressure : 2,334 Psig (at atmospheric conditions With BF = 1.00)
Theoretical Shear-Blind Ram Pressure : 2,124 Psig (at atmospheric conditions With BF = 0.91)

The results of the test data obtained by SAS through the aforementioned testing program demonstrate that the B&C Shear-Blind Ram (ES56 Dual Combi Ram 123-37672) meets the performance expectations referenced in **API RP 16ST** to a **MASP** of **15,000 psig** for the coiled tubing workstring and accumulator system design parameters stated in **Table 8**.

Table 8. Well Control Stack Performance Qualification for CT String and MASP Service

Coiled Tubing Workstring OD	Wall	Grade	Wellbore MASP	Accumulator Volume	30-Minute Stabilized Accumulator Pressure	Pre-Charge Accumulator Pressure
1.750"	0.203"	CT – 130	15,000 Psig	77 Gallons	2,920 Psig	1,200 Psig

Based on the results of all performance testing concluded on March 21, 2014, SAS certifies that the aforementioned B&C coiled tubing well control equipment meets or exceeds the performance expectations stipulated in **API RP 16ST** for the operating conditions shown in **Table 9** below when used with the accumulator system parameters seen in **Table 5**.

Table 9. Well Control Stack Performance Qualification for Additional CT Workstrings

Coiled Tubing Workstring Conditions		
CT Outside Diameter	CT Wall Thickness	Grade
1.750" and Below	0.203" and Below	CT-130 and Below

SAS certifies that the statements made in this report regarding performance test results are true and complete to the best of our knowledge and belief, based on the data collected prior to and during the inspection and testing activities which concluded on or about March 21, 2014.

Alexander Sas-Jaworsky P.E.

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DISCLAIMER

This report was prepared by SAS Industries, Inc. ("SAS") based upon verified and documented performance audit testing activities concluded on March 21, 2014. The SAS performance audit testing process employs sound engineering practices, applied mathematical methods, assumptions of service application and data provided by the client (or service vendor). SAS makes no representation or warranty, expressed or implied, as to the accuracy of the information furnished by the client used to prepare test conditions described in this report. Due to variable well conditions, inaccurate well data, changing well conditions, tolerance variations of mechanical components tested, mechanical malfunctions and other factors and information which must be relied upon that are not within SAS's control, SAS makes no warranty, express or implied, that the mechanical components observed during the audit testing environment as described in this report will perform in future field applications in the same manner as that observed in the performance audit test program or that the calculations and/or opinions expressed herein are accurate as applied to any conditions in the field.

The user of this report is advised to consult with SAS if there are any questions concerning this report or its application to any specific field condition. The details regarding performance testing and qualification test methodology are seen in the SAS Formal Report to be issued to B&C at a later date.

ATTACHMENT A – Texas Oil Tools Theoretical Shear Performance Calculations

CT OD	CT ID	Material Yield Strength	Piston Diameter, D_p	Piston Rod Diameter, D_r	Booster Piston Diameter, D_{pb}	Booster Rod Diameter, D_{br}	Tail Rod Diameter, D_{tr}
1.7515"	1.3355"	146,000 psi	7.000"	1.625"	N/A	N/A	1.625"

TOT Calculations - 5.125" ES56 Shear-Blind Ram Assembly

OD_{CT} = Coiled Tube Outside Diameter, (inch)
Sy = Material Yield Strength, (psi)
SA = Shear Ram Area, (inch^2)

ID_{CT} = Coiled Tube Inside Diameter, (inch)
T_{Shear} = Theoretical Shear Force, (Lb_f)
CR = Closing Ratio, (dimensionless)
BF = Blade Factor (**0.91**)

MASP = Maximum Anticipated Surface Pressure, (psig)
P_{Shear} = Theoretical Ram Pressure to Shear at Atmospheric Conditions, (psig)
$P_{Critical}$ = Theoretical Ram Pressure to Shear at Wellbore Pressure Conditions, (psig)

$$\text{Theoretical Shear} = 0.7854\left(OD^2 - ID^2\right)\left(S_y\right)\left(0.577\right) \quad \textbf{Eq. A1}$$

$$\text{SBR Area} = 0.7854\left(D_p^2\right) - 0.7854\left(D_{tr}^2\right) \quad \textbf{Eq. A2}$$

$$\text{Closing Ratio} = \text{Shear Ram Area} \div (0.7854)(D_r^2) \quad \textbf{Eq. A3}$$

$$P_{Shear} = (\text{Theoretical Shear x Blade Factor / Shear-Blind Ram Area}) \quad \textbf{Eq. A4}$$

$$P_{critical} = P_{shear} + (\text{MASP / Closing Ratio}) \quad \textbf{Eq. A5}$$

The TOT theoretical calculations for estimating ES56 Shear-Blind Ram pressure for well conditions where the MASP is 15,000 psig, are shown below:

$$\text{Theoretical Shear} = 0.7854\left(1.7515^2 - 1.3355^2\right)\left(146{,}000\,psi\right)\left(0.577\right) = 84{,}967\ Lb_f$$

$$\text{SBR Area} = 0.7854\left(7.000^2\right) - 0.7854\left(1.625^2\right) = 36.41\,Inches^2$$

Closing Ratio = **208.1** (SBR is Nearly Pressure Balanced)

P_{Shear} = (84,967 lb_f x **0.91** /36.41 in^2) = **2,124 psig**

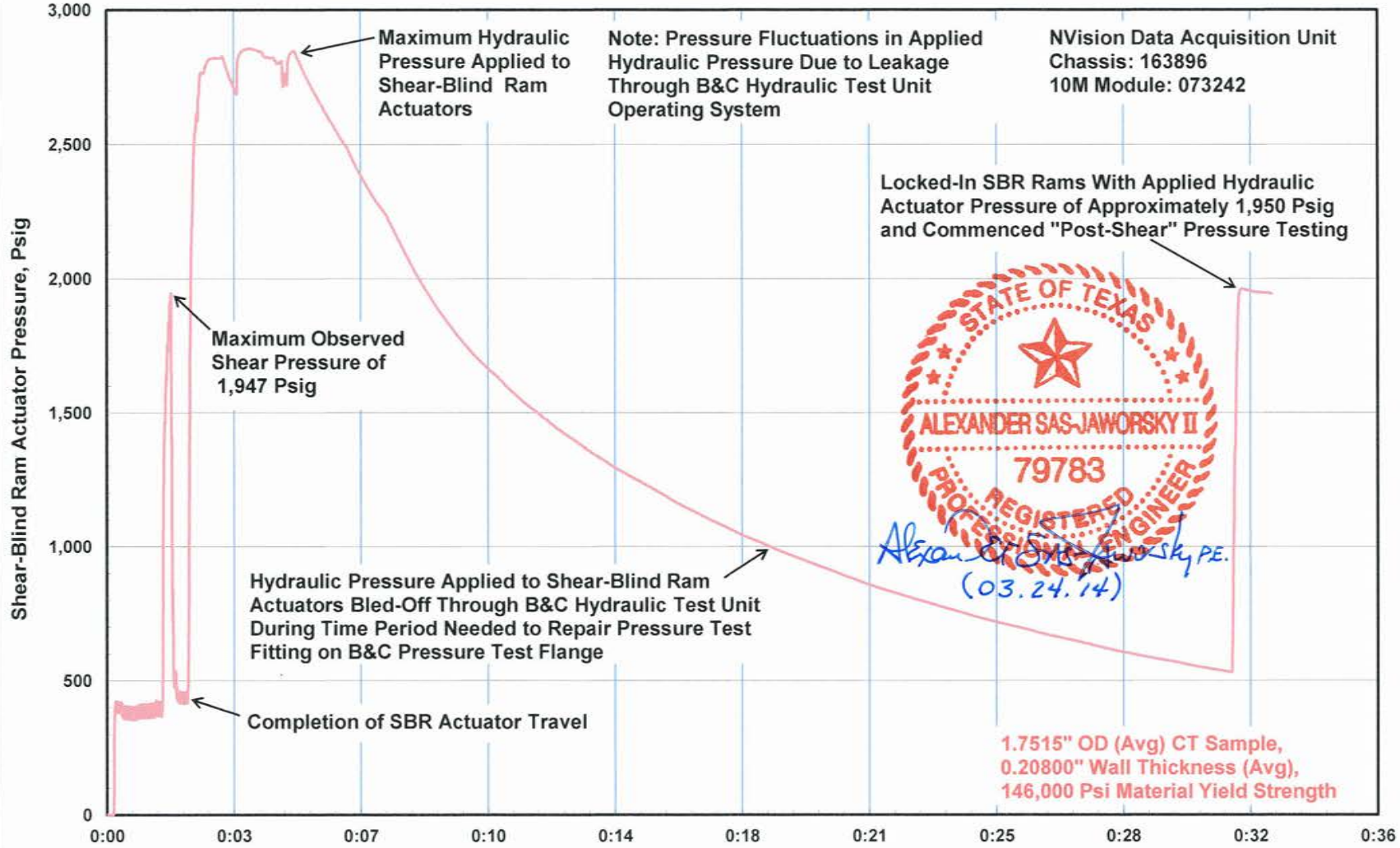
$P_{critical}$ = 2,124 psig + (15,000 / 208.1) = **2,196 psig**

Alex Sas-Jaworsky P.E.
(TX 79783 03.24.14)

To the extent that there are differences between the Shear-Blind Ram performance tests observed by SAS Industries, Inc. and the TOT Calculations, SAS Industries, Inc. bases the findings in this Report on observed physical performance testing and does not rely on the TOT Calculations as a means for determining "fitness-for-purpose". SAS Industries, Inc. makes no representation or warranties regarding the accuracy of the TOT Calculations and provides them at the request of B&C for comparative analysis only.

TOT ES56 123-37672 SHEAR-BLIND RAM PERFORMANCE TEST

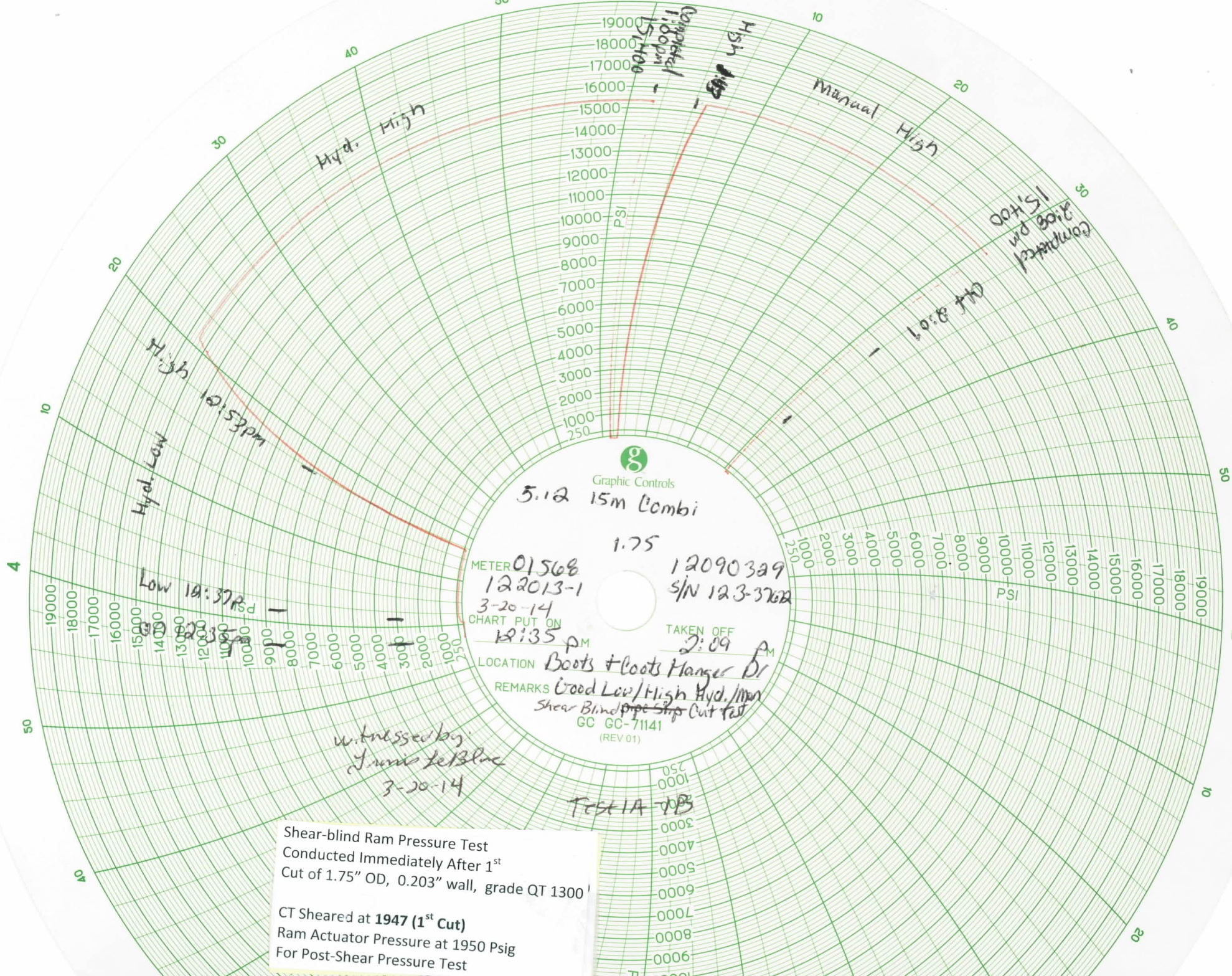
SHEAR-BLIND RAM TEST CONDUCTED ON MARCH 20, 2014 AT B&C FACILITY (New Iberia, LA)



SAS INDUSTRIES, INC.

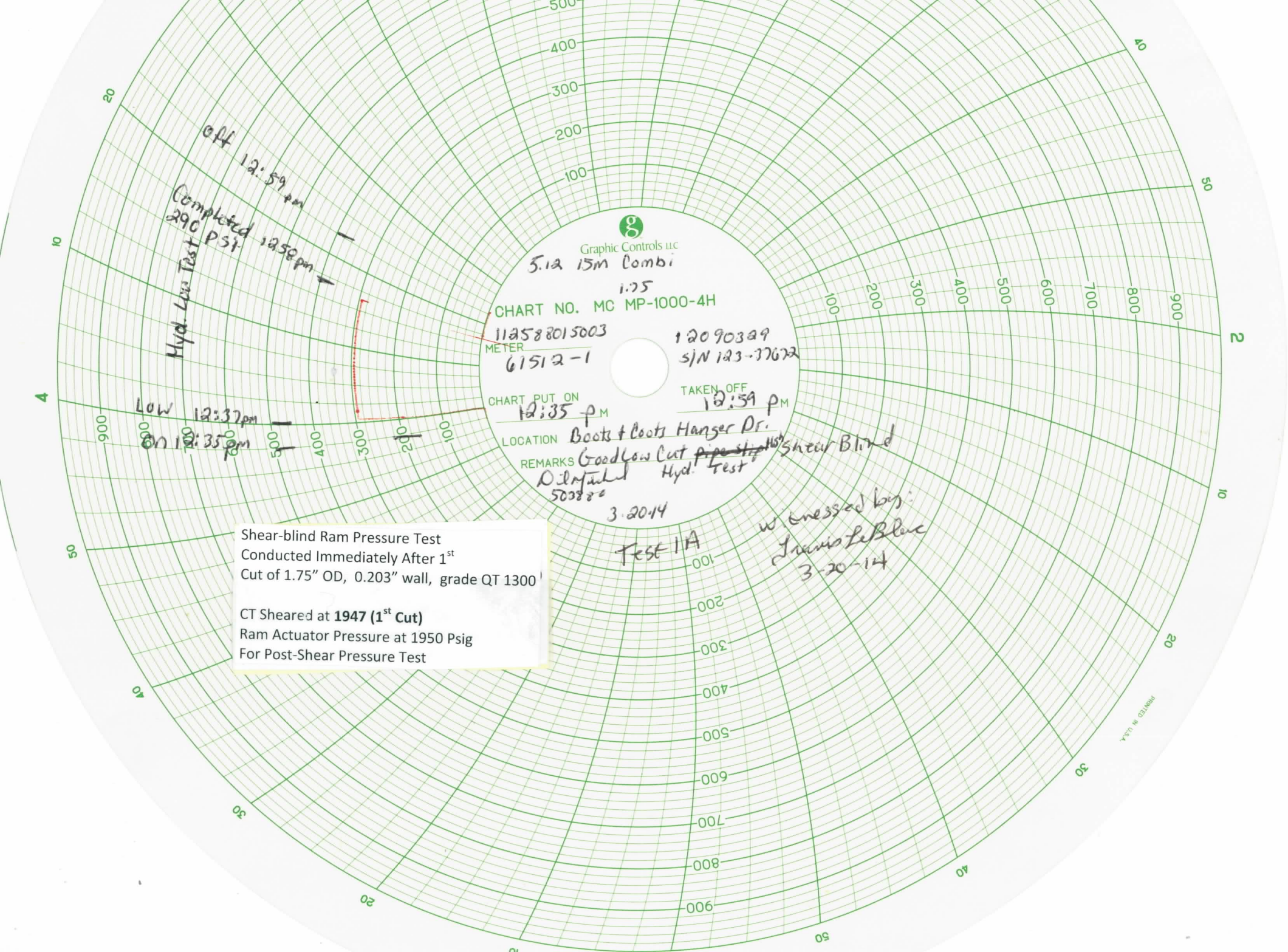
TIME DURATION OF TEST, Hours:Minutes

March 24, 2014



Shear-blind Ram Pressure Test
Conducted Immediately After 1st
Cut of 1.75" OD, 0.203" wall, grade QT 1300

CT Sheared at **1947 (1st Cut)**
Ram Actuator Pressure at 1950 Psig
For Post-Shear Pressure Test



Shear-blind Ram Pressure Test
Conducted Immediately After 1st
Cut of 1.75" OD, 0.203" wall, grade QT 1300

CT Sheared at **1947 (1st Cut)**
Ram Actuator Pressure at 1950 Psig
For Post-Shear Pressure Test