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ASTM D02.B0.07 Semi-Annual Report Bench Test Monitoring

D6417, D5133 (GI), D5800, D6335 (TEOST), D7097(MTEOS), D6082, D874 and D7528 (ROBO)

April 2018

B0.07 Bench Testing Executive Summary

- D6417 (Volatility by GC)
- Precision (Pooled s) is more precise than prior period
  - More precise than target precision
- Performance (Mean Δ/s) is 0.14 s severe
- CUSUM plot shows overall near on-target performance this period (slight severe bias).

B0.07 Bench Testing
Executive Summary

- D5800 (Volatility by Noack)
- Precision (Pooled s), at 0.81 mass %, is less precise than the target LTMS pooled precision of 0.73 mass %, but comparable to prior period with one extreme result excluded from prior period.
- Performance (Mean Δ/s) is 0.15 s severe, using the current LTMS target precision (0.73 mass % across oils). Prior reported periods use the target pooled s.d. in place at the time.
- Fail rate of operationally valid tests (AC & OC) has dropped to 5% or less for the most recent three report periods using LTMS, compared to 26% under the Shewhart severity only system.
- **CUSUM shows recent leveling this period for the first time since at least 2014**, when there was a brief period of less severe performance. With LTMS monitoring, since 20161019, D5800 non-reference results are severity adjusted by instrument, with SA's updated by LTMS calibration evaluation.

B0.07 Bench Testing
Executive Summary

- D5133 (Gelation Index)
- Fail rate of operationally valid tests is 17% this period (9% with Instrument E1 1 excluded). Fail rates have been high the last three periods, with a 10% fail rate last period, and 26% before that. Four periods back the fail rate was 6%.
- Overall severity is 0.16 s severe (-0.30 s mild with Instrument E1 1 excluded).
- Precision (Pooled s), is more precise than target precision, and comparable to prior period with one extreme result excluded from prior period.
- Lab E1, Rig 1, had three consecutive severe fails on non-gelling oil 58, with no known operational cause reported (validity OC), followed by two successful shakedown runs and a passing (AC) calibration. The next calibration attempt resulted in two consecutive severe (OC) fails on low GI oil 1009, followed by a successful calibration (AC). The lab never found (or reported) a cause for the OC runs, so they remain in the statistics.

B0.07 Bench Testing
Executive Summary

- D5133 (Gelation Index, continued)
- Severe oil 62 period mean performance is GI 14.3 compared to the target GI of 17.0 (similar to last period). This shows a continuing mild bias on the high GI oil at the same time that we are conducting a round robin to replace the oil.
- The calibration performance of instrument E1 1 this period, as well as past similar experiences with other instruments, should raise concerns about the adequacy of the current 'single-test' monitoring system to catch severe or mild performing instruments or heads in a timely manner, and whether these instruments, after demonstrating multiple failing results, should subsequently be considered properly calibrated based on just one passing test result.
- Oli 62 is in low supply, a round robin is well under way to evaluate two proposed replacement oils.

B0.07 Bench Testing Executive Summary

- D6335 (TEOST-33C)

- Precision (Pooled s) is significantly less precise than prior period.
  - Excluding one result -4.6 s mild, reported as operationally valid, brings the precision in line with the past two report periods.
  - Less precise than target precision, even with mild result excluded.
  - Severe oil 75 performance continues to be imprecise
- Performance (Mean Δ/s) is mild.
- All calibration tests this period report using Rod Batch M
- Round robin on replacement oil 75-1 is completed, waiting on surveillance panel action.

B0.07 Bench Testing Executive Summary

- D7097 (MHT-4 TEOST)
- Precision (Pooled s) is comparable to last period
  - More precise than target precision for two consecutive periods
    - Precision of both oils is better than target for two consecutive periods
    - Possibly because use of new end cap flask seals has improved test precision?
- Performance (Mean Δ/s) is 0.33 s severe.
- All operationally valid tests this period report using Rod Batch M
- All operationally valid calibration tests this period report using Catalyst Batch 15AA (n=6) or 16DA (n=82).

B0.07 Bench Testing Executive Summary

- D7097 (MHT-4 TEOST) continued

- CUSUM severity plot shows slightly severe performance.
  - However, lab performance differences persist

- Severity bias of new catalyst batch 16DA on severe performing oil 432 is more severe (0.72 s) than typically seen with batch 15AA (0.49 s), though batch 14AA had similar overall severity. Mild performing oil 434 is, overall, on target with batch 16DA.

B0.07 Bench Testing Executive Summary

- D6082 (High Temperature Foam)
- Foam Tendency Precision (Pooled s) is degraded compared to the prior period
  - But, comparable to prior period, and much more precise than target precision, with one OC failing result excluded (Yi = 2.3 s, Lab V)
- Performance (Mean Δ/s) is on target (slightly mild with one result excluded)
- No non-zero occurrences of Foam Stability (on operationally valid tests)
- All severe oil discrimination runs demonstrated acceptable discrimination.

B0.07 Bench Testing
Executive Summary

- D874 (Sulfated Ash)
- Precision (Pooled s) is comparable to the prior period (which was less precise than the prior three periods)
  - Comparable to the target precision
- Performance (Mean Δ/s) is 0.37 s severe

B0.07 Bench Testing Executive Summary

- D7528 (ROBO)
- Precision (Pooled s) is more precise than all prior periods since at least October 2104.
  - But, continues to be less precise than target precision
- Performance (Mean Δ/s) is -0.76 s mild with all labs mild to some degree and all four oils performing overall mild
- Lab G, with, by far, the highest n size of any lab this period has a few issues of note:
  - Only three tests exceed 3 s (severe or mild) this period: (-3.8, 3.4, -3.5), but all are from Lab G, and each failing result is on a different rig.
  - Rig G6 has 4 failing OC runs this period (three mild and one severe; two consecutive fails), alternating with passing (AC) runs.
  - Rig G2 has 3 failing OC runs (all mild, two consecutive), alternating with passing (AC) runs.
  - These two rigs (G2 and G6) account for 7 of the 15 OC tests reported this period.

B0.07 Bench Testing
Executive Summary

- D7528 (ROBO) continued
- Oil 434-1 is nearly depleted, Reblend 434-2 has been introduced with preliminary targets set by round robin.
  - 434-2 is running -1.34 s mild on nine tests, however targets were set with consideration of preserving (or not canceling out) the mild trend on oil 434-1, and the 434-2 performance reflects that ongoing mild trend.

- CUSUM Severity Plot shows an overall mild trend since the 01APR11 timeline (following a 2011 ROBO workshop) with a brief leveling coincident with the October 2015 ROBO workshop held in San Antonio, TX, but the mild trend returns following the April 2016 timeline.

Calibrated Labs and Stands*

Test	Labs	Stands
D6417	6	9
D5800	10	22
D5133 (GI)	8	12
D6335 (TEOST)	6	10
D7097 (MTEOS)	9	40
D6082	5	6
D874	4	--
D7528 (ROBO)	6	18

*As of 3/31/2018

D02.B0.07
TMC Monitored Tests

- October 1, 2017 –
  March 31, 2018

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D6417: Estimation of Engine Oil Volatility by Capillary GC

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	15
Failed Calibration Test	OC	0
Operationally Invalidated by Lab	LC, XC	0
Operationally Invalidated After Initially Reported as Valid	RC	0
Total		**15**

Number of Labs Reporting Data: 6
Fail Rate of Operationally Valid Tests: 0%

D6417: Estimation of Engine Oil Volatility by Capillary GC

Statistically Unacceptable Tests (OC)	No. Of Tests
Volatility Loss Mild	0
Volatility Loss Severe	0

- There were no operationally or statistically unacceptable D6417 tests reported this period.

- There were no technical memos issued this period for D6417.

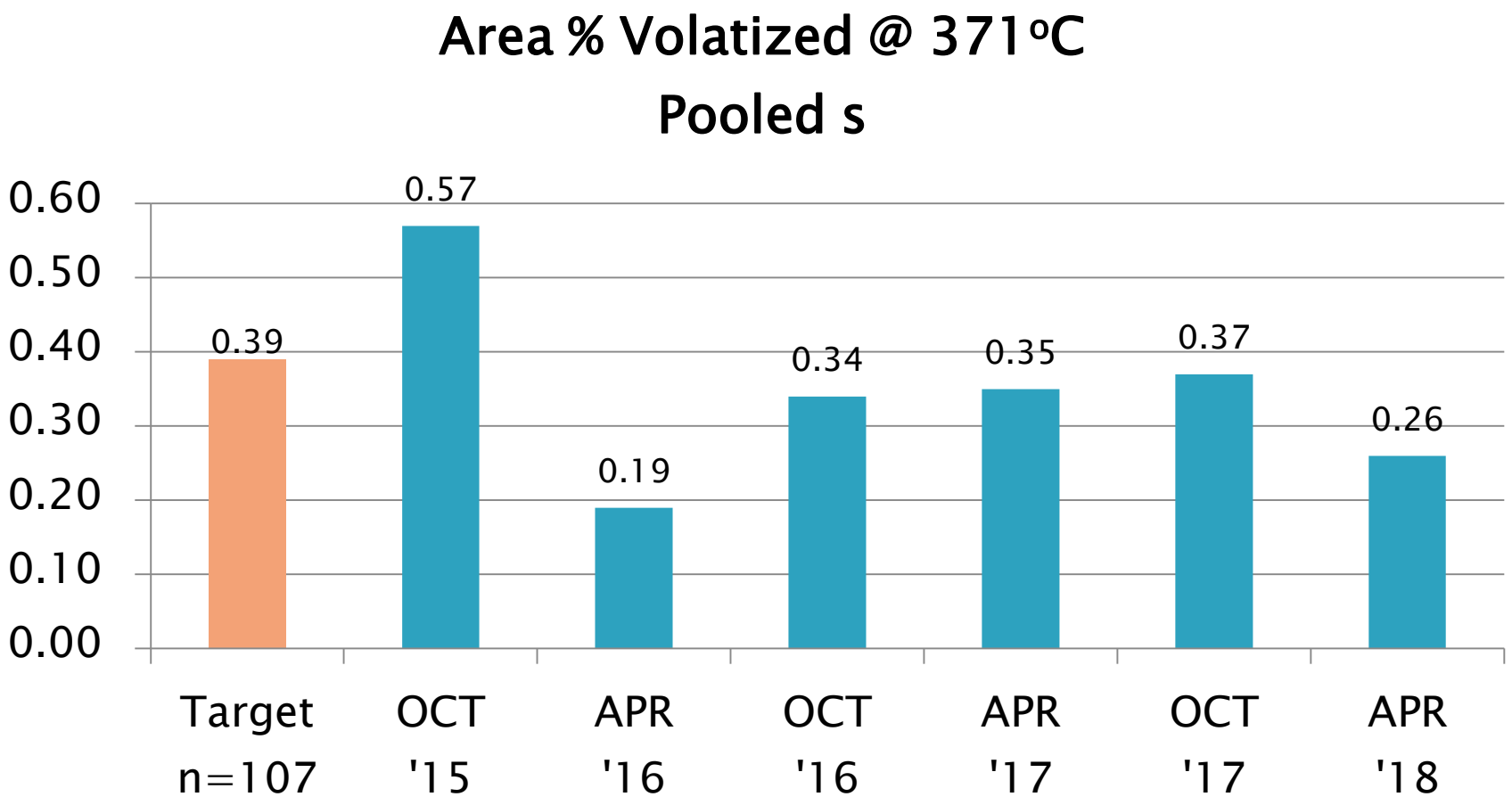
D6417: Estimation of Engine Oil Volatility by Capillary GC

Period Precision and Severity Estimates

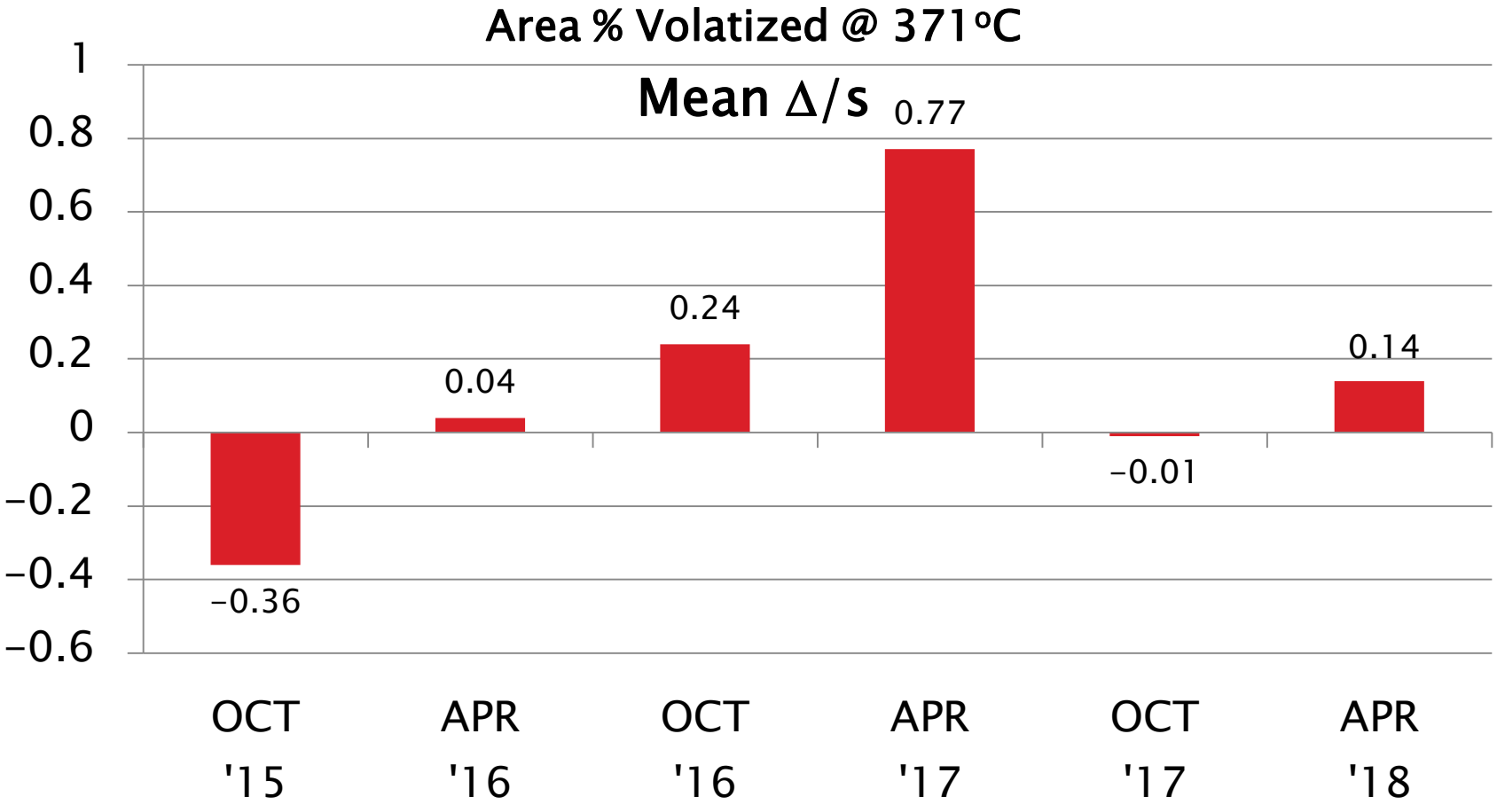
Area % Volatized @ 371°C	n	df	Pooled s	Mean Δ/s
Initial Selected Oils from RR	54	51	0.39	-----
4/1/15 through 9/30/15*	16	13	0.57	-0.36
4/1/15 through 9/30/15*	15	12	0.42	-0.04
10/1/15 through 3/31/16	13	10	0.19	0.04
4/1/16 through 9/30/16	11	8	0.34	0.24
10/1/16 through 3/31/17	13	10	0.35	0.77
4/1/17 through 9/30/17	15	12	0.37	-0.01
10/1/17 through 3/31/18	15	12	0.26	0.14

*Extreme OC result included and excluded

D6417 Precision Estimates



D6417 Severity Estimates

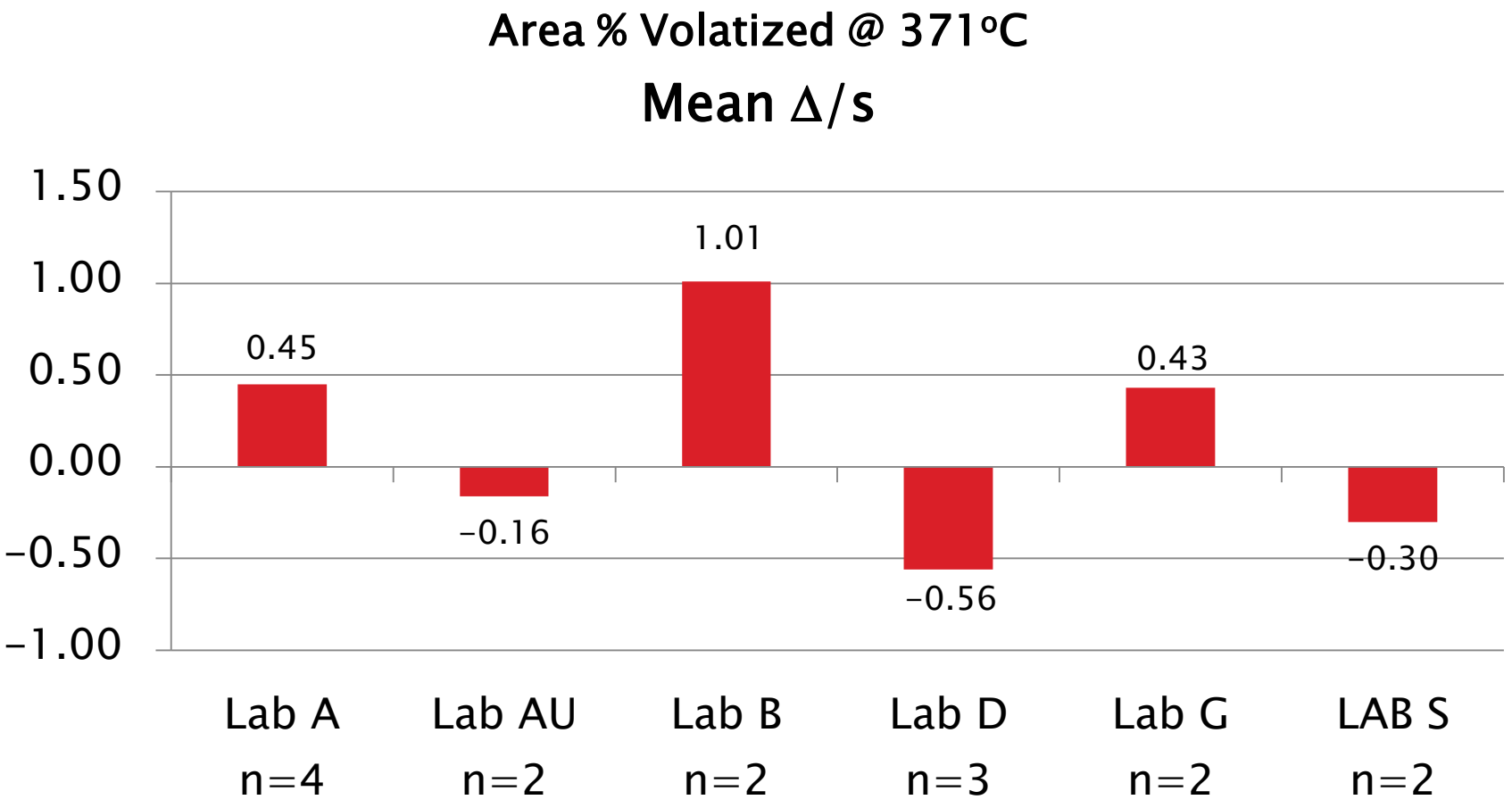


D6417: Estimation of Engine Oil Volatility by Capillary GC

Current Period Severity Estimates by Lab
Area % Volatized @ 371°C

	n	Mean Δ/s
Lab A	4	0.45
Lab AU	2	-0.16
Lab B	2	1.01
Lab D	3	-0.56
Lab G	2	0.43
Lab S	2	-0.30

D6417 Lab Severity Estimates



D6417: Estimation of Engine Oil Volatility by Capillary GC

- Precision (Pooled s) is more precise than prior period
  - More precise than target precision
- Performance (Mean Δ/s) is 0.14 s severe
- CUSUM plot shows overall near on-target performance this period (slight severe bias).

D6417 VOLATILITY BY GC INDUSTRY OPERATIONALLY VALID DATA

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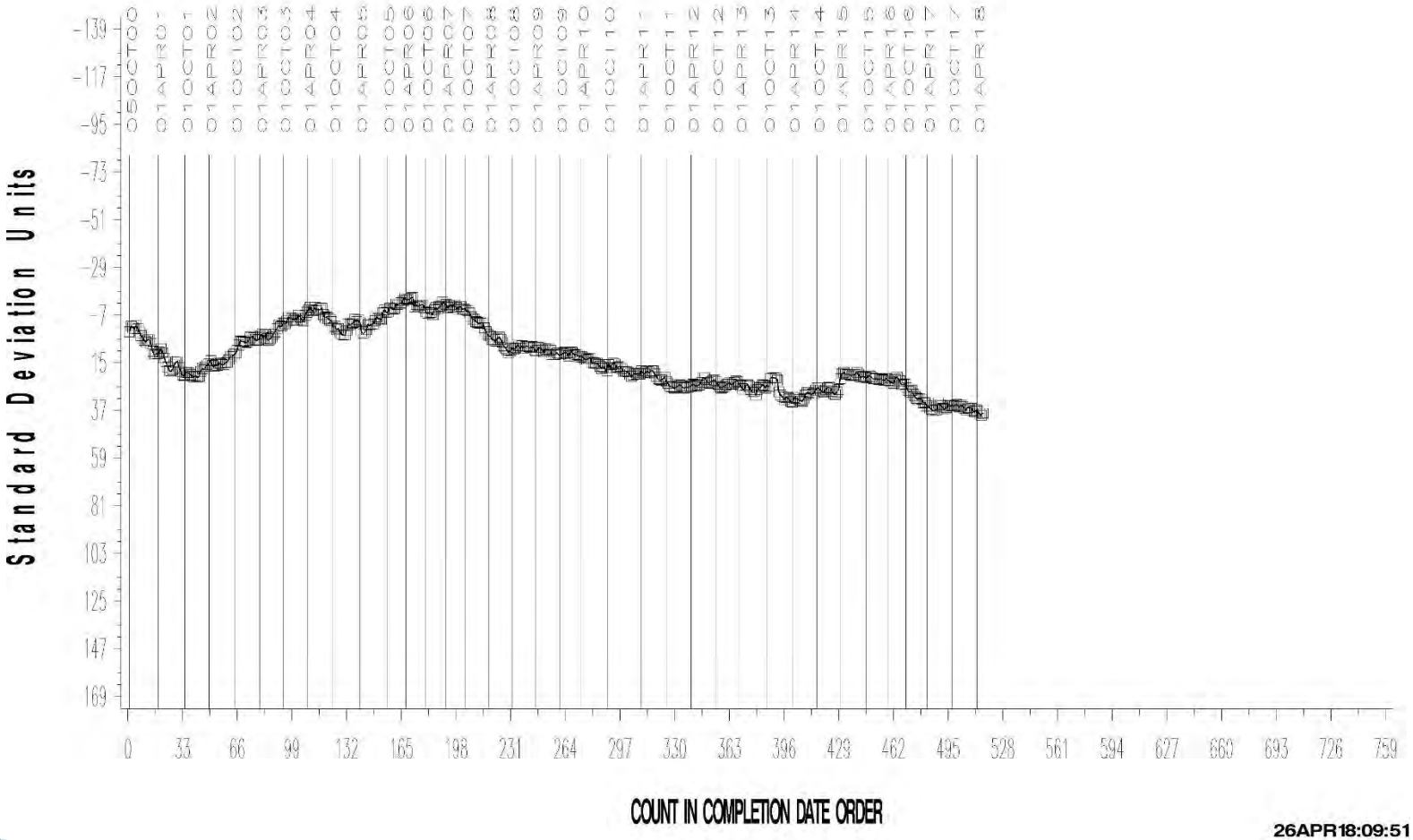
SAMPLE AREA % VOLATIZED

CUSUM Severity Analysis



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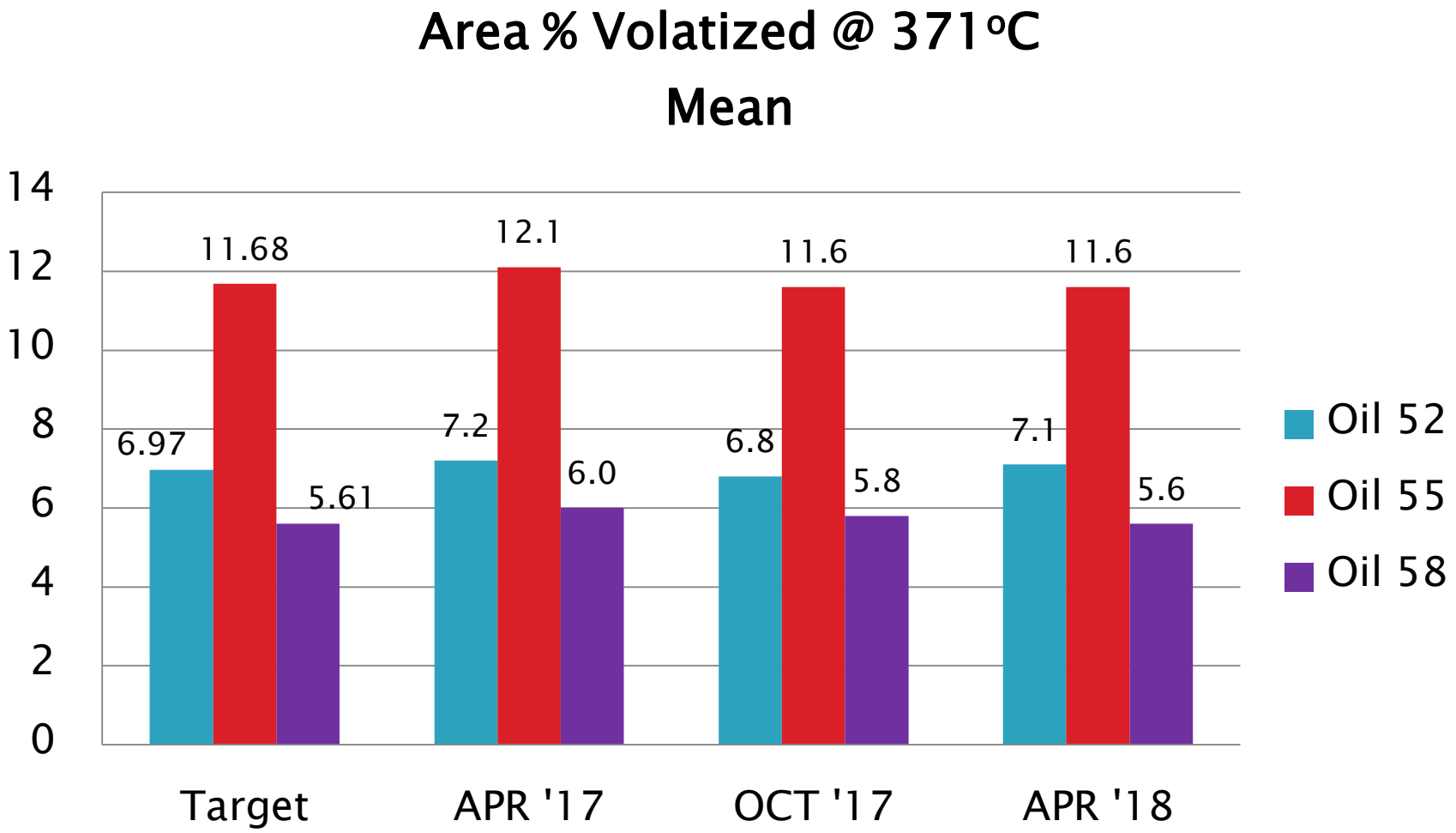
D6417: Estimation of Engine Oil Volatility by Capillary GC

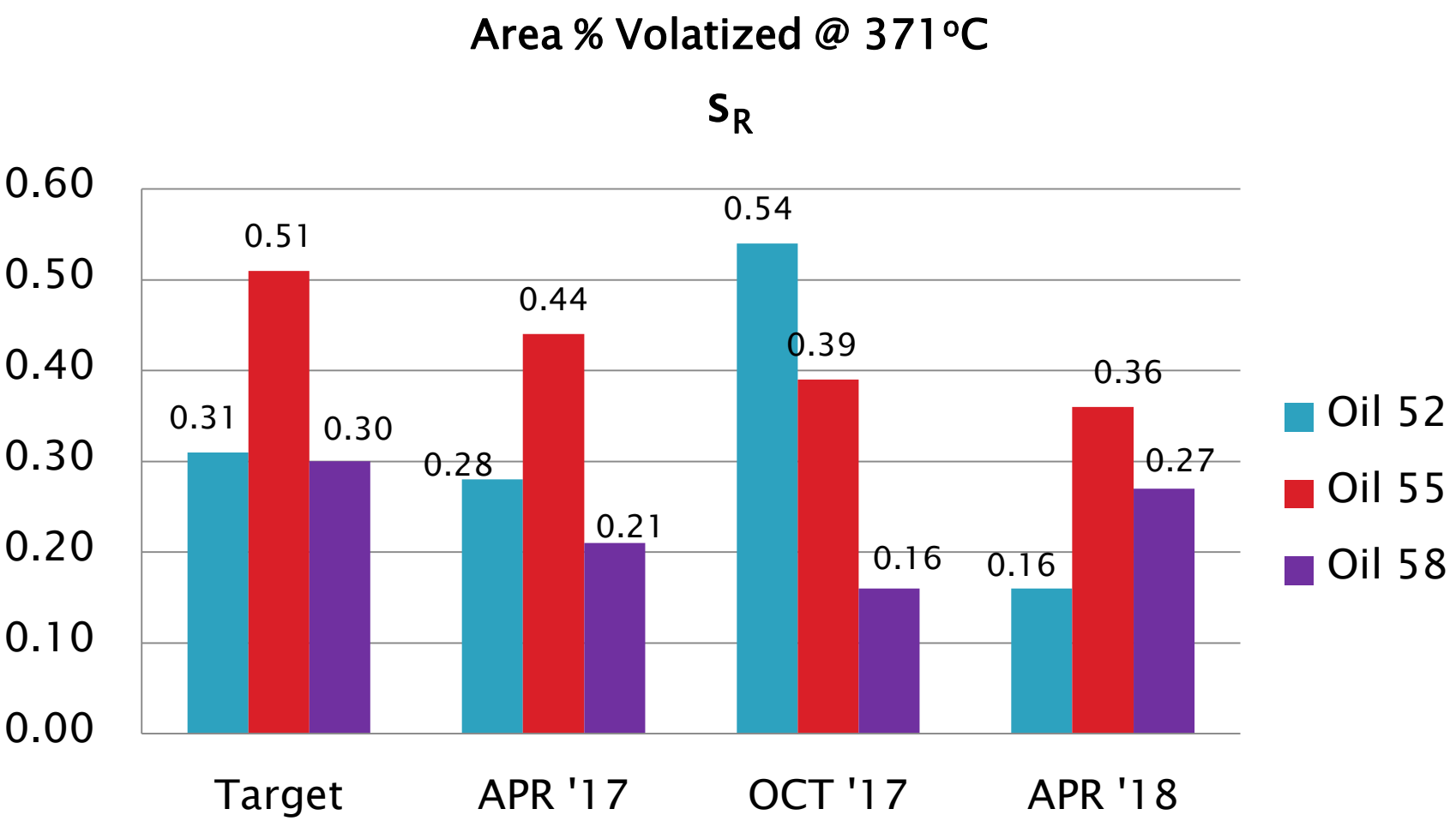
Area % Volatized @ 371°C
Performance by Oil

	Targets			10/1/16 - 3/31/17				4/1/17- 9/30/17				10/1/17 - 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
52	18	6.97	0.31	6	7.2	0.28	0.63	4	6.8	0.54	-0.63	6	7.1	0.16	0.37
55	18	11.68	0.51	5	12.1	0.44	0.78	5	11.6	0.39	-0.08	4	11.6	0.36	-0.16
58	18	5.61	0.30	2	6.0	0.21	1.13	6	5.8	0.16	0.47	5	5.6	0.27	0.10

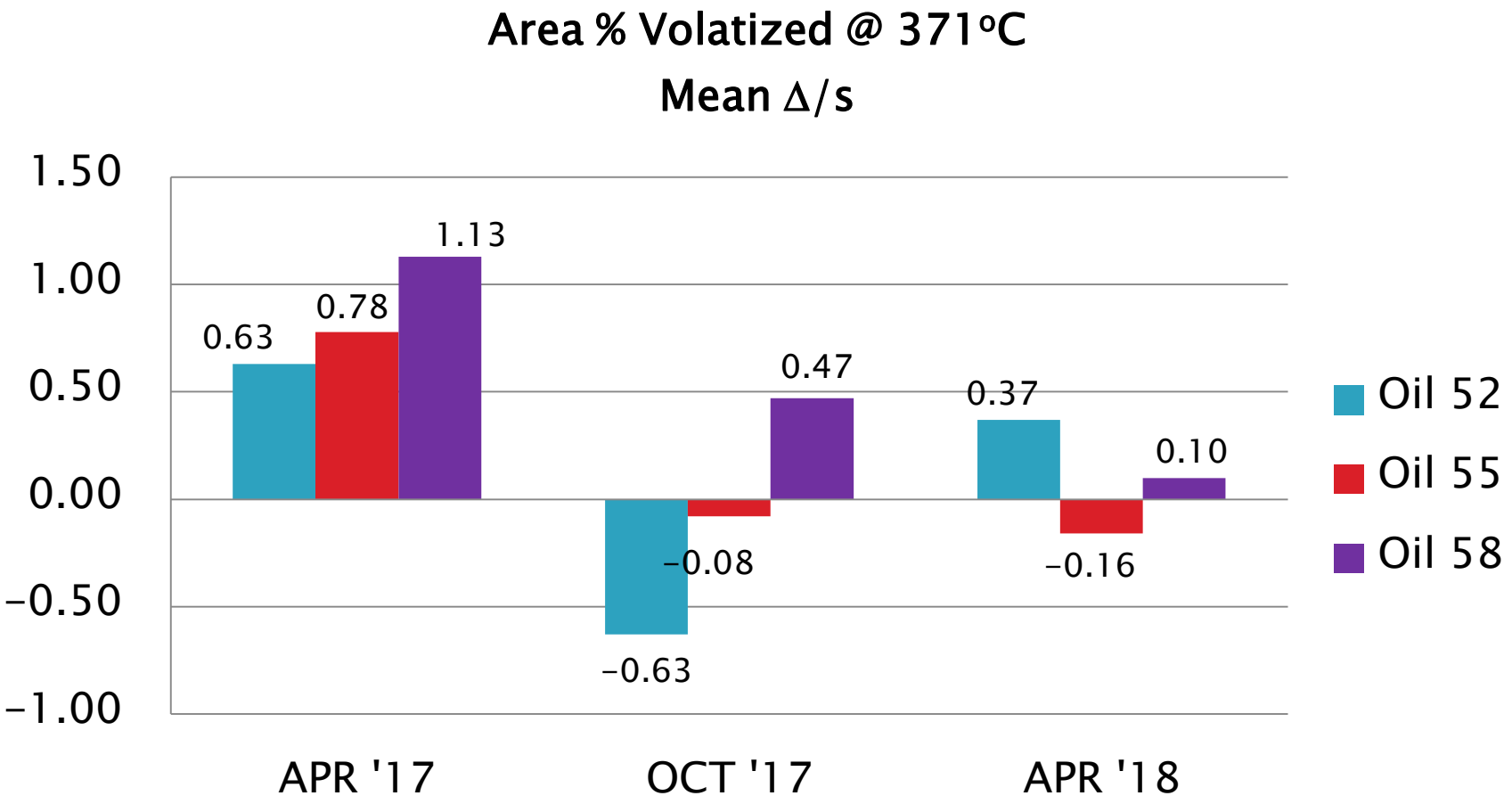
D6417 Performance by Oil



D6417 Performance by Oil



D6417 Performance by Oil



Return to Executive Summary

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	128
Failed Calibration Test	OC	5
Operationally Invalidated by Lab	LC, XC	0
Operationally Invalidated After Initially Reported as Valid	RC	0
Non-Blind Instrument Shakedown	NN	14
Total		**147**

Number of Labs Reporting Data: 10
Fail Rate of Operationally Valid Tests: 4%

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Statistically Unacceptable Tests (OC)	No. Of Tests
Ei Level 3 Precision Alarm Mild	2
Ei Level 3 Precision Alarm Severe	3
Zi Level 2 Severity Severe	1
Zi Level 2 Severity Mild	0

- One test triggered both Ei L3 severe and Zi L2 severe alarms.
- Five OC tests were on five different rigs at four labs.
- No operational failing runs reported this period.
- Lab A ran all 14 shakedown runs, on both established instruments (to troubleshoot) and a new rig (pre-calibration and stability checks).
- There were no technical updates issued this report period.

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Period Precision and Severity Estimates

Sample Evaporation Loss, mass %	n	df	Pooled s	Mean Δ/s
Targets Effective 10/19/2016	--	--	0.73	-----
4/1/15 through 9/30/15*	55	52	0.67	1.04
4/1/15 through 9/30/15*	54	51	0.61	0.95
10/1/15 through 3/31/16	57	54	0.50	1.08
4/1/16 through 9/30/16	62	59	0.60	0.99
10/1/16 through 3/31/17	136	133	0.70	0.53
4/1/17 through 9/30/17*	147	144	1.13	0.56
4/1/17 through 9/30/17*	146	143	0.84	0.47
10/1/17 through 3/31/18	133	130	0.81	0.15

*Extreme OC result included and excluded

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Performance Comparison by Procedure & Model

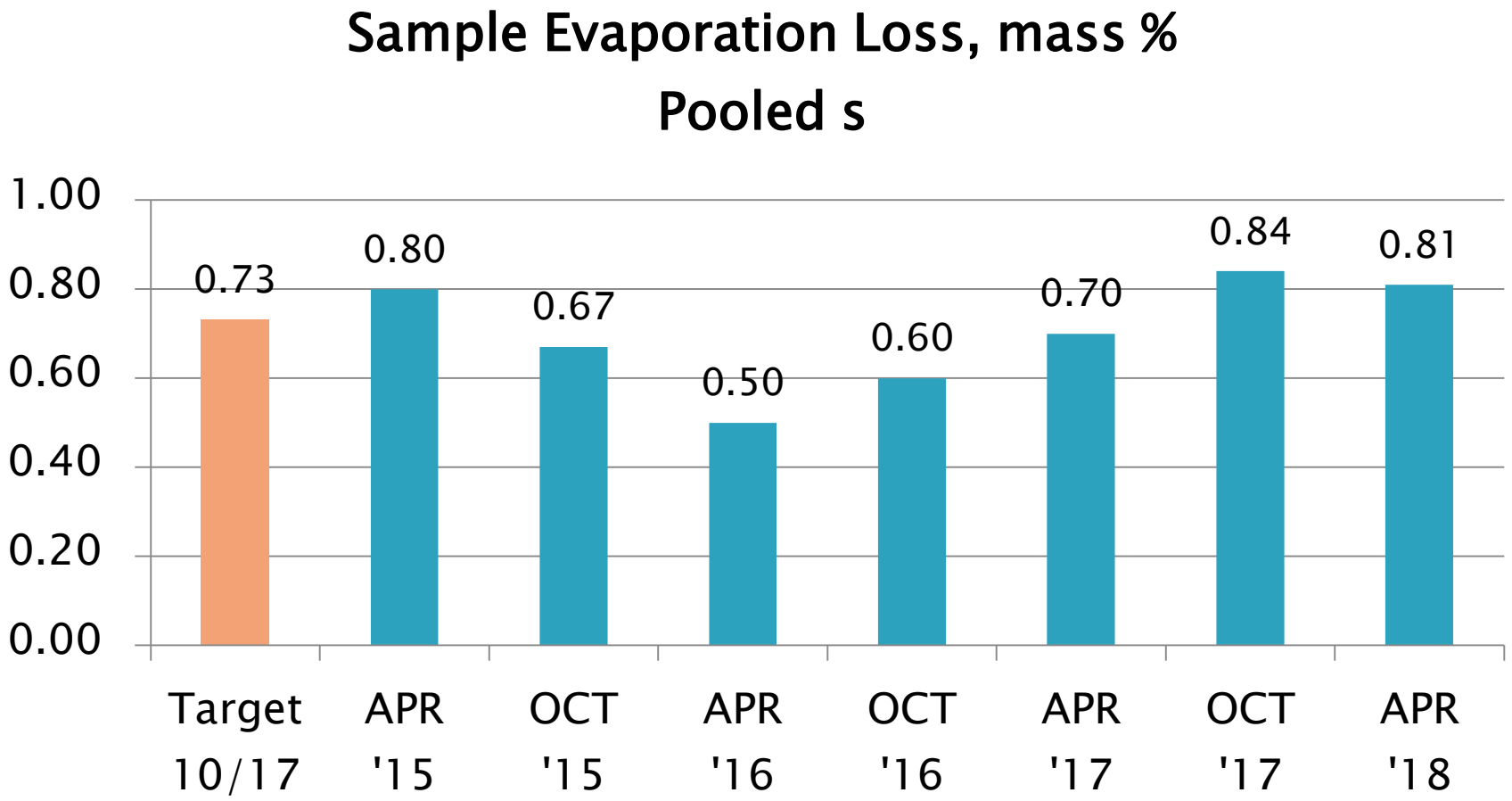
Sample Evaporation Loss, Mass %

	n	df	Pooled s	Mean Δ/s
Procedure B	115	112	0.78	0.25
Procedure C	18	15	0.86	-0.50

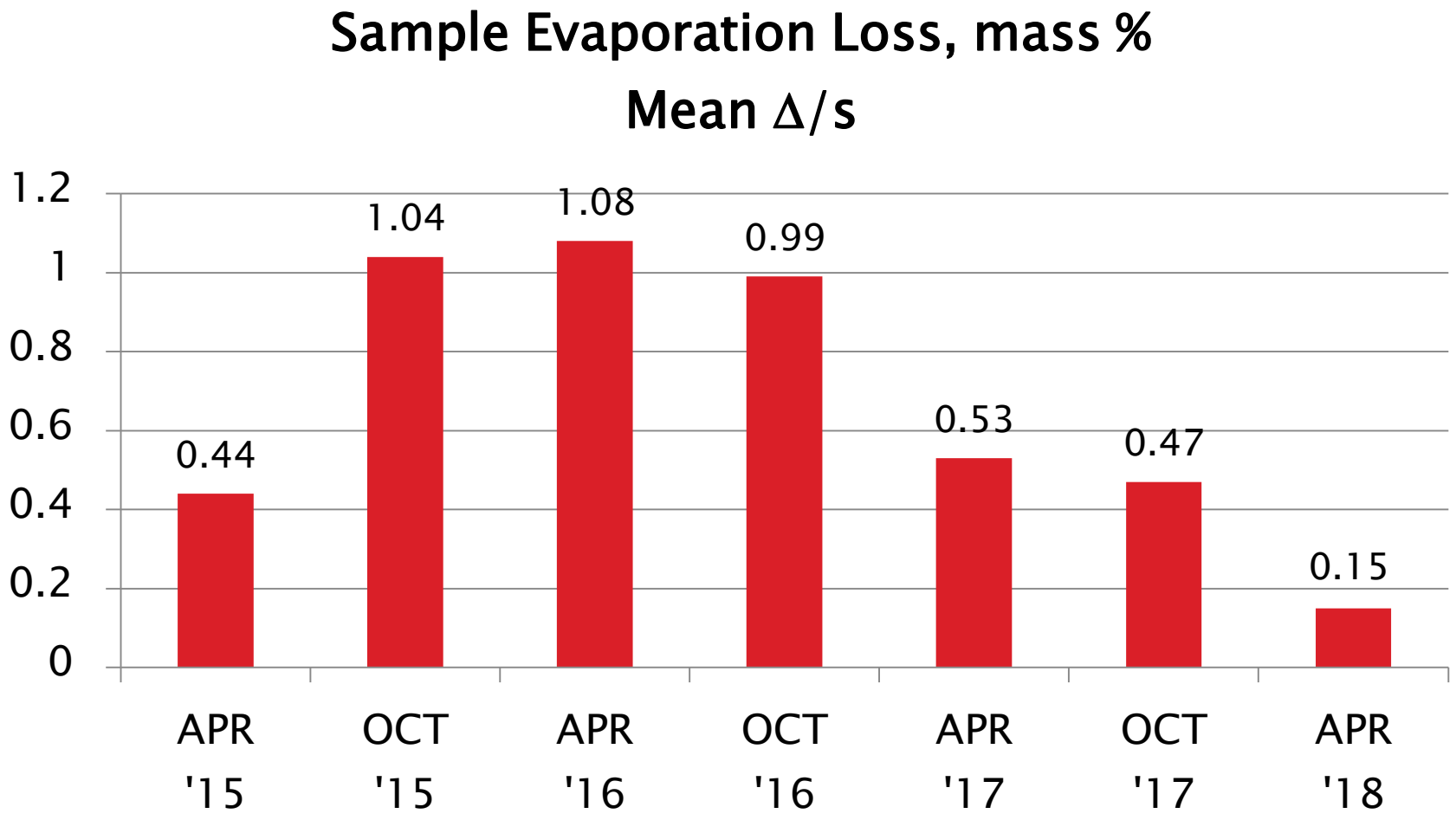
Model	n	df	Pooled s	Mean Δ/s
NCK2	13	10	0.23	0.04
NCK25G	102	99	0.82	0.28
SVT1	18	15	0.86	-0.50

2 NCK2 Rigs
21 NCK25G Rigs
3 SVT1 Rigs

D5800 Precision Estimates



D5800 Severity Estimates

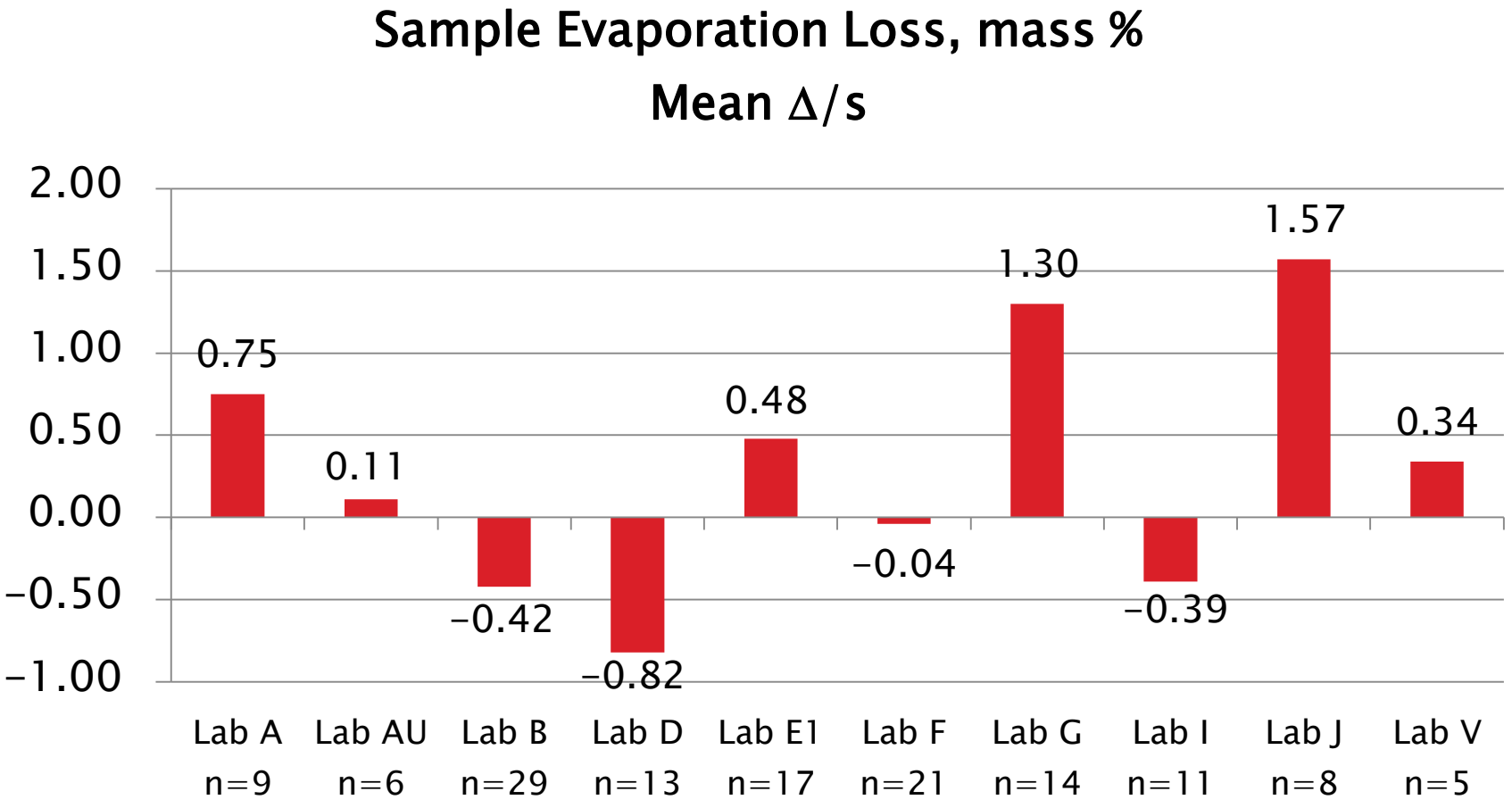


D5800: Evaporation Loss of Lubricating Oil by Noack Method

Current Period Severity Estimates by Lab
Sample Evaporation Loss, mass %

Lab	n	Mean Δ/s	Lab	n	Mean Δ/s
Lab A	9	0.75	Lab F	21	-0.04
Lab AU	6	0.11	LAB G	14	1.30
Lab B	29	-0.42	Lab I	11	-0.39
Lab D	13	-0.82	Lab J	8	1.57
Lab E1	17	0.48	Lab V	5	0.34

D5800 Lab Severity Estimates



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D5800: Evaporation Loss of Lubricating Oil by Noack Method

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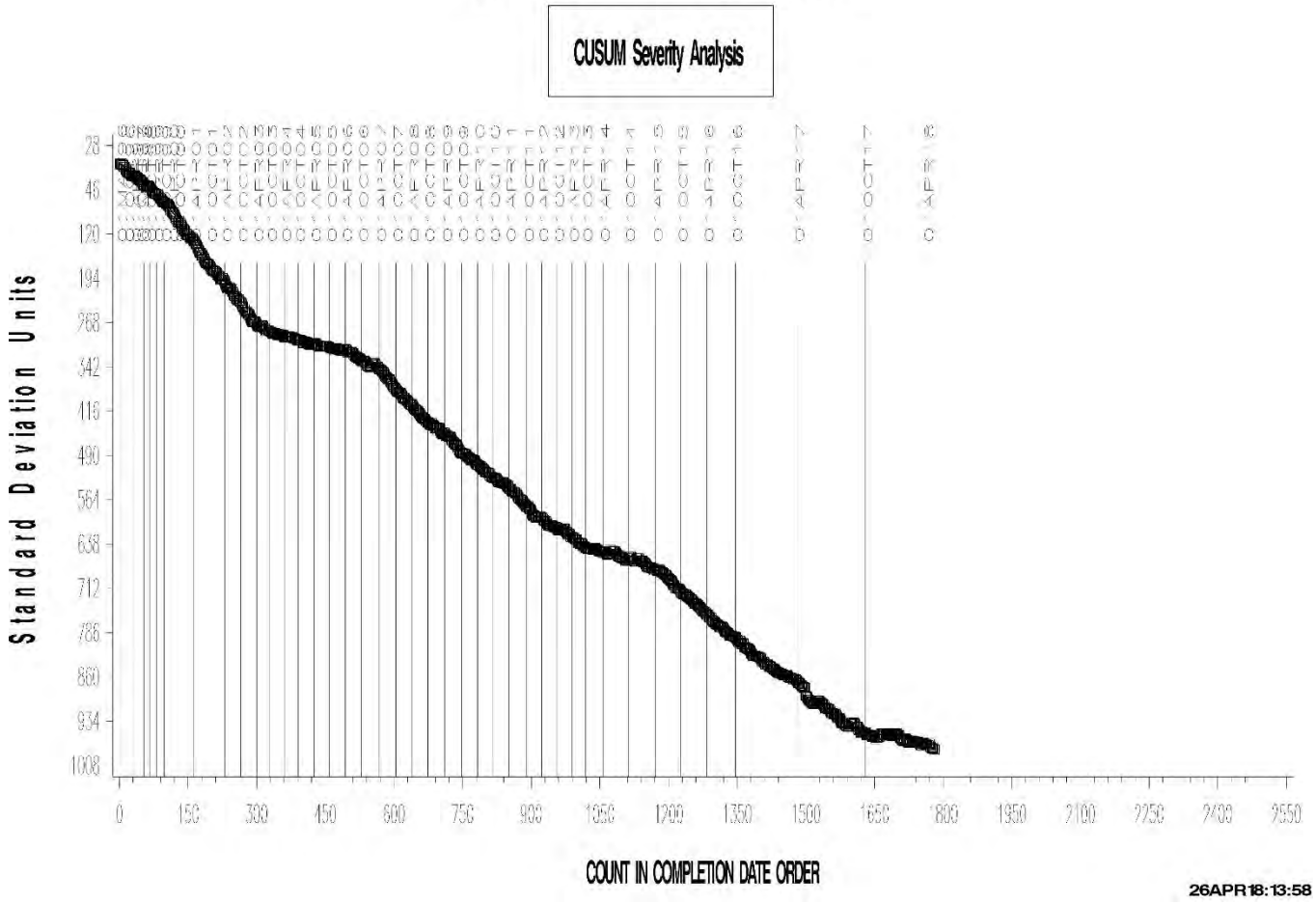
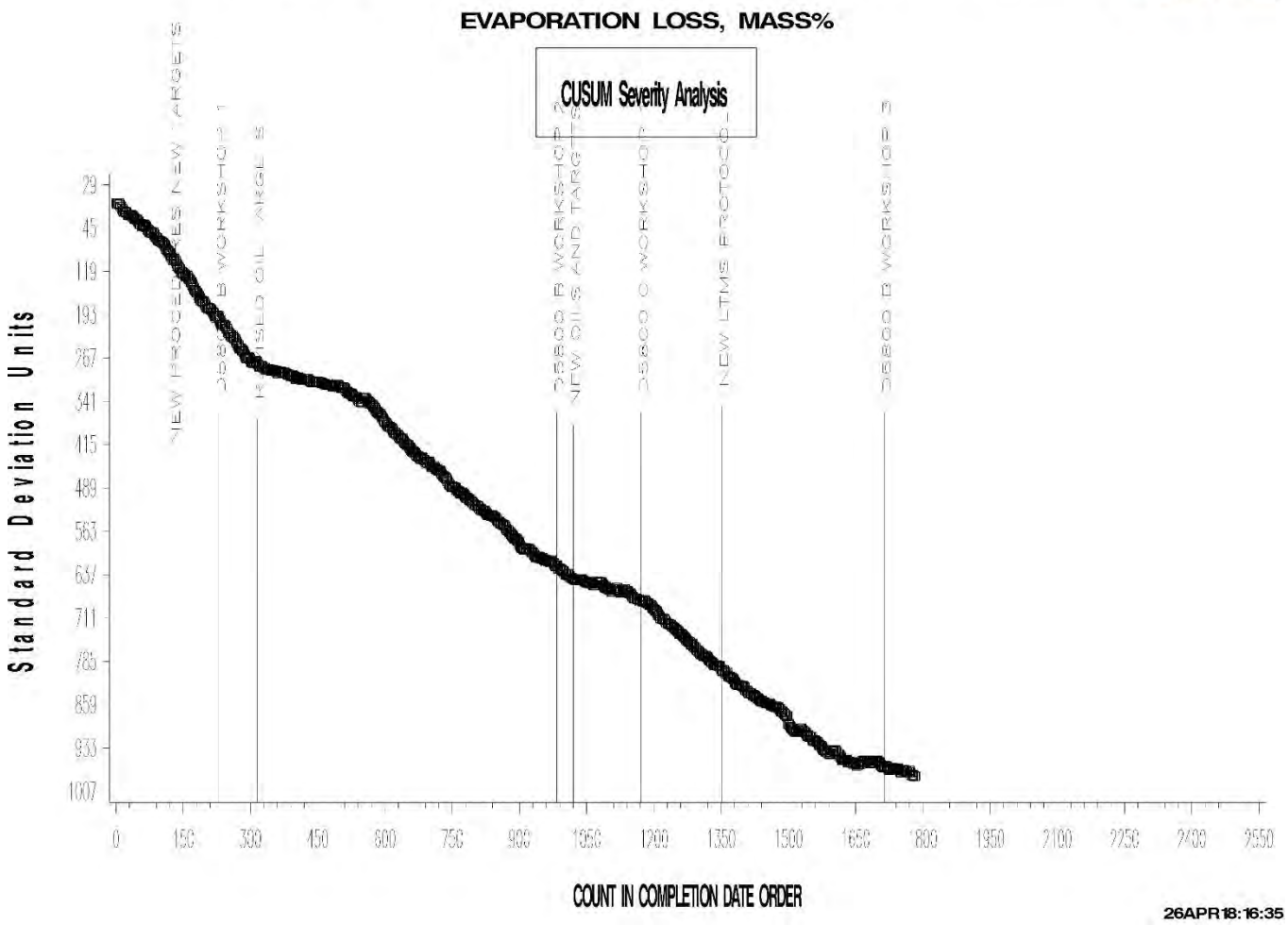
- Fail rate of operationally valid tests (AC & OC) has dropped to 5% or less for the most recent three report periods using LTMS, compared to 26% under the Shewhart severity only system.
- **CUSUM shows recent leveling this period for the first time since at least 2014**, when there was a brief period of less severe performance. With LTMS monitoring, since 20161019, D5800 non-reference results are severity adjusted by instrument, with SA's updated by LTMS calibration evaluation.

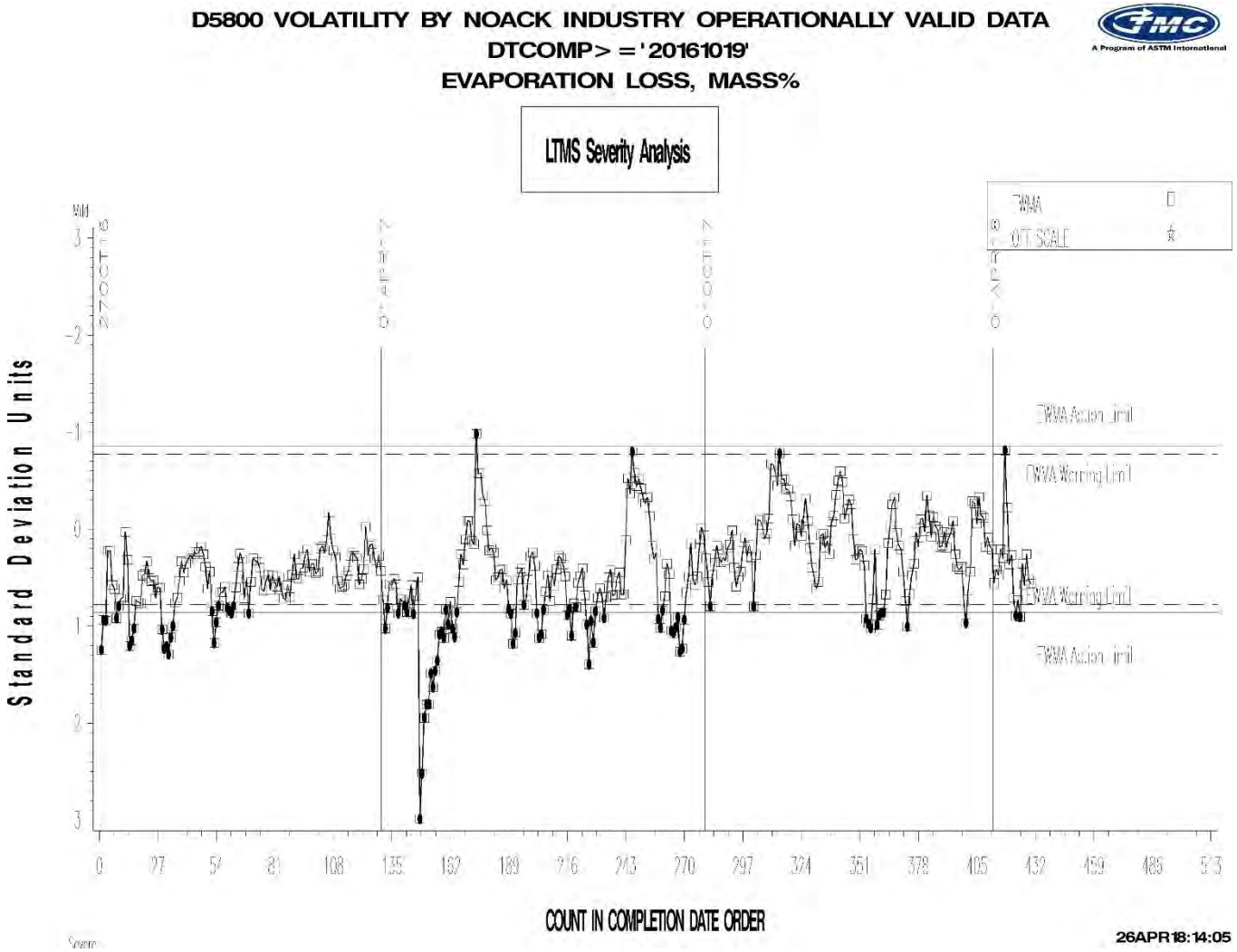
D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA

EVAPORATION LOSS, MASS%



D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA




D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
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EVAPORATION LOSS, MASS%
LTMS Severity Analysis
EWMA
OT SCALE
EWMA Action Limit
EWMA Warning Limit
EWMA Warning Limit
EWMA Action Limit
Standard Deviation Units
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D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
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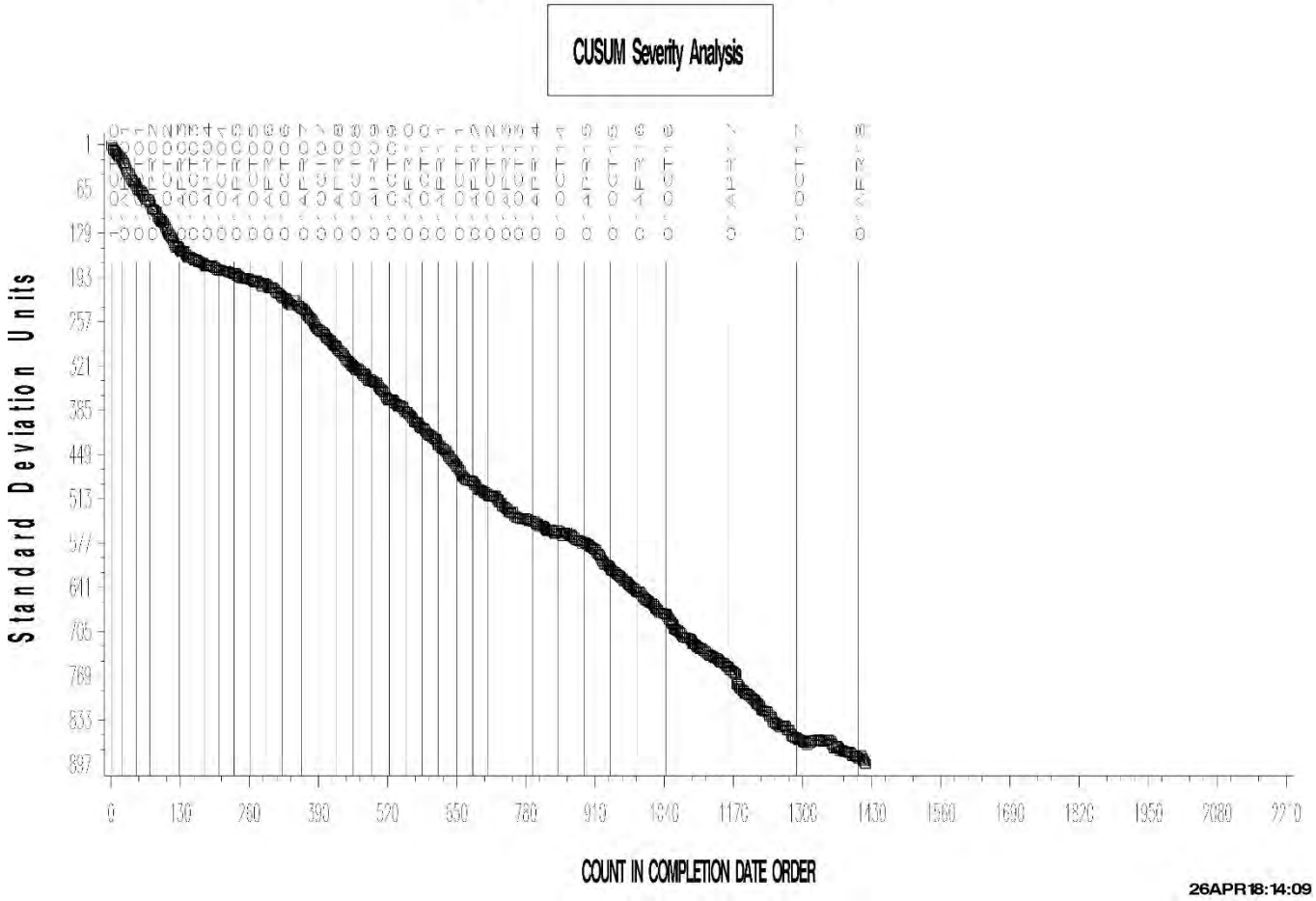
EVAPORATION LOSS, MASS%



D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
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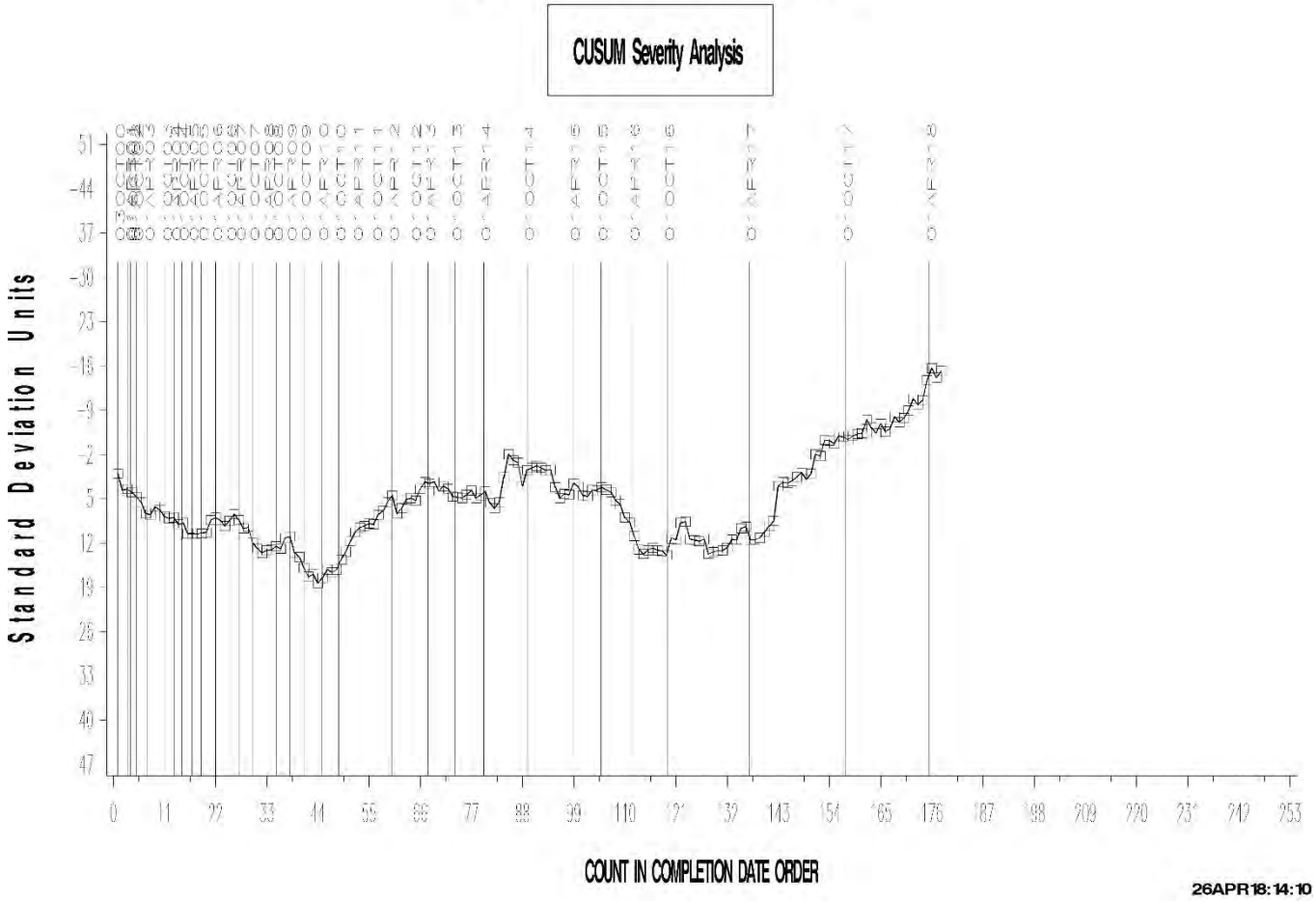
EVAPORATION LOSS, MASS%

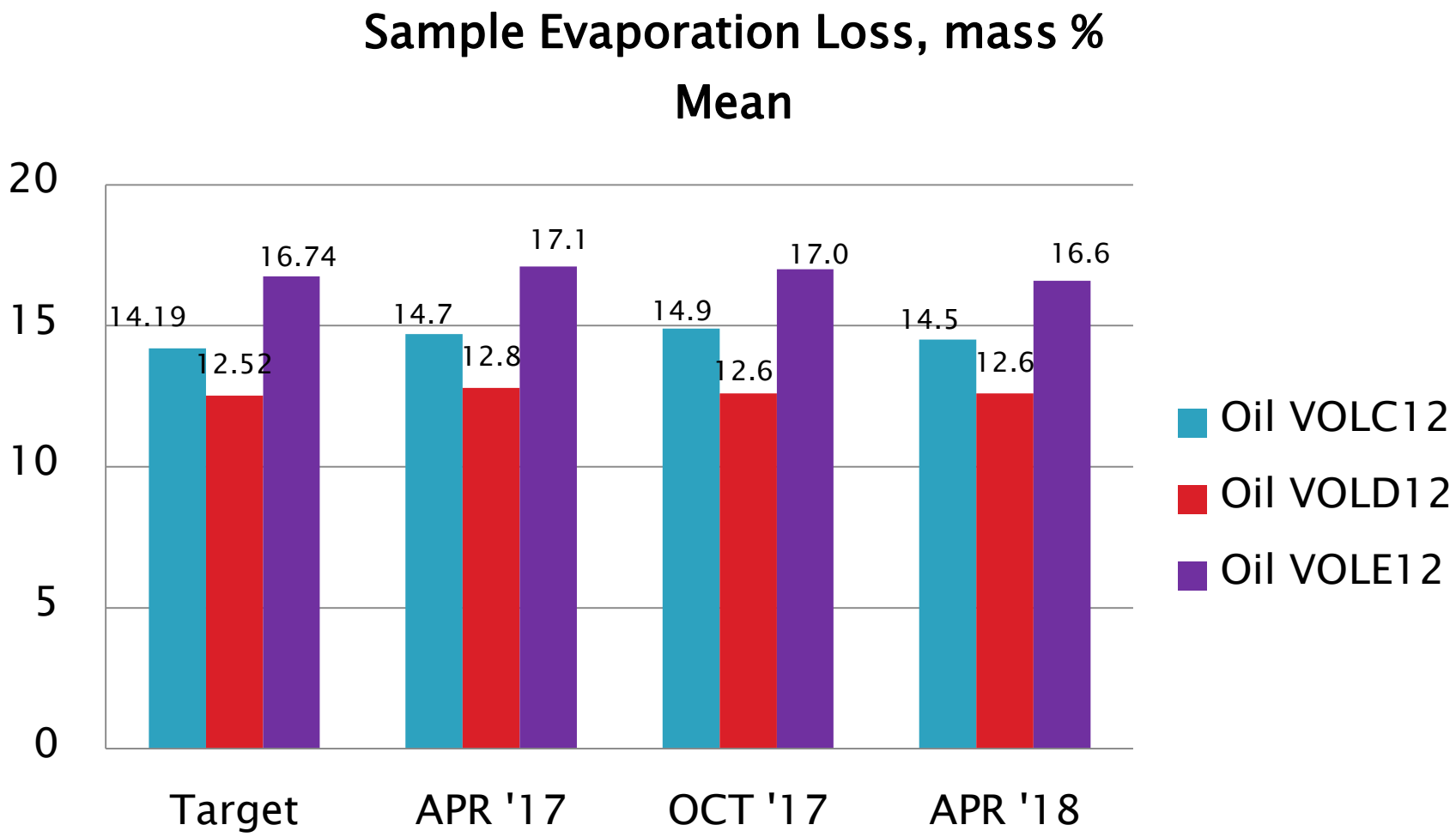


D5800: Evaporation Loss of Lubricating Oil by Noack Method

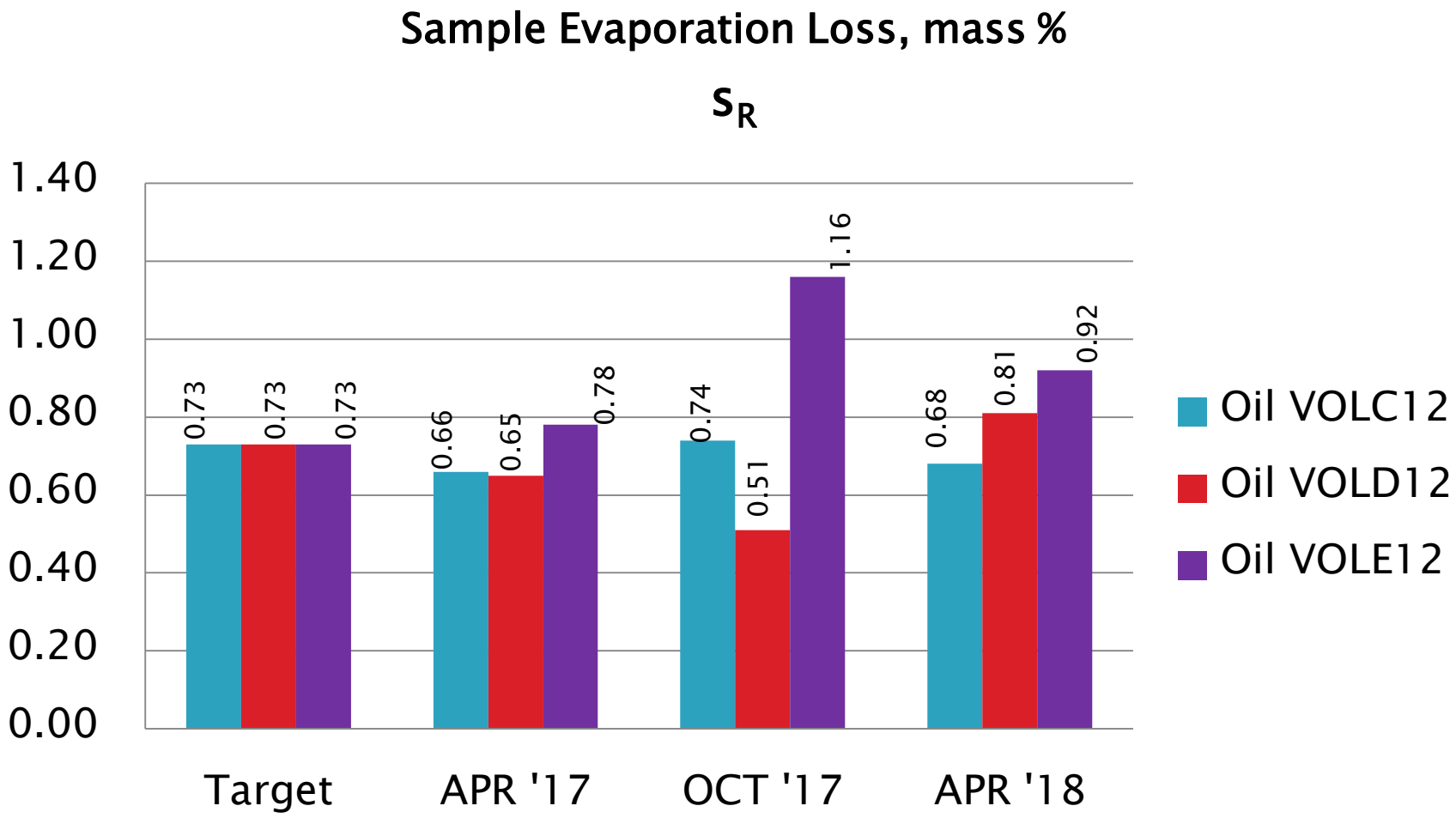
Sample Evaporation Loss, mass %
Performance by Oil

	Targets			10/1/16– 3/31/17				4/1/17 – 9/30/17				10/1/17– 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
VOLC12	24	14.19	0.73	47	14.7	0.66	0.69	46	14.9	0.74	0.92	44	14.5	0.68	0.43
VOLD12	27	12.52	0.73	40	12.8	0.65	0.45	51	12.6	0.51	0.14	45	12.6	0.81	0.15
VOLE12	27	16.74	0.73	49	17.1	0.78	0.46	49	17.0	1.16	0.40	44	16.6	0.92	-0.13

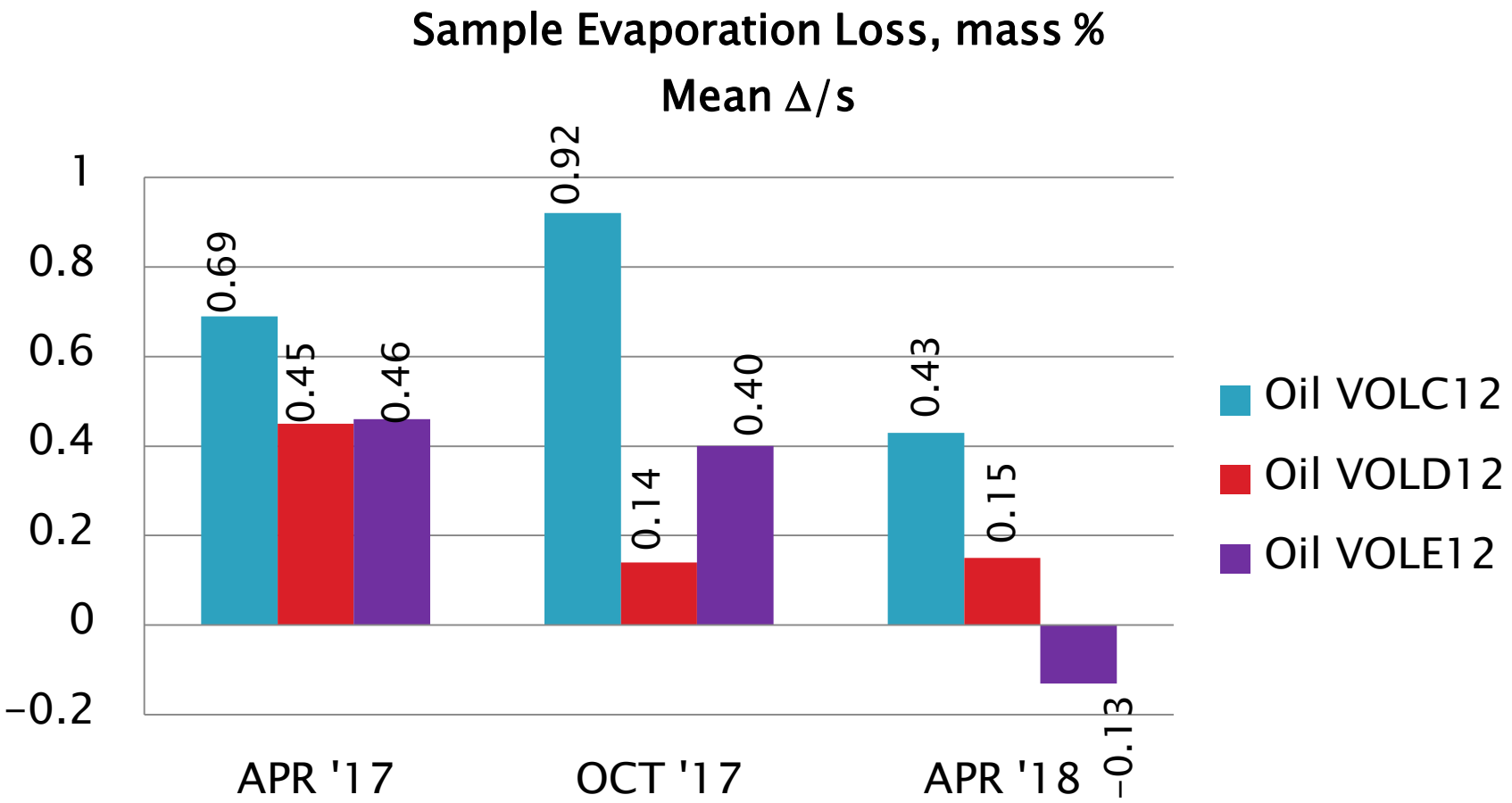
D5800 Performance by Oil



D5800 Performance by Oil



D5800 Performance by Oil



Return to Executive Summary

D5133: Gelation Index

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	30
Failed Calibration Test	OC	6
Operationally Invalidated by Lab	LC, XC	2
Operationally Invalidated After Initially Reported as Valid	RC	0
Non-blind Instrument Shakedowns	NN, LN	19
Total		**57**

Number of Labs Reporting Data: 9 (only 8 calibrated)
Fail Rate of Operationally Valid Tests: 17%

D5133: Gelation Index

Statistically Unacceptable Tests (OC)	No. Of Tests
Gelation Index Mild	2
Gelation Index Severe	4

- All 4 severe OC fails were on instrument E1 2 over three calibrations during the period.
  - Lab also ran two shakedowns to troubleshoot rig.

- Operationally failing runs:
  - One aborted due to a float switch failure (XC)
  - One declared invalid due to off-spec bath temperature (LC)

D5133: Gelation Index

- Lab/rig AM 1 (new rig) ran numerous shakedowns to confirm performance of all heads.
  - Lab has not yet proceeded to a blind calibration.

- No TMC technical updates were issued this period

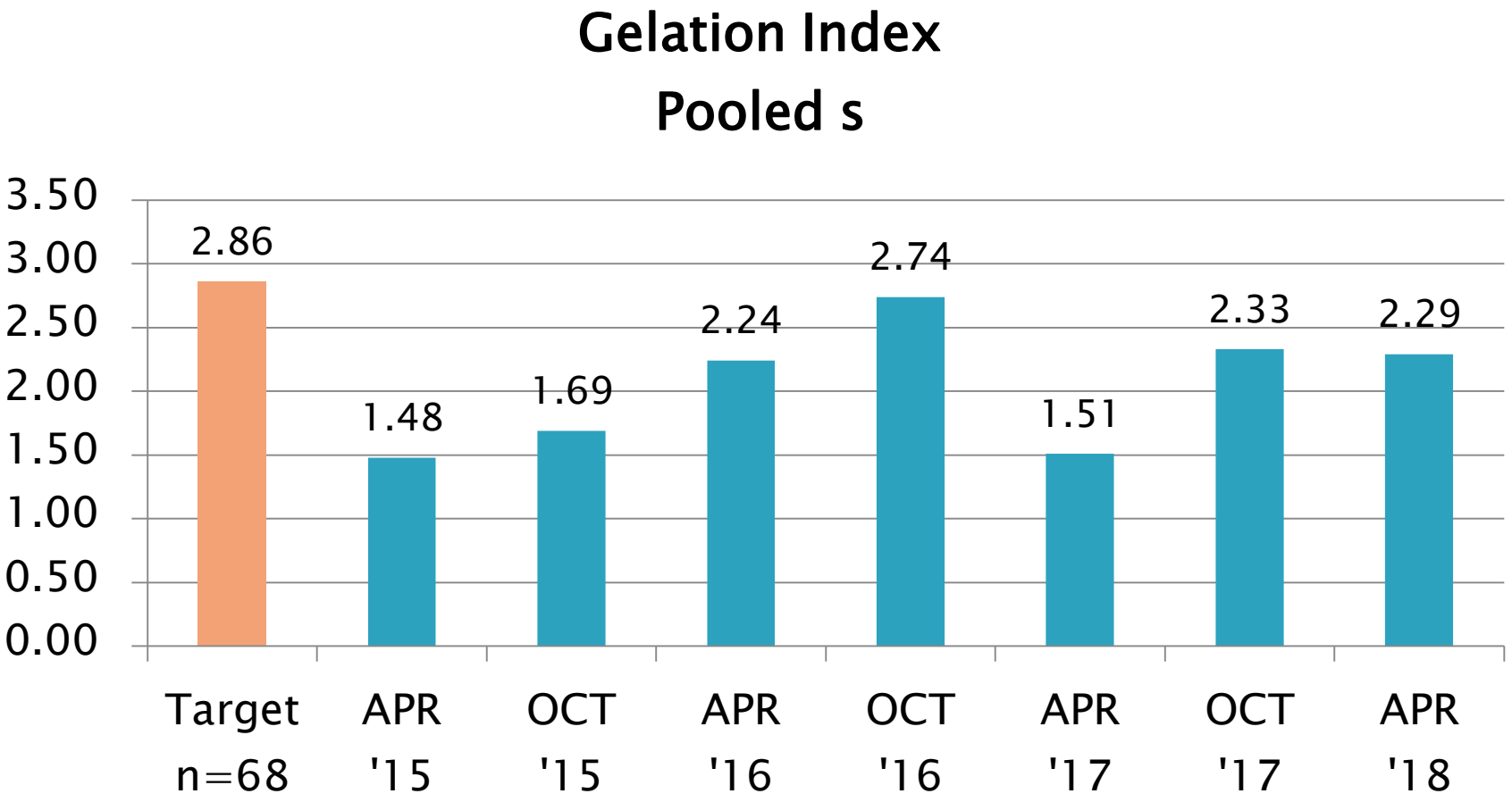
D5133: Gelation Index

Period Precision and Severity Estimates

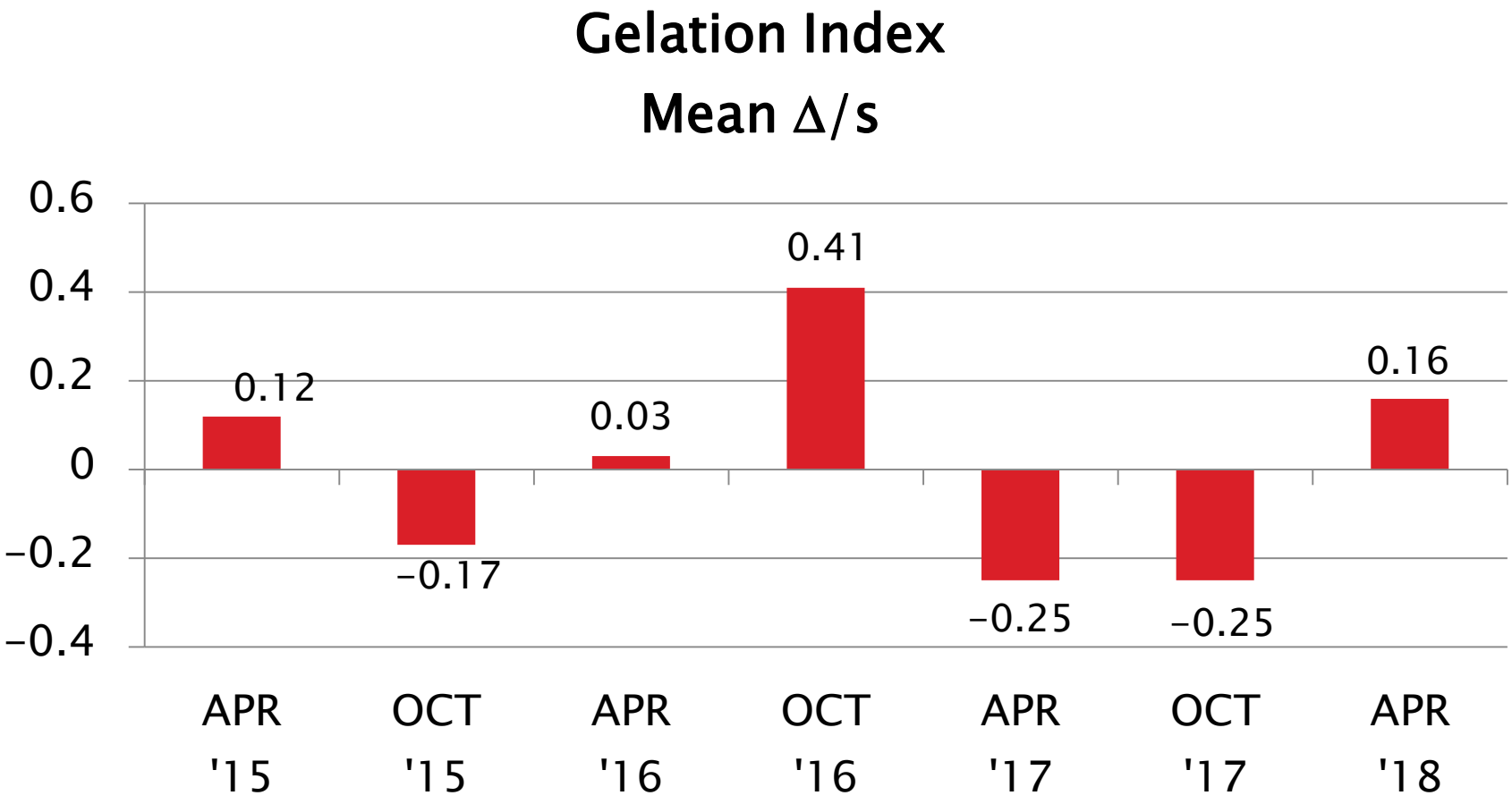
Gelation Index	n	df	Pooled s	Mean Δ/s
Current Targets 7/15/2003	68	65	2.86	-----
4/1/15 through 9/30/15	34	31	1.69	-0.17
10/1/15 through 3/31/16	31	28	2.24	0.03
4/1/16 through 9/30/16	31	28	2.74	0.41
10/1/16 through 3/31/17	35	32	1.51	-0.25
4/1/17 through 9/30/17* 4/1/17 through 9/30/17*	30 29	27 26	4.69 2.33	-0.08 -0.25
10/1/17 through 3/31/18	36	33	2.29	0.16

*Extreme OC result included and excluded

D5133 Precision Estimates



D5133 Severity Estimates



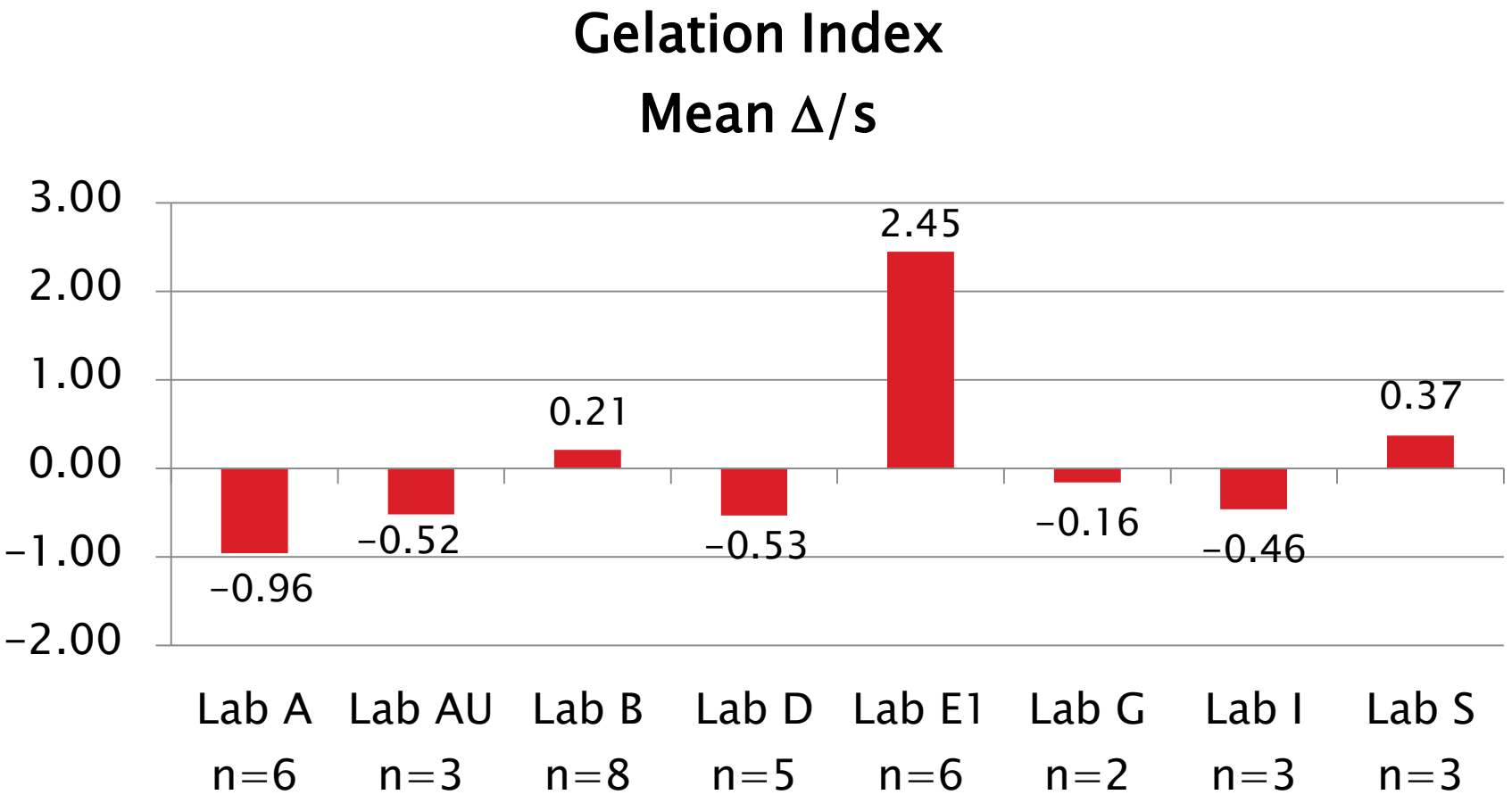
D5133: Gelation Index

Current Period Severity Estimates by Lab

Gelation Index

	n	Mean Δ/s
Lab A	6	-0.96
Lab AU	3	-0.52
Lab B	8	0.21
Lab D	5	-0.53
Lab E1	6	2.45
Lab G	2	-0.16
Lab I	3	-0.46
Lab S	3	0.37

D5133 Lab Severity Estimates



D5133: Gelation Index

- Fail rate of operationally valid tests is 17% this period (9% with Instrument E1 1 excluded). Fail rates have been high the last three periods, with a 10% fail rate last period, and 26% before that. Four periods back the fail rate was 6%.
- Overall severity is 0.16 s severe (-0.30 s mild with Instrument E1 1 excluded).
- Precision (Pooled s), is more precise than target precision, and comparable to prior period with one extreme result excluded from prior period.
- Lab E1, Rig 1, had three consecutive severe fails on non-gelling oil 58, with no known operational cause reported (validity OC), followed by two successful shakedown runs and a passing (AC) calibration. The next calibration attempt resulted in two consecutive severe (OC) fails on low GI oil 1009, followed by a successful calibration (AC). The lab never found (or reported) a cause for the OC runs, so they remain in the statistics.

D5133: Gelation Index

- Severe oil 62 period mean performance is GI 14.3 compared to the target GI of 17.0 (similar to last period). This shows a continuing mild bias on the high GI oil at the same time that we are conducting a round robin to replace the oil.
- The calibration performance of instrument E1 1 this period, as well as past similar experiences with other instruments, should raise concerns about the adequacy of the current 'single-test' monitoring system to catch severe or mild performing instruments or heads in a timely manner, and whether these instruments, after demonstrating multiple failing results, should subsequently be considered properly calibrated based on just one passing test result.
- Oli 62 is in low supply, a round robin is well under way to evaluate two proposed replacement oils.

D5133 GELATION INDEX INDUSTRY OPERATIONALLY VALID DATA

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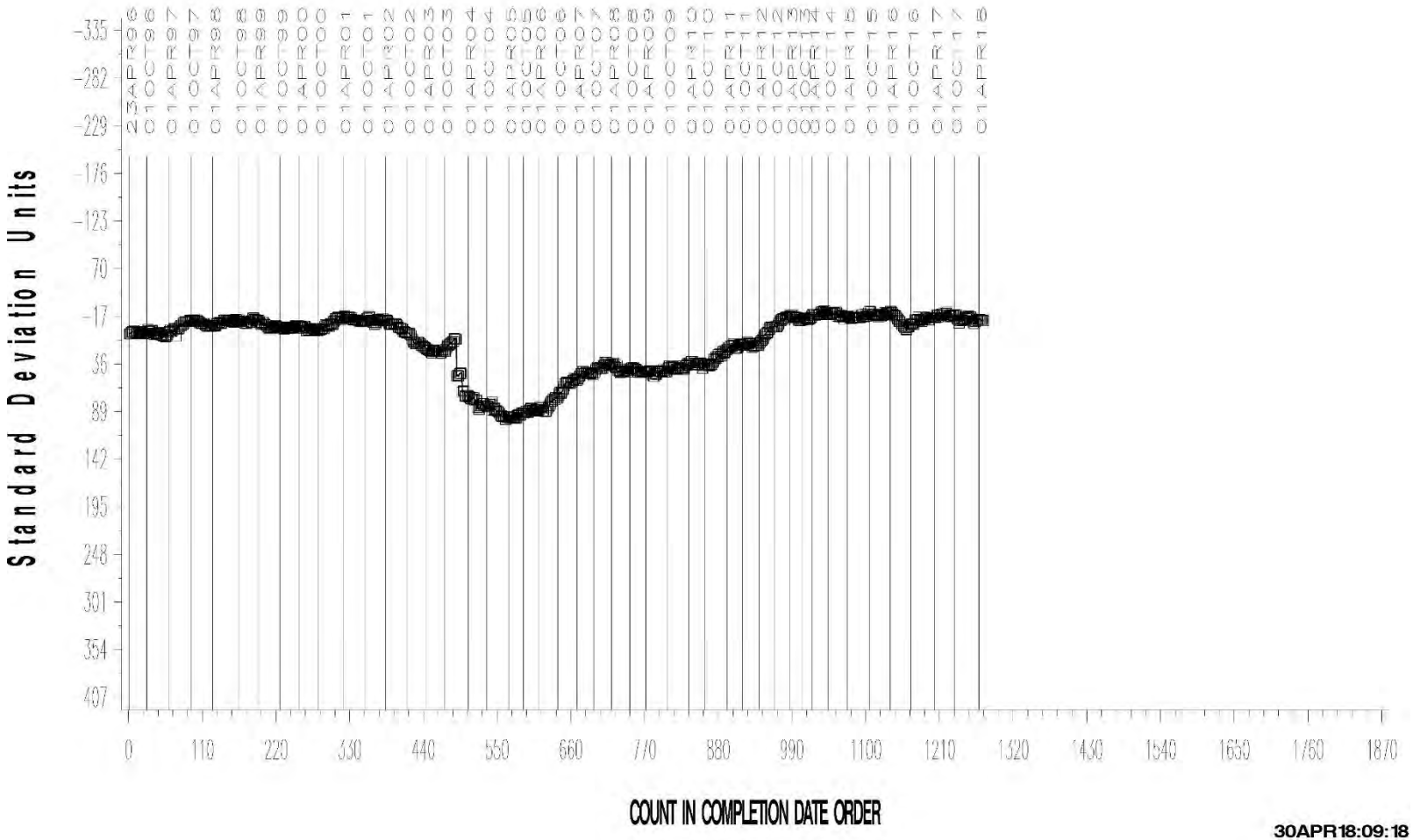
GELATION INDEX

CUSUM Severity Analysis



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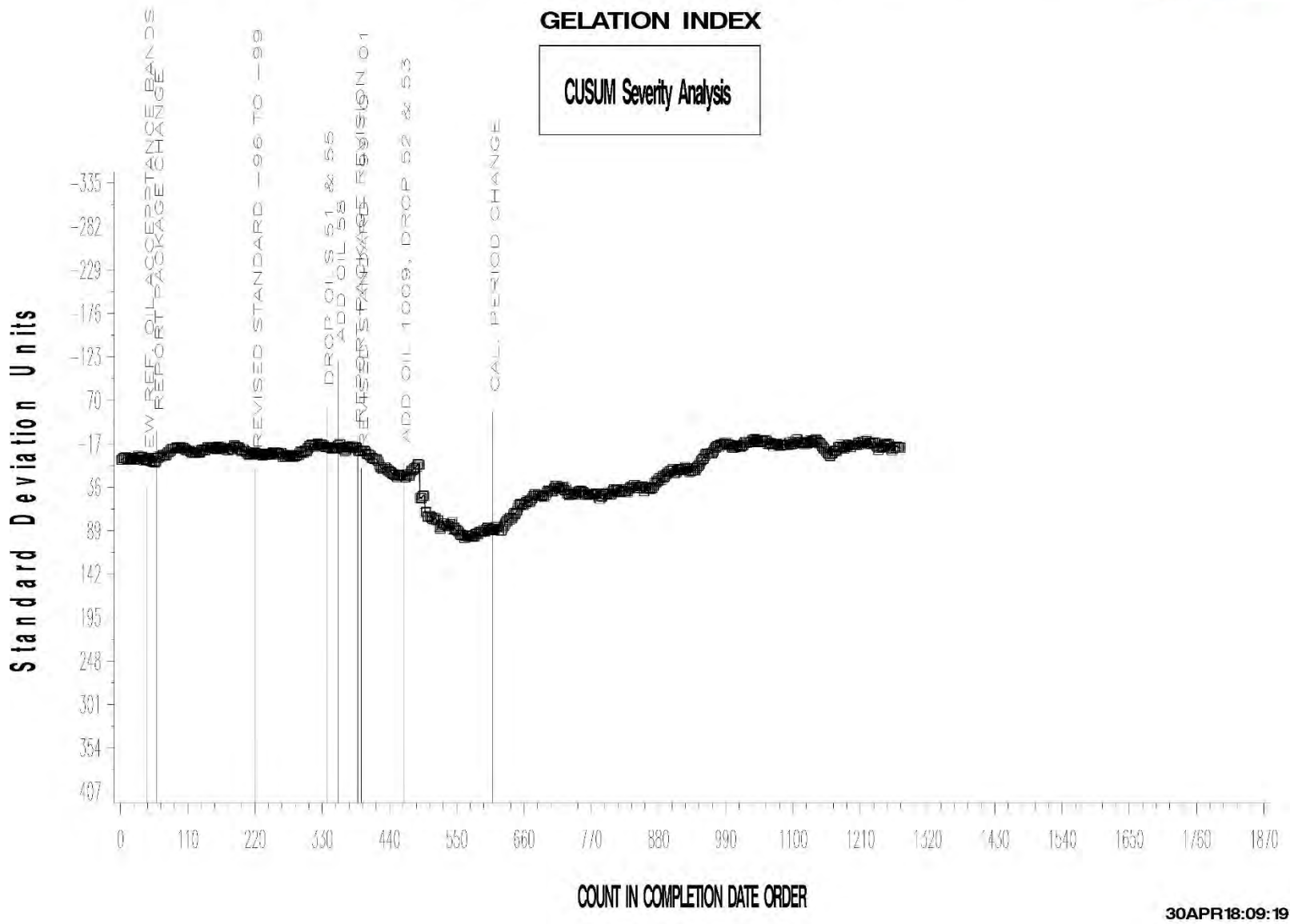
D5133 GELATION INDEX INDUSTRY OPERATIONALLY VALID DATA



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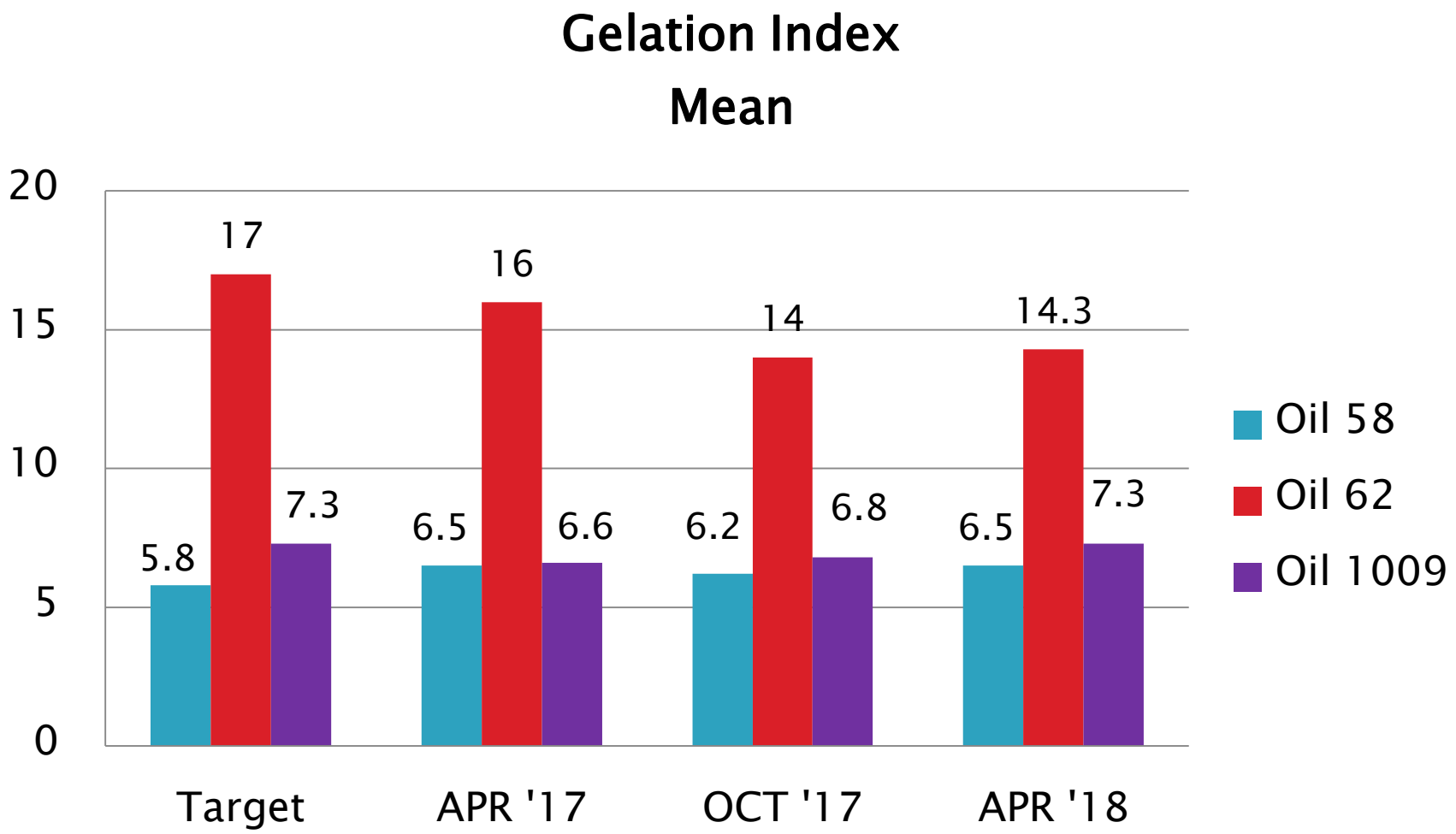
D5133 Performance by Oil

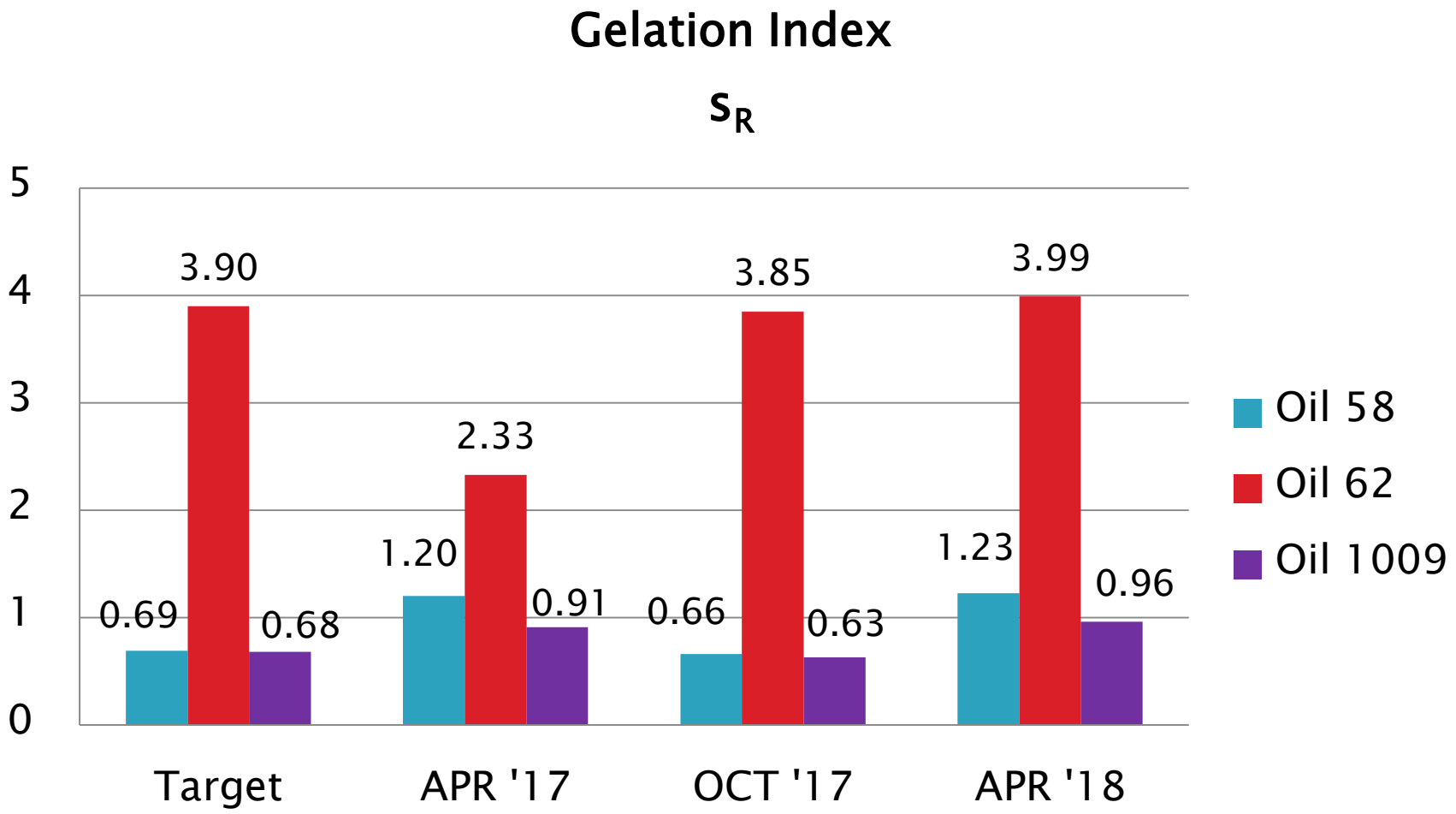
Gelation Index
Performance by Oil

	Targets			10/1/16– 3/31/17				4/1/17– 9/30/17				10/1/17– 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
58	17	5.8	0.69	9	6.5	1.20	1.05	11	6.2	0.66	0.55	13	6.5	1.23	1.00
62	35	17.0	3.90	10	16.0	2.33	-0.26	10	14.0	3.85	-0.77	10	14.3	3.99	-0.69
1009	16	7.30	0.68	16	6.6	0.91	-0.97	8	6.8	0.63	-0.70	13	7.3	0.96	-0.02

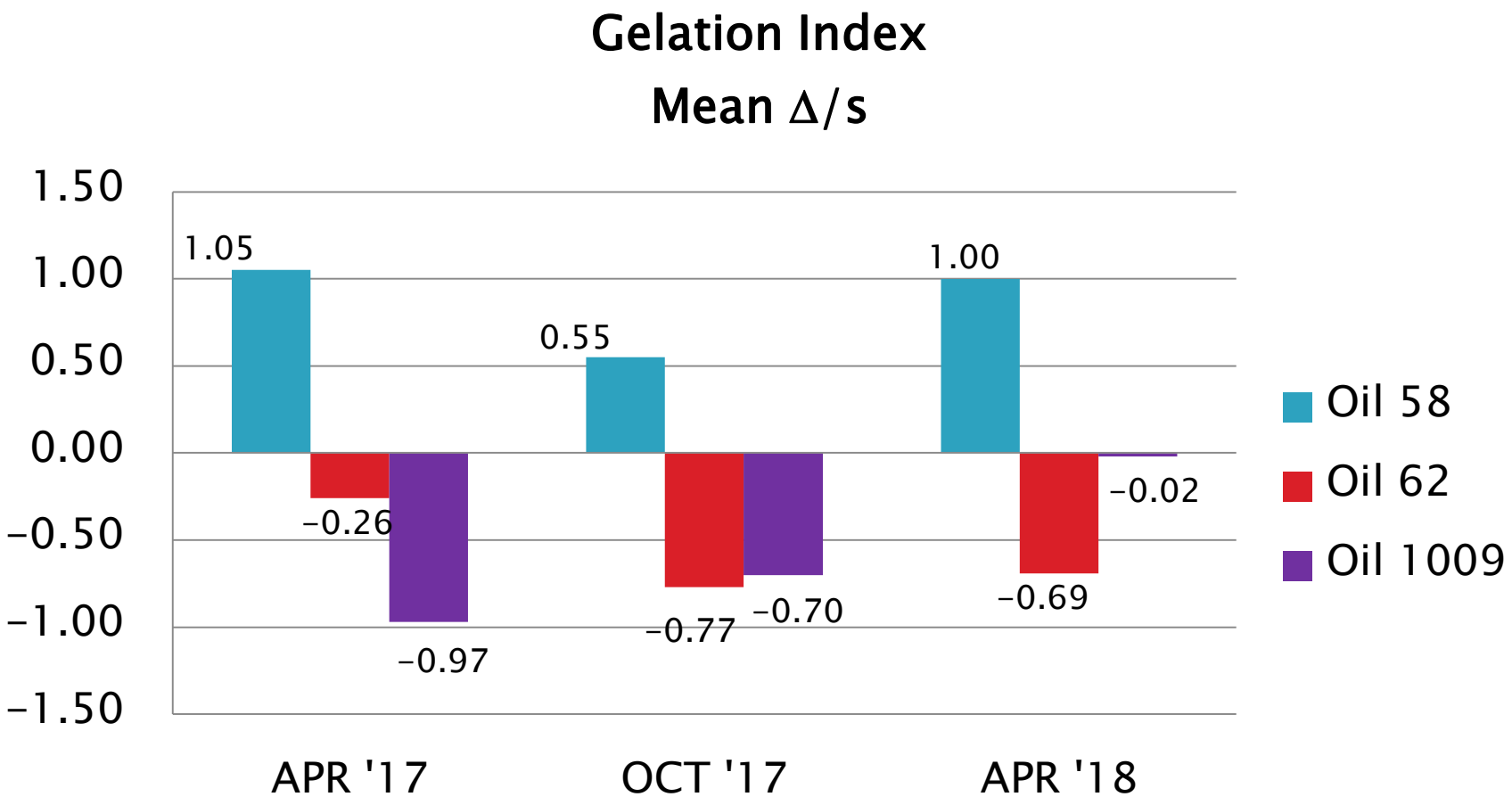
D5133 Performance by Oil



D5133 Performance by Oil



D5133 Performance by Oil



Return to Executive Summary

D6335: Deposits by TEOST-33C

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	24
Failed Calibration Test	OC	3
Operationally Invalidated by Lab	LC, XC	0
Operationally Invalidated After Initially Reported as Valid	RC	0
Non-blind Instrument Shakedown	NN	1
Donated Runs Oil 75-1 (RR)	AG	16
Total		**44**

Number of Labs Reporting Data: 7
Fail Rate of Operationally Valid Tests: 11%

D6335: Deposits by TEOST-33C

Statistically Unacceptable Tests (OC)	No. Of Tests
Total Deposits Mild	3
Total Deposits Severe	0

- No operationally invalid tests reported this period.
- One statistically failing run (OC) was -4.6 s mild of target (Rig V5, Oil 75)
- 16 donated round robin runs (AG) on proposed replacement reblend of oil 75 (75-1), plus 5 from prior period, to complete the preliminary round robin. Waiting on SP action.
- No TMC technical updates were issued this report period.

D6335: Deposits by TEOST-33C

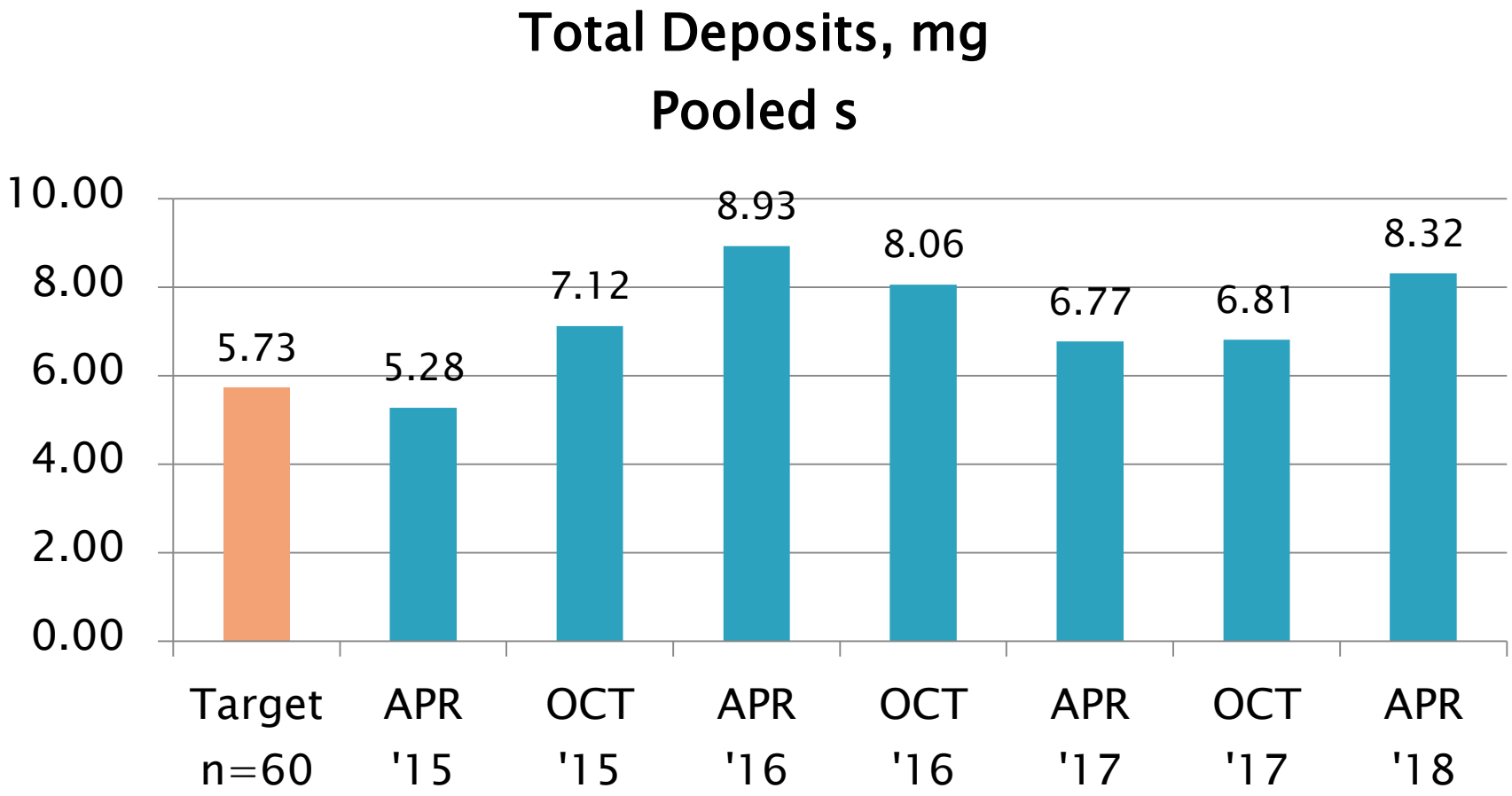
Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Updated Targets 20130415	60	58	5.73	-----
10/1/14 through 3/31/15	15	13	5.28	-0.28
4/1/15 through 9/30/15	16	14	7.12	-0.11
10/1/15 through 3/31/16	21	19	8.93	-0.43
4/1/16 through 9/30/16	21	19	8.06	-0.68
10/1/16 through 3/31/17	21	19	6.77	-0.14
4/1/17 through 9/30/17* 4/1/17 through 9/30/17*	26 23	24 21	6.81 5.19	0.00 -0.28
10/1/17 through 3/31/18** 10/1/17 through 3/31/18**	27 26	25 24	8.32 6.43	-0.61 -0.45

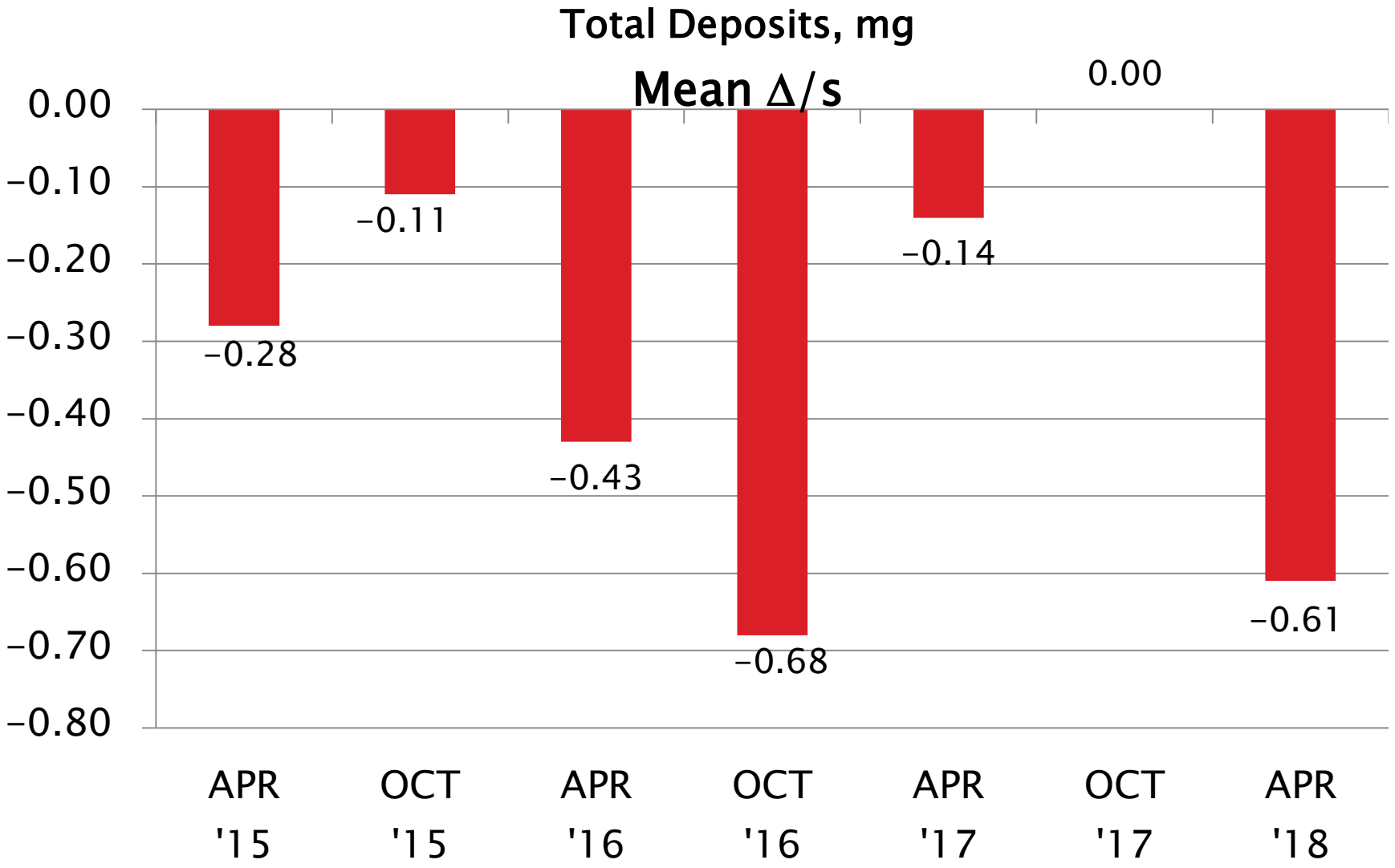
*Three consecutive OC results on same rig included and excluded.

**Single result of -4.6 s mild included and excluded

D6335 Precision Estimates



D6335 Severity Estimates



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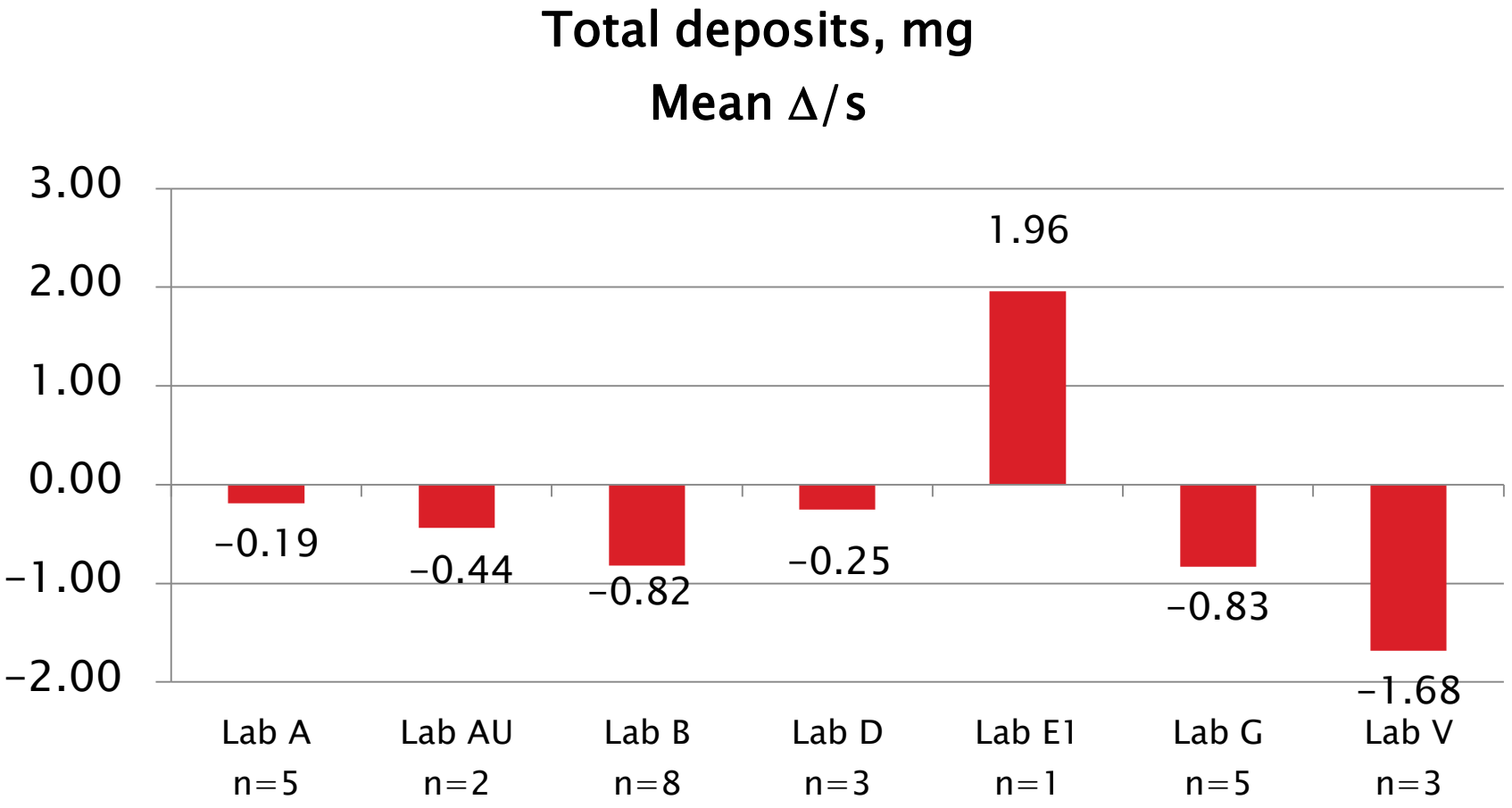
D6335: Deposits by TEOST-33C

Current Period Severity Estimates by Lab
Total Deposits, mg

	n	Mean Δ/s
Lab A	5	-0.19
Lab AU	2	-0.44
Lab B	8	-0.82
Lab D	3	-0.25
Lab E1	1	1.96
Lab G	5	-0.83
Lab V	3	-1.68

D6335 Lab Severity Estimates



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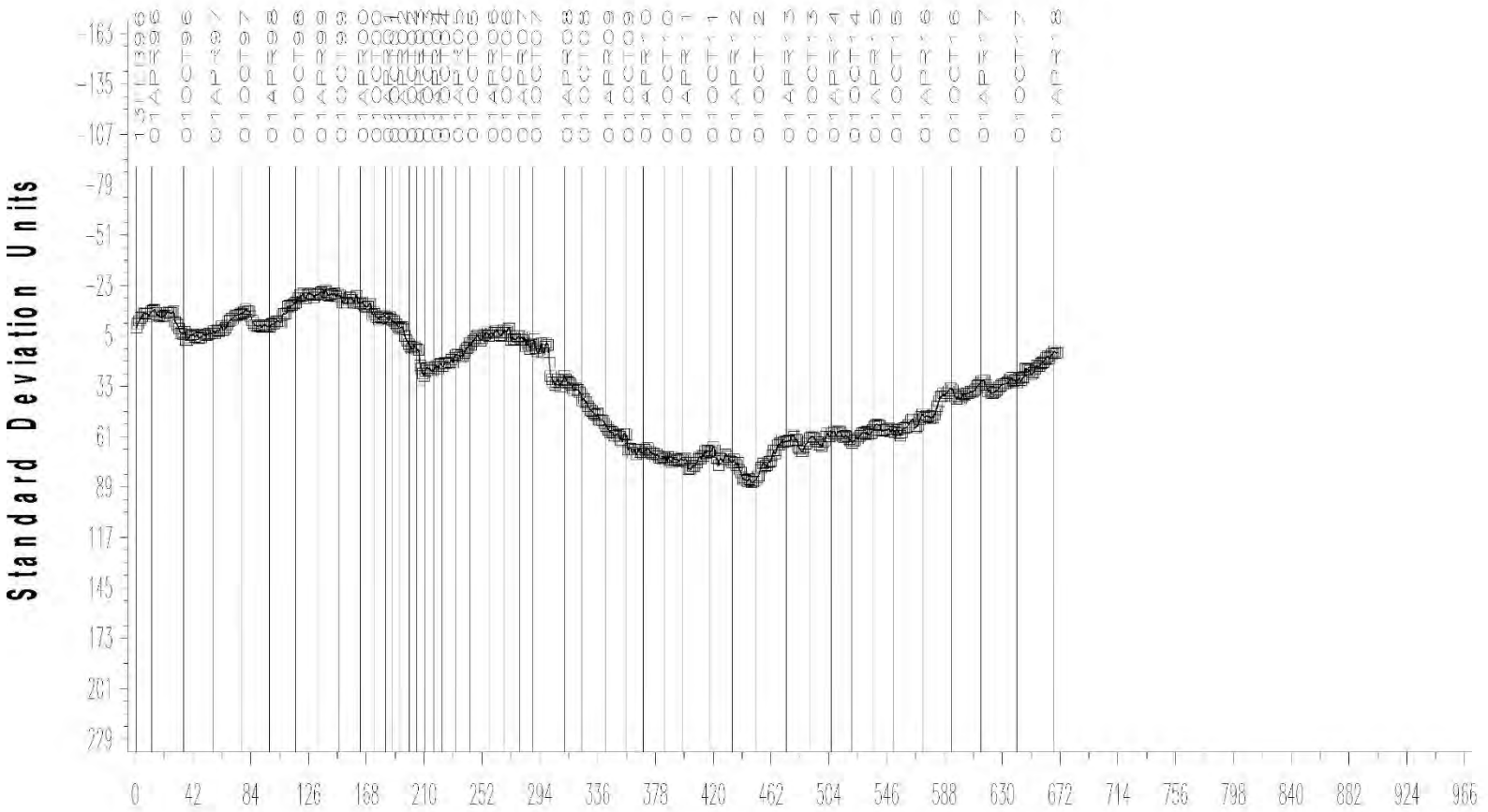
D6335: Deposits by TEOST-33C

- Precision (Pooled s) is significantly less precise than prior period.
  - Excluding one result -4.6 s mild, reported as operationally valid, brings the precision in line with the past two report periods.
  - Less precise than target precision, even with mild result excluded.
  - Severe oil 75 performance continues to be imprecise
- Performance (Mean Δ/s) is mild.
- All calibration tests this period report using Rod Batch M
- Round robin on replacement oil 75-1 is completed, waiting on surveillance panel action.

TEOST—33C INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

CUSUM Severity Analysis



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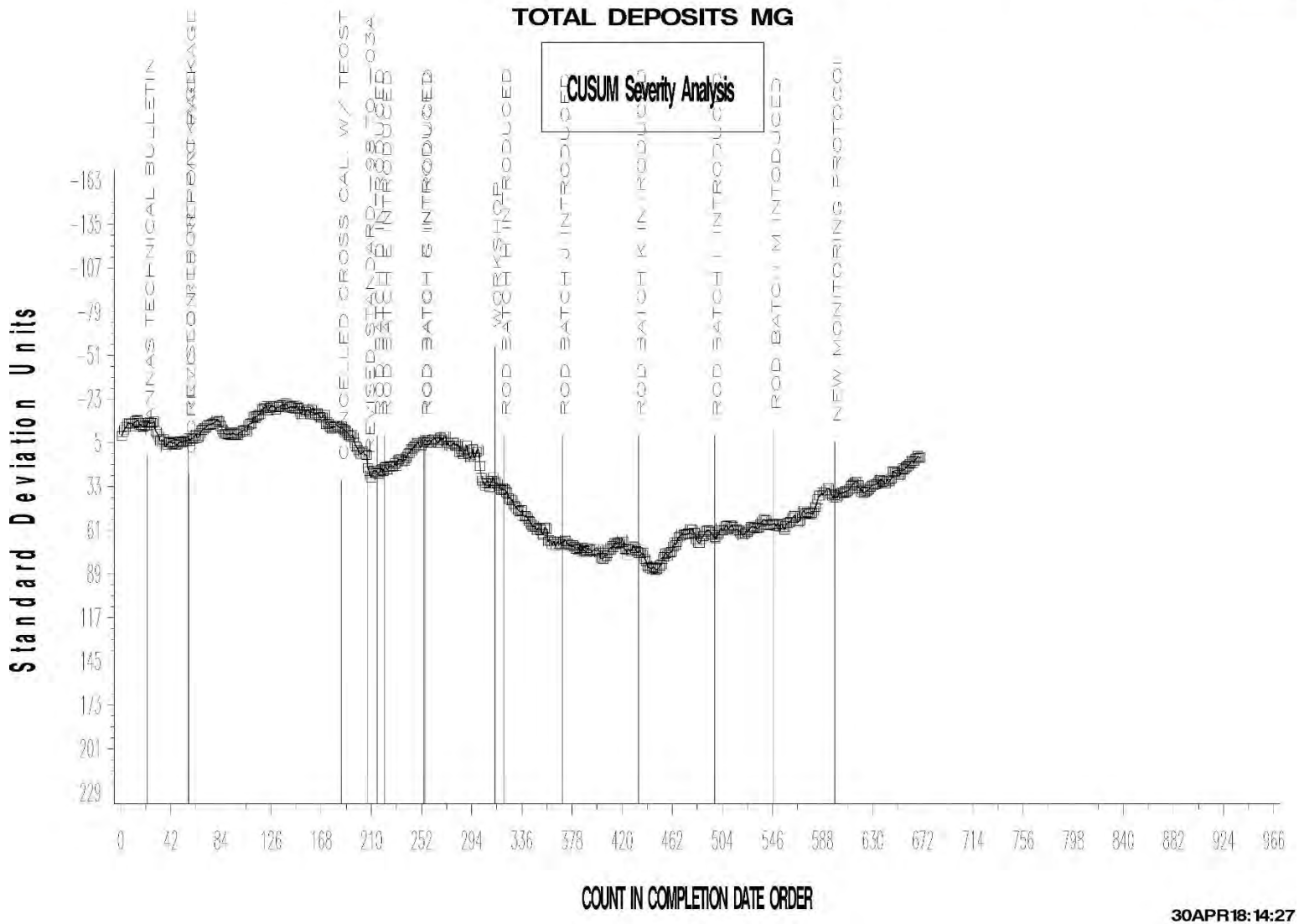
TEOST—33C INDUSTRY OPERATIONALLY VALID DATA

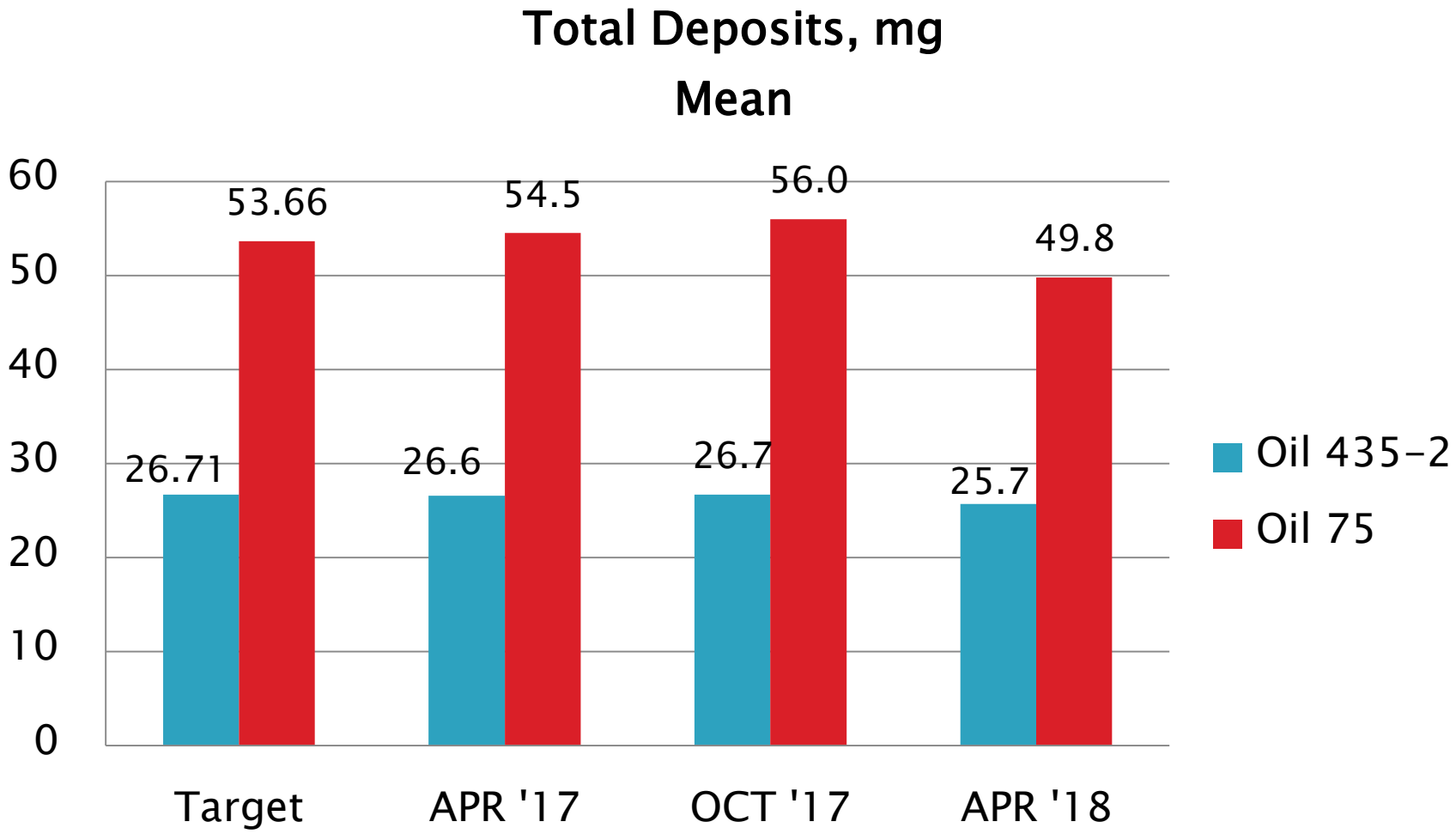


D6335 Performance by Oil

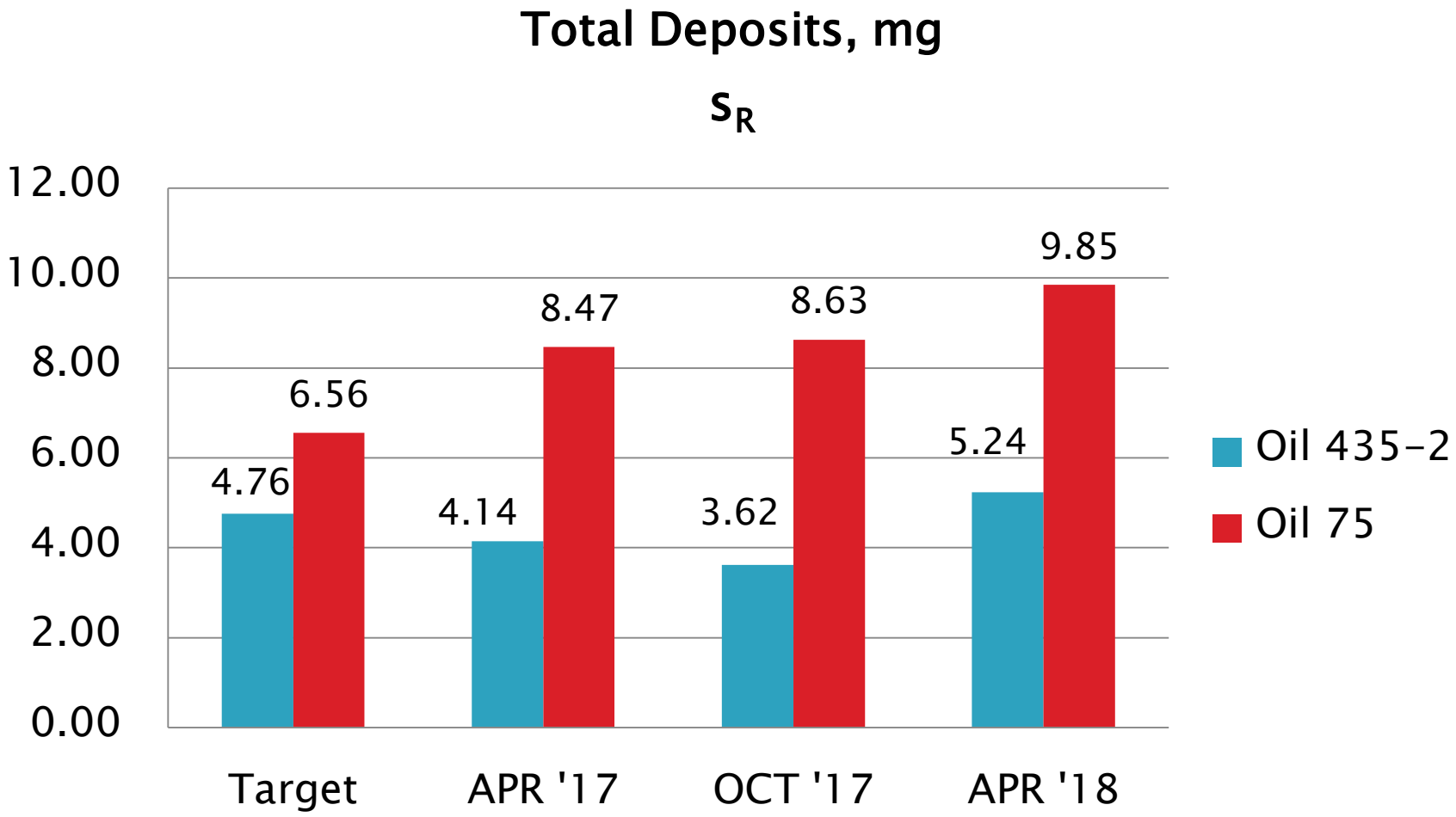
Total Deposits, mg
Performance by Oil

	Targets 20130415			10/1/16 – 3/31/17				4/1/17– 9/30/17				10/1/17 – 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
435-2	30	26.71	4.76	10	26.6	4.14	-0.45	12	26.7	3.62	-0.42	11	25.7	5.24	-0.64
75	30	53.66	6.56	11	54.5	8.47	0.13	14	56.0	8.63	0.36	16	49.8	9.85	-0.58

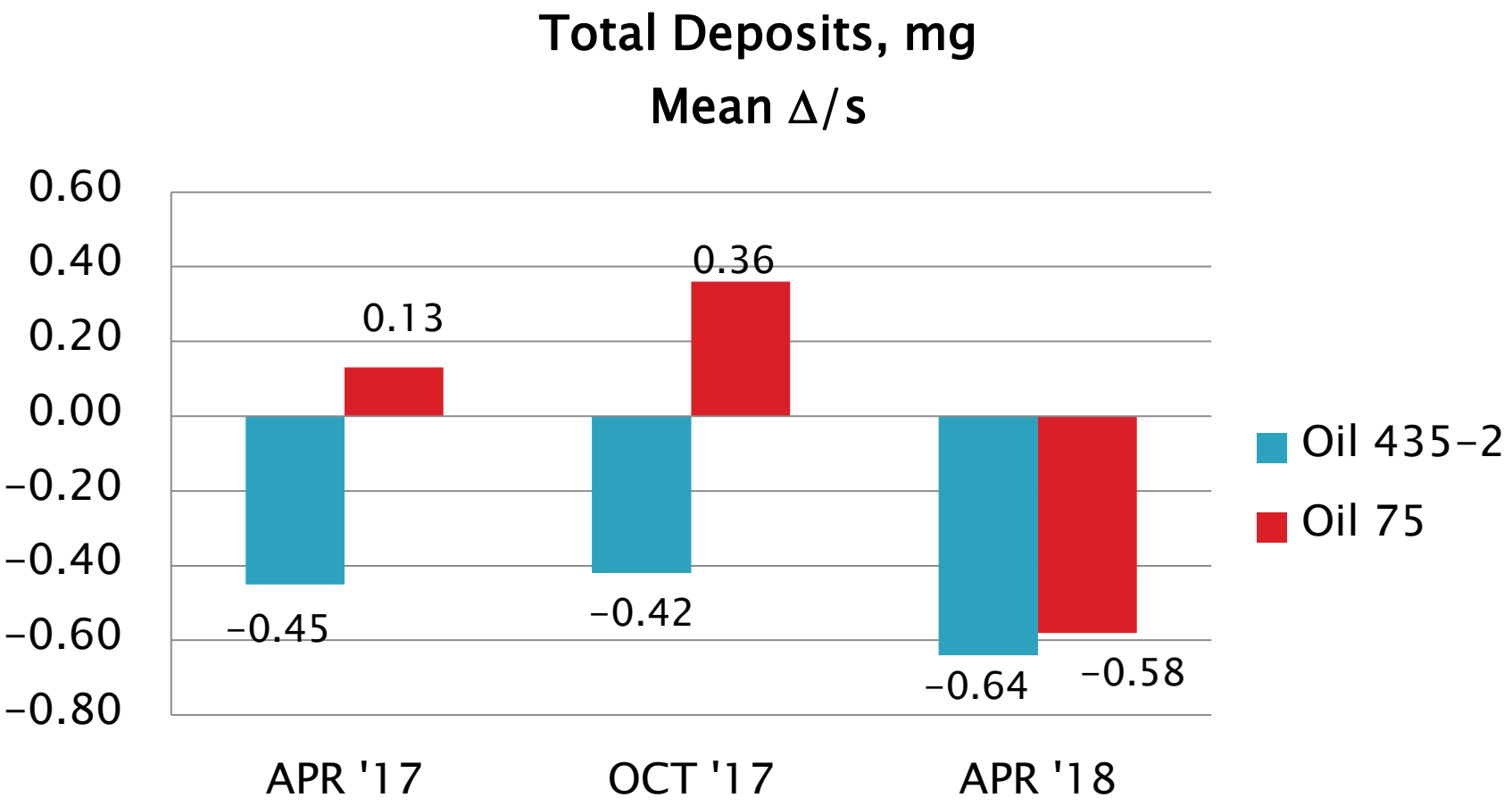
D6335 Performance by Oil



D6335 Performance by Oil



D6335 Performance by Oil



Return to Executive Summary

D7097: Deposits by MHT TEOST

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	82
Failed Calibration Test	OC	6
Operationally Invalidated by Lab	LC, XC	2
Operationally Invalidated After Initially Reported as Valid	RC	1
Instrument Shakedown	NN	8
Total		**99**

Number of Labs Reporting Data: 10
Fail Rate of Operationally Valid Tests: 7%

D7097: Deposits by MHT TEOST

Statistically Unacceptable Tests (OC)	No. Of Tests
Total Deposits Mild	1
Total Deposits Severe	5

- Three severe fails (OC) were from Lab A, but on three different instruments.

- Three operationally invalid calibration test reported this period:
  - Pump speed off spec (RC, initially reported as operationally valid)
  - Sample completely volatized for unknown reason (LC)
  - Spilled sample EOT (XC)

- Eight shakedown runs reported to confirm performance of two new instruments before blind calibration (NN), both rigs subsequently passed calibration.

- No TMC technical updates were issued this report period.

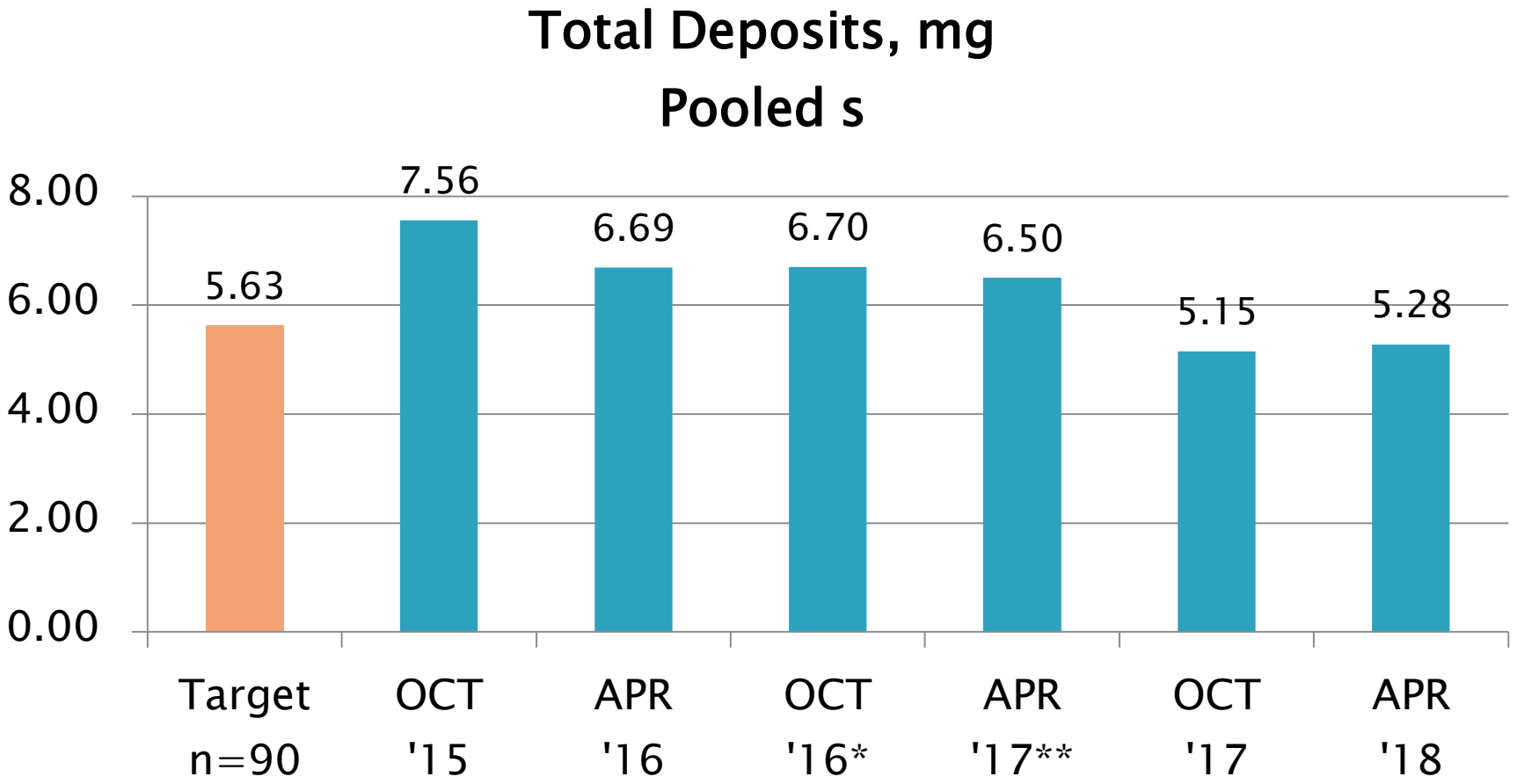
D7097: Deposits by MHT TEOST

Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Current Targets 7/31/2006	90	87	5.63	-----
10/1/15 through 3/31/16	84	82	6.69	0.29
4/1/16 through 9/30/16*	96	94	15.8	0.53
4/1/16 through 9/30/16*	93	91	6.70	0.13
10/1/16 through 3/31/17**	105	103	7.11	0.17
10/1/16 through 3/31/17**	97	95	6.50	0.03
4/1/17 through 9/30/17	83	81	5.15	0.14
10/1/17 through 3/31/18	88	86	5.28	0.33

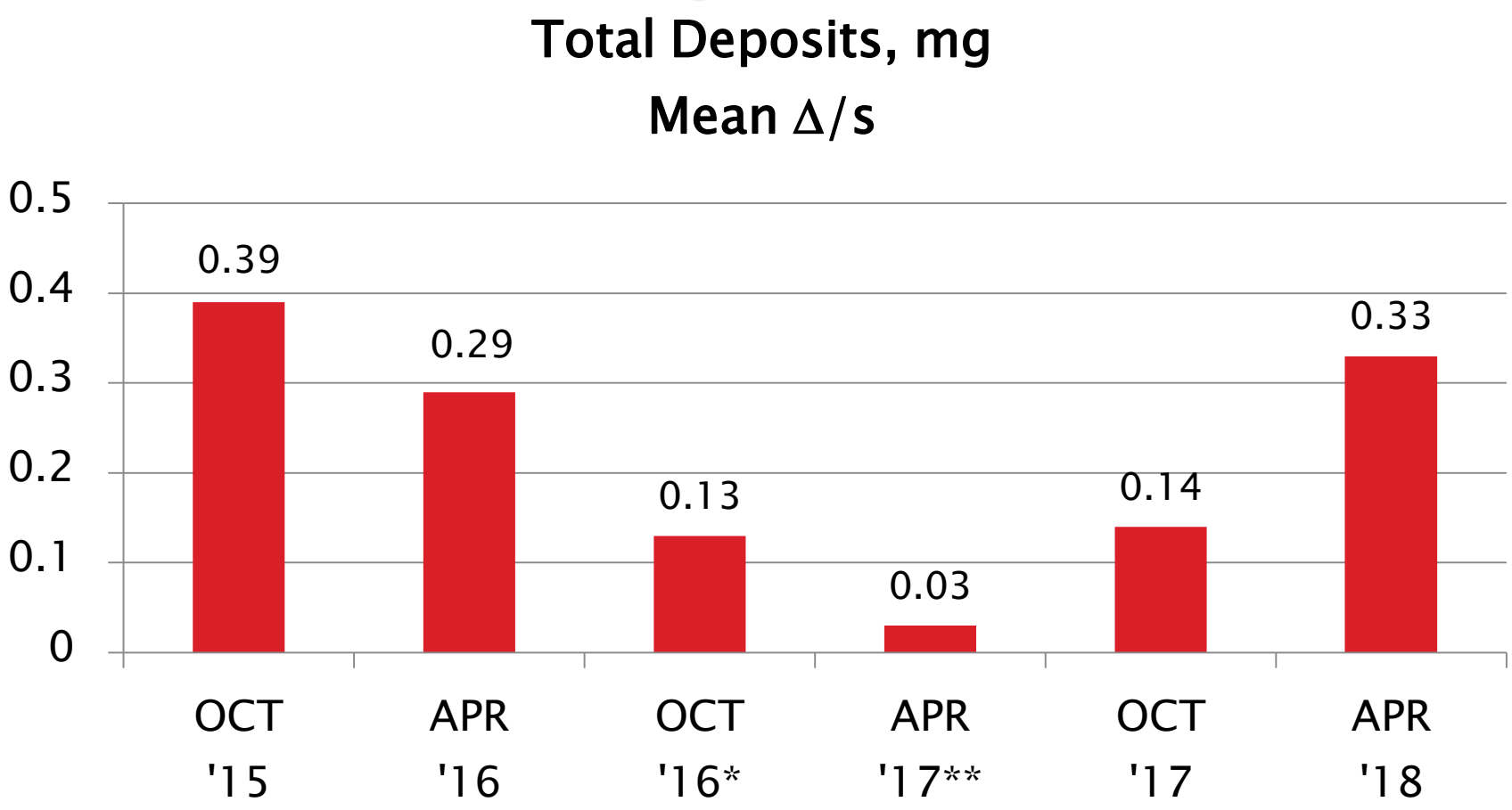
*Three severe OC tests from instrument P1 included and excluded
**Eight 2TESTCAL tests from instrument J2 included and excluded

D7097 Precision Estimates



*Three severe OC tests from instrument P1 excluded
**Eight tests instrument J2 excluded (failed to calibrate)

D7097 Severity Estimates



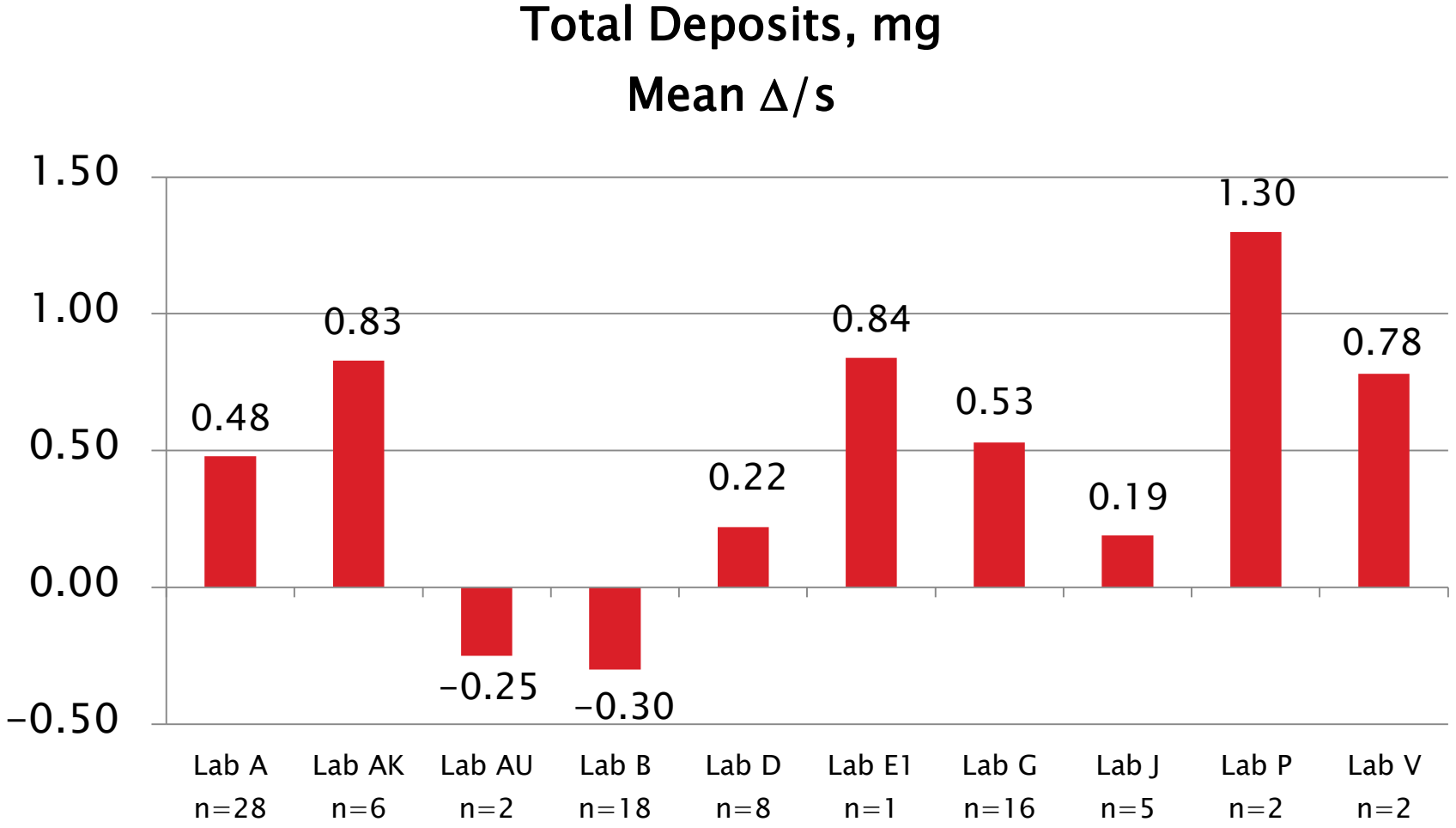
*Three severe OC tests from instrument P1 excluded
**Eight tests from instrument J2 excluded (failed to calibrate)

D7097: Deposits by MHT TEOST

Current Period Severity Estimates by Lab
Total Deposits, mg

Lab	n	Mean Δ/s	Lab	n	Mean Δ/s
Lab A	28	0.48	Lab E1	1	0.84
Lab AK	6	0.83	Lab G	16	0.53
Lab AU	2	-0.25	Lab J	5	0.19
Lab B	18	-0.30	Lab P	2	1.30
Lab D	8	0.22	Lab V	2	0.78

D7097 Lab Severity Estimates



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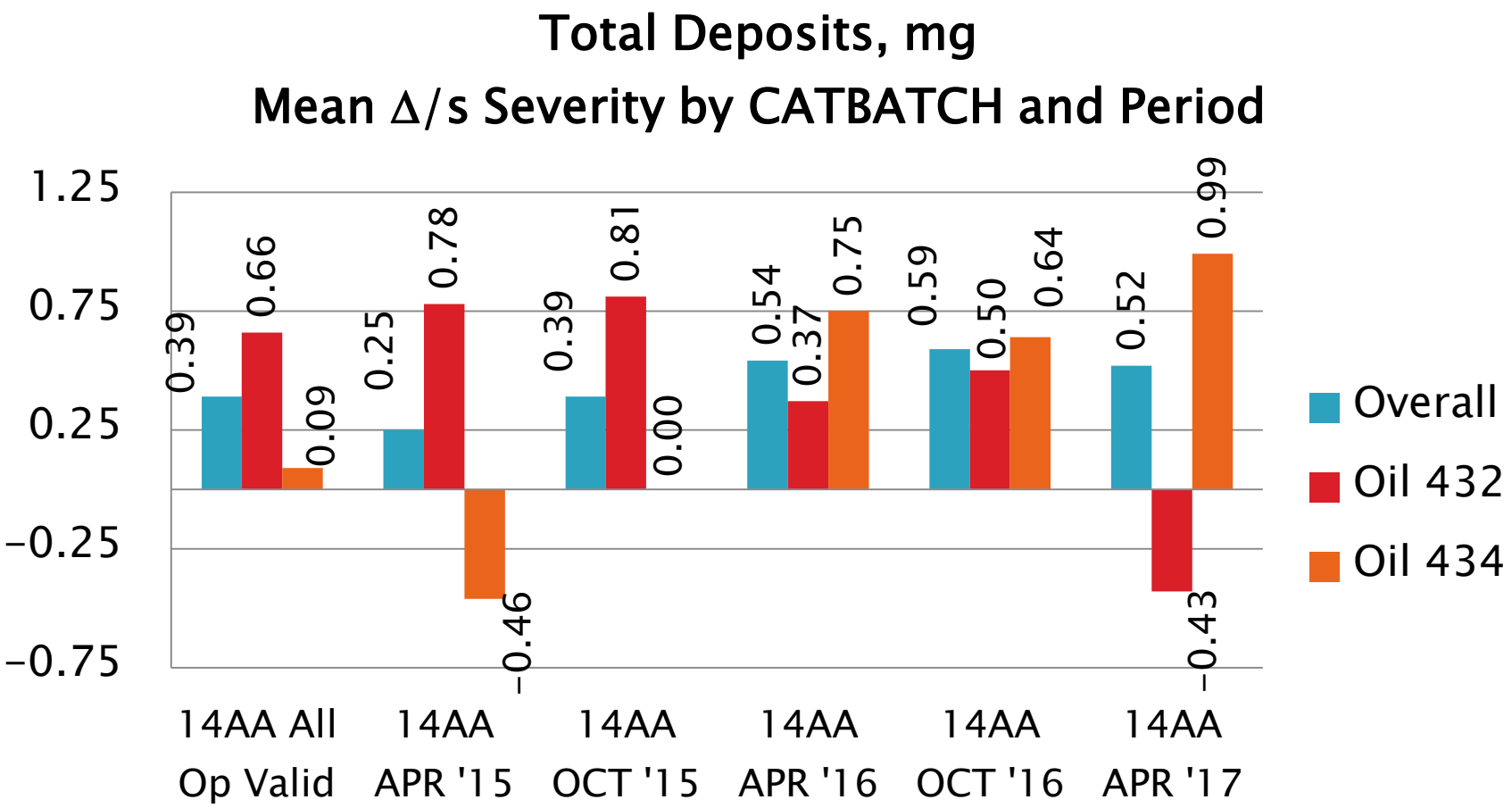
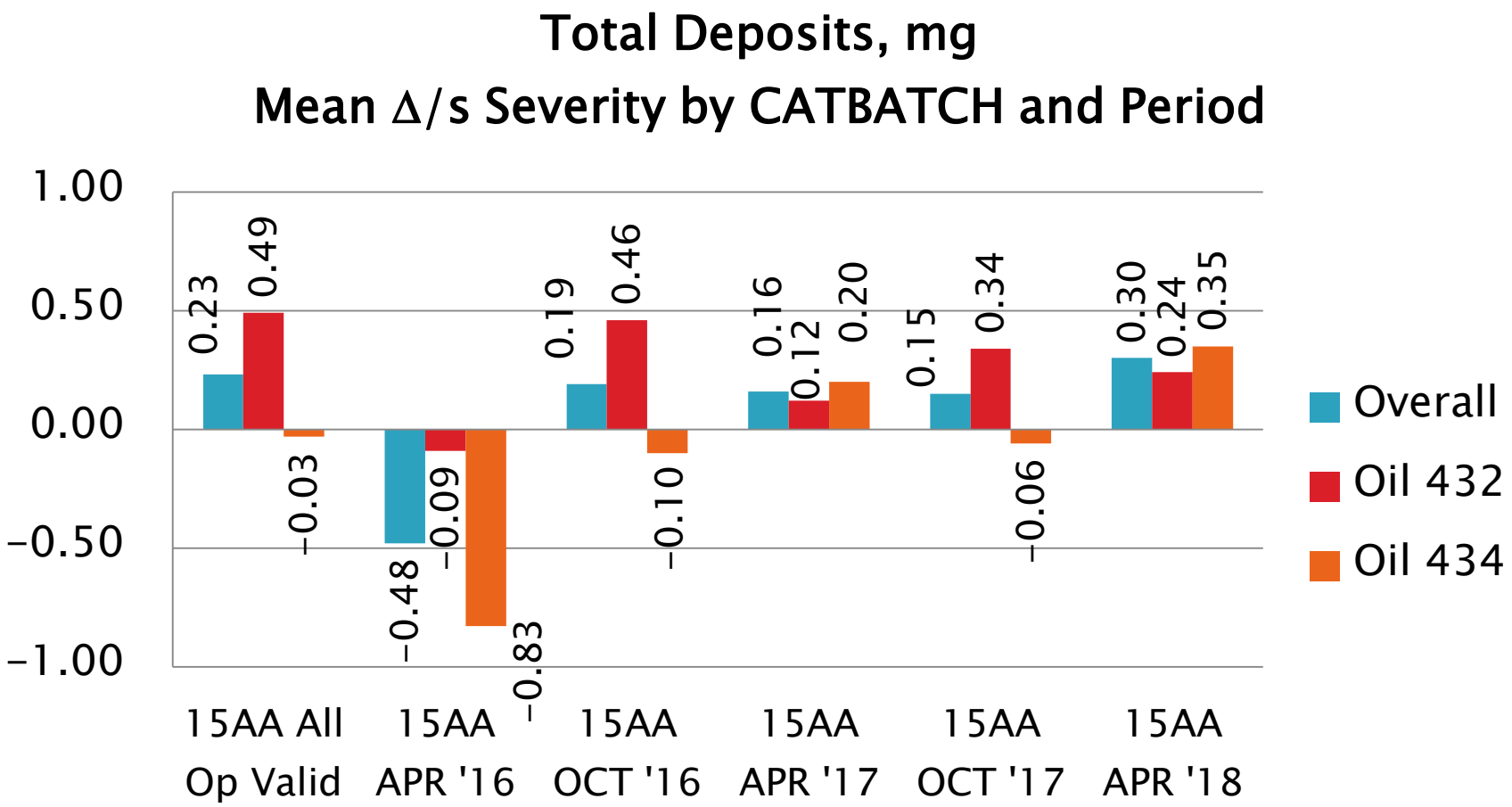
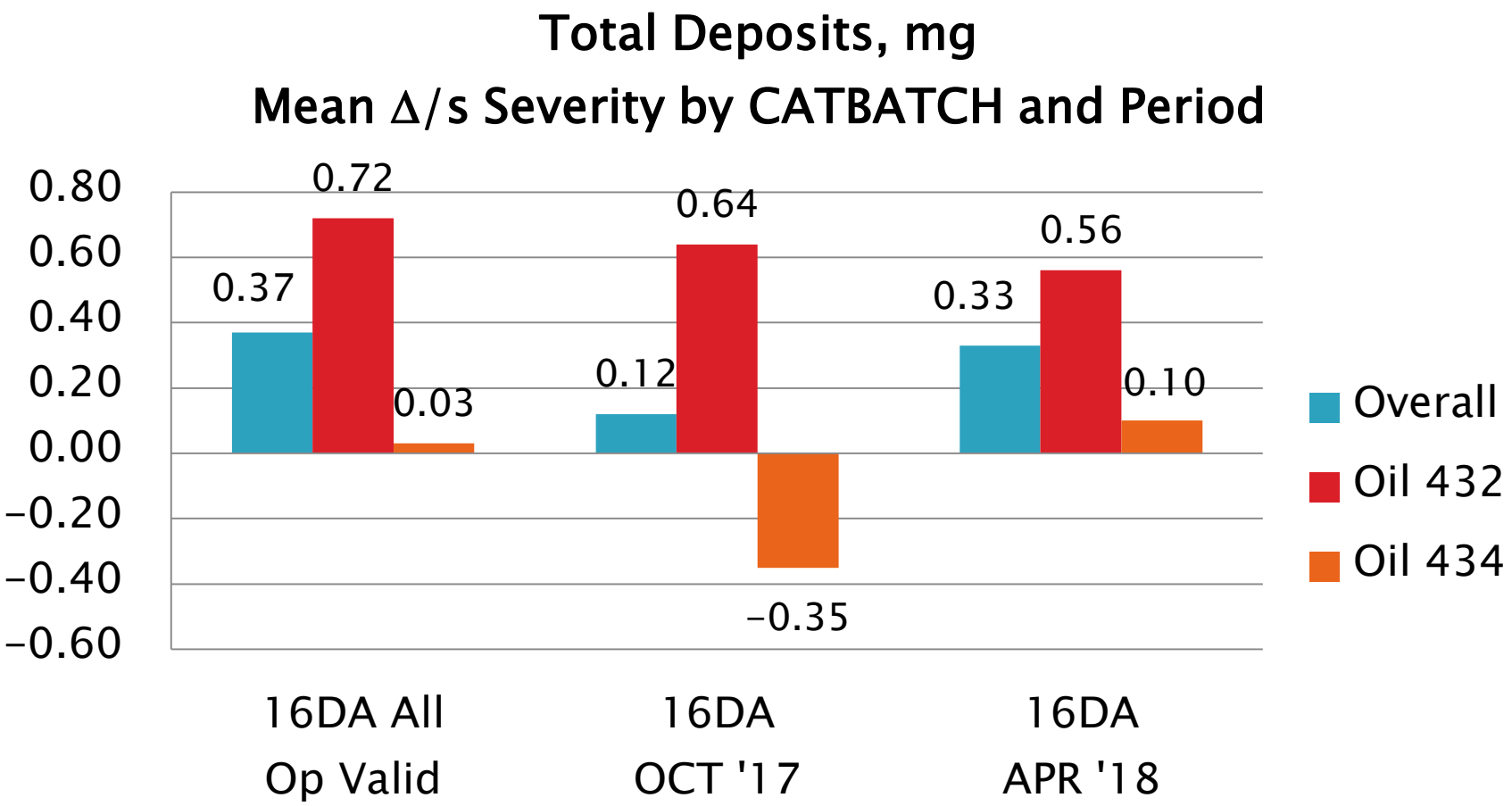
D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST

- Precision (Pooled s) is comparable to last period
  - More precise than target precision for two consecutive periods
    - Precision of both oils is better than target for two consecutive periods
    - Possibly because use of new end cap flask seals has improved test precision?
- Performance (Mean Δ/s) is 0.33 s severe.
- All operationally valid tests this period report using Rod Batch M
- All operationally valid calibration tests this period report using Catalyst Batch 15AA (n=6) or 16DA (n=82).

D7097: Deposits by MHT TEOST

- CUSUM severity plot shows slightly severe performance.
  - However, lab performance differences persist

- Severity bias of new catalyst batch 16DA on severe performing oil 432 is more severe (0.72 s) than we had typically seen with batch 15AA (0.49 s), though batch 14AA had similar overall severity. Mild performing oil 434 is, overall, on target with batch 16DA.

MHT—4 TEOST INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

CUSUM Severity Analysis

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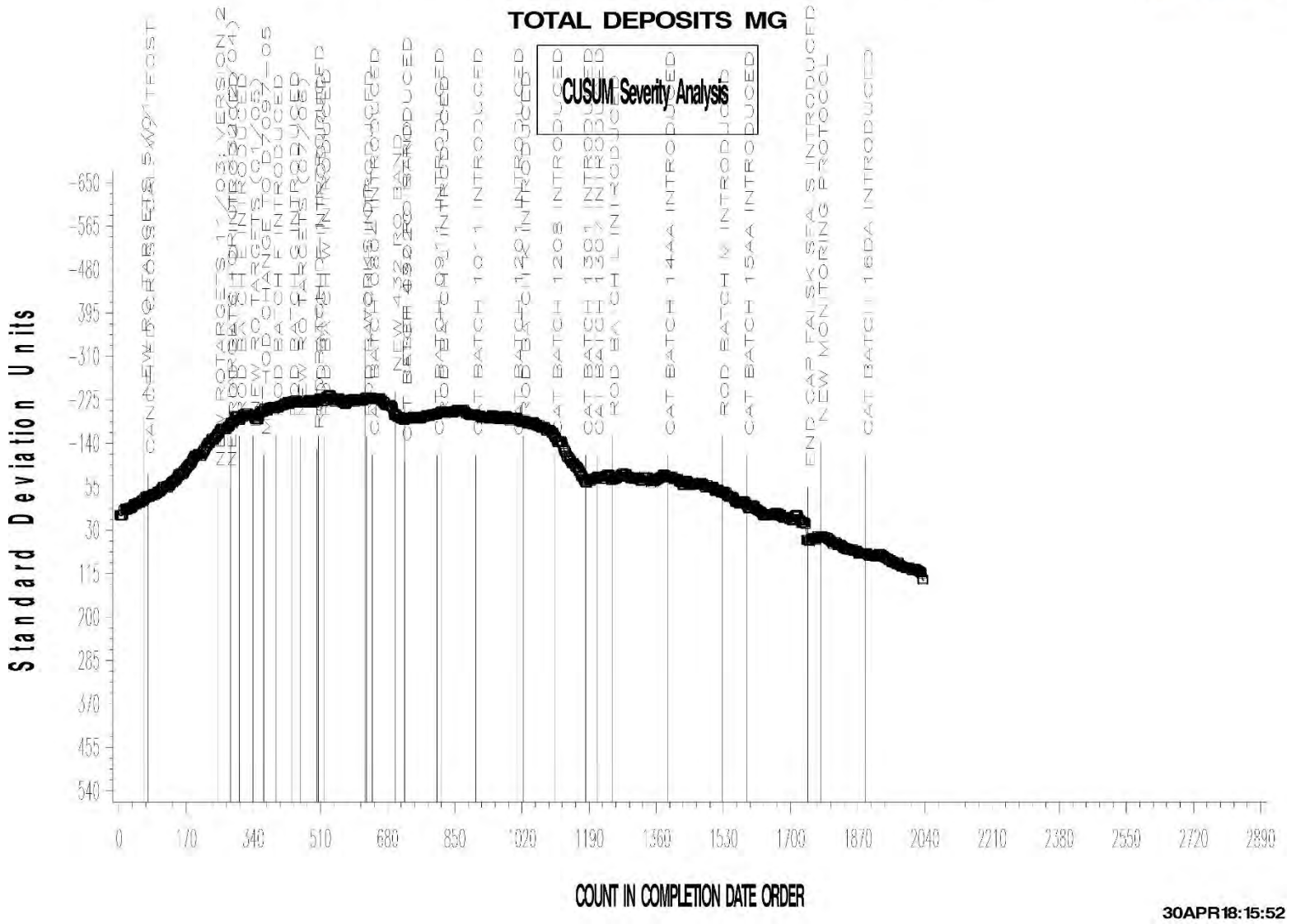
MHT—4 TEOST INDUSTRY OPERATIONALLY VALID DATA



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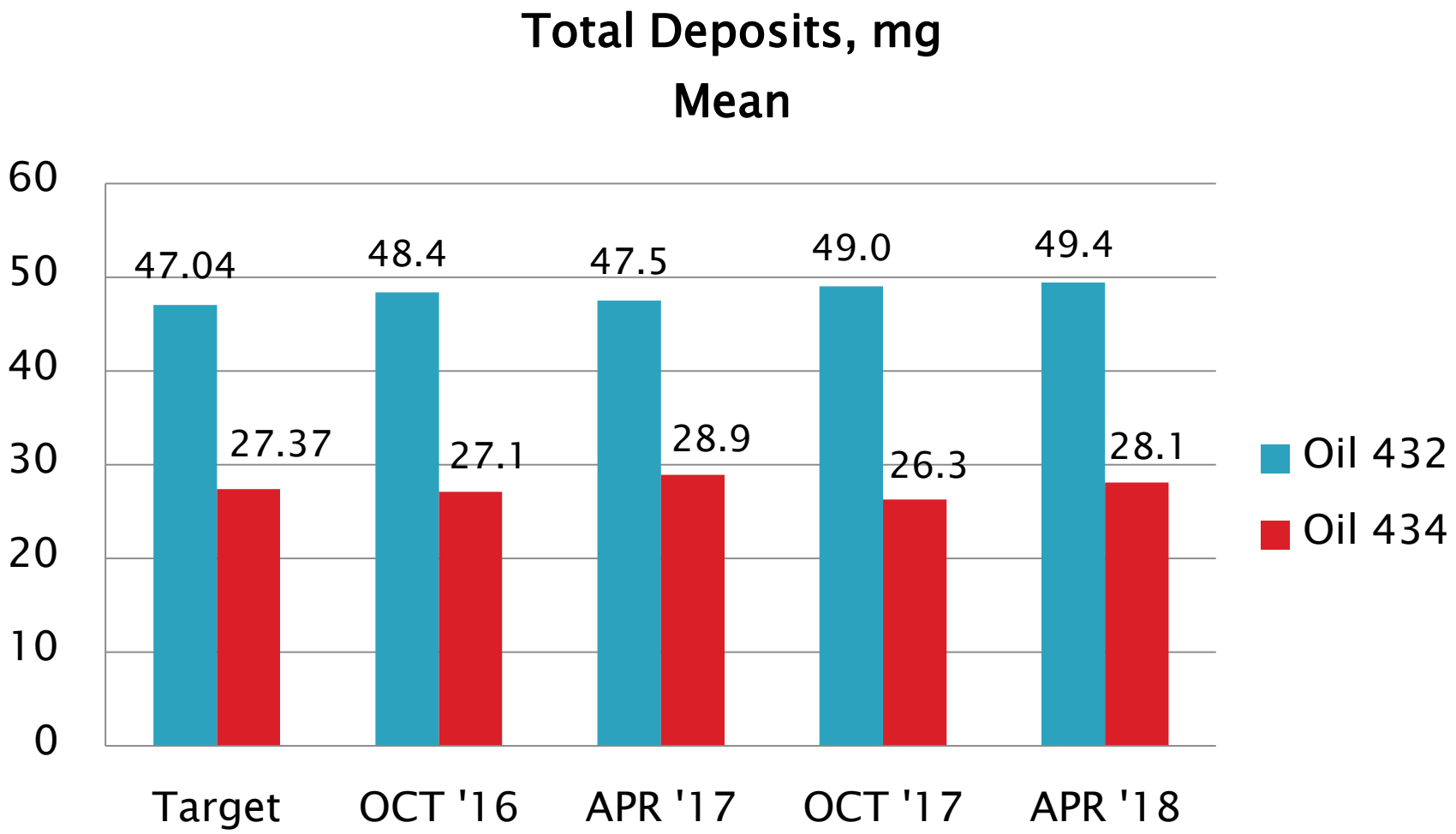
D7097 Performance by Oil

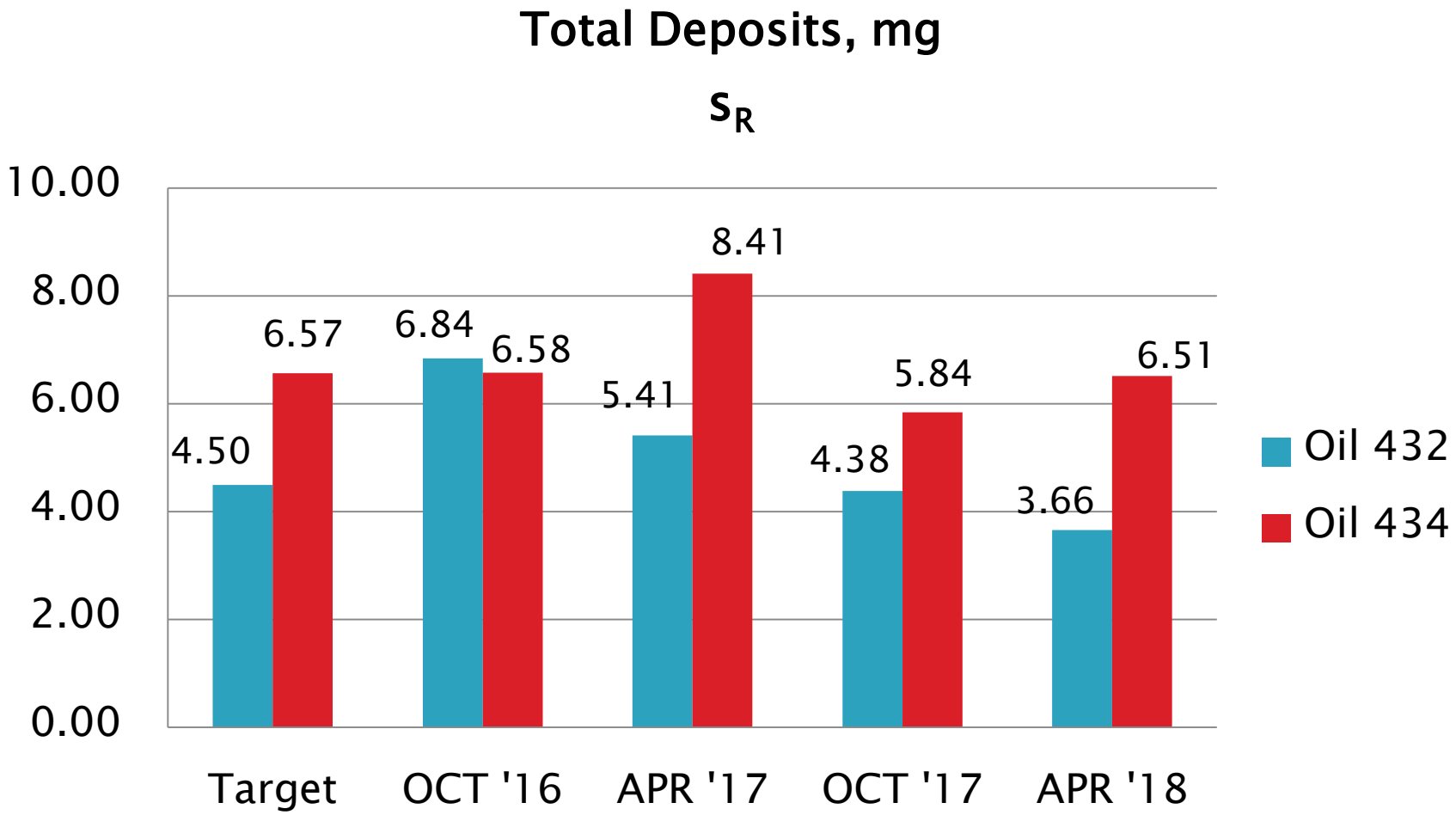
Total Deposits, mg
Performance by Oil

	Targets			10/1/16 – 3/31/17				4/1/17- 9/30/17				10/1/17 – 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
432	30	47.04	4.50	51	47.5	5.41	0.11	42	49.0	4.38	0.44	44	49.4	3.66	0.53
434	30	27.37	6.57	54	28.9	8.41	0.23	41	26.3	5.84	-0.17	44	28.1	6.51	0.12

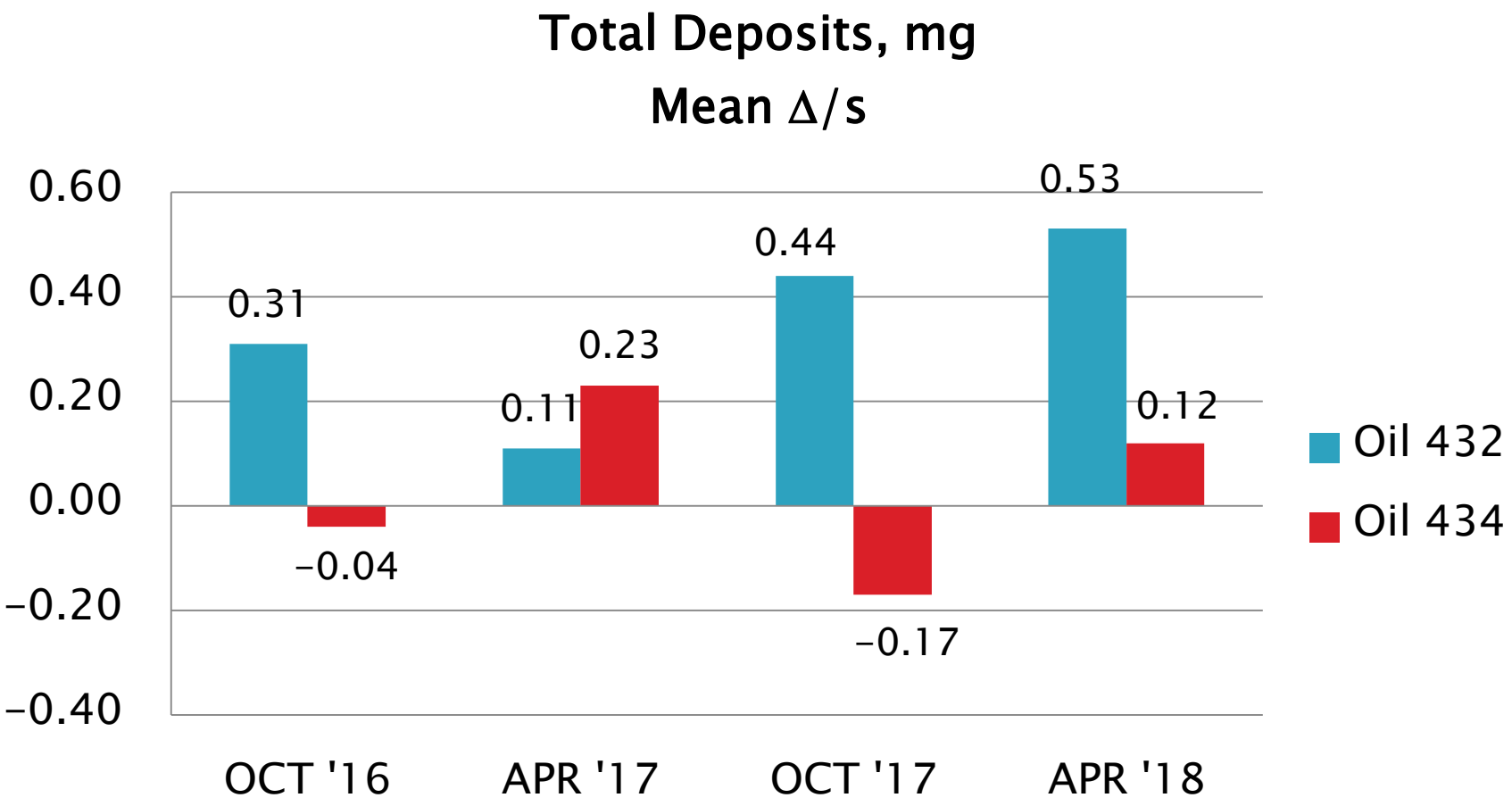
D7097 Performance by Oil



D7097: Deposits by MHT TEOST



D7097: Deposits by MHT TEOST



Return to Executive Summary

D6082: High Temperature Foam

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	13
Acceptable Discrimination Test	AS	6
Failed Calibration Test	OC	1
Operationally Invalidated by Lab	LC, XC	0
Donated New Oil Screener Tests	AG	10
Total		**30**

Number of Labs Reporting Data: 6
Fail Rate of Operationally Valid Tests: 7%

D6082: High Temperature Foam

Statistically Unacceptable Tests (OC)	No. Of Tests
Foam Tendency Mild	0
Foam Tendency Severe	1

- 10 Donated runs reported this period to evaluate replacement reference oils for oil 1007

- No TMC technical updates were issued this period

D6082: High Temperature Foam

Period Precision and Severity Estimates Oil 1007

Foam Tendency, ml	n	Mean	Pooled s	Mean Δ/s
Current Targets	28	65.71	19.28	-----
4/1/14 through 9/30/14	11	65	22	-0.05
10/1/14 through 3/31/15	10	61	12	-0.26
4/1/15 through 9/30/15	11	59	16	-0.36
10/1/15 through 3/31/16	8	58	10	-0.45
4/1/16 through 9/30/16	12	59	18	-0.38
10/1/16 through 3/31/17	14	54	19	-0.62
4/1/17 through 9/30/17	12	69	10	0.17
10/1/17 through 3/31/18*	14	66	17	-0.02
10/1/17 through 3/31/18*	13	62	11	-0.19

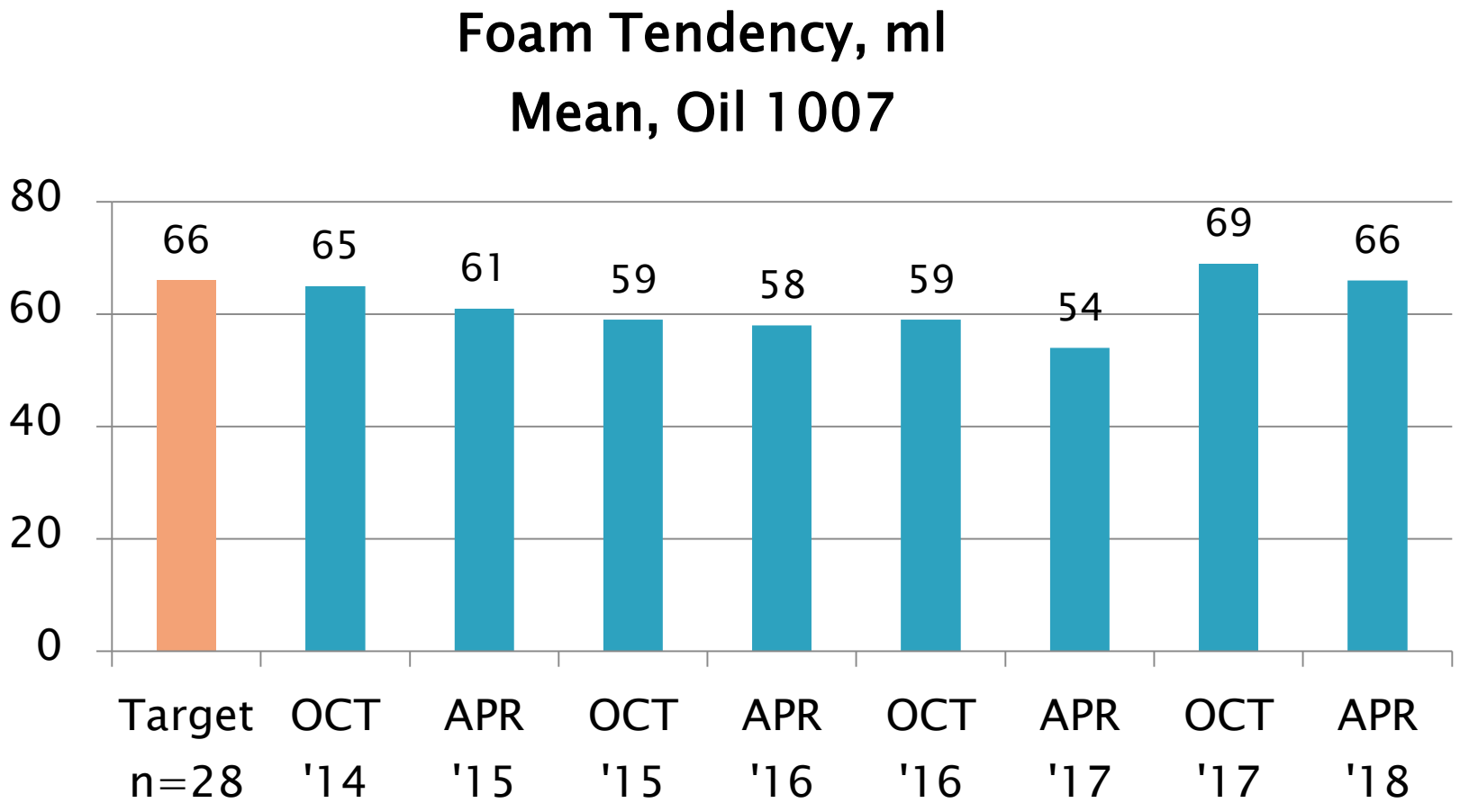
*Single OC result Yi=2.3 s severe included and excluded

D6082: High Temperature Foam

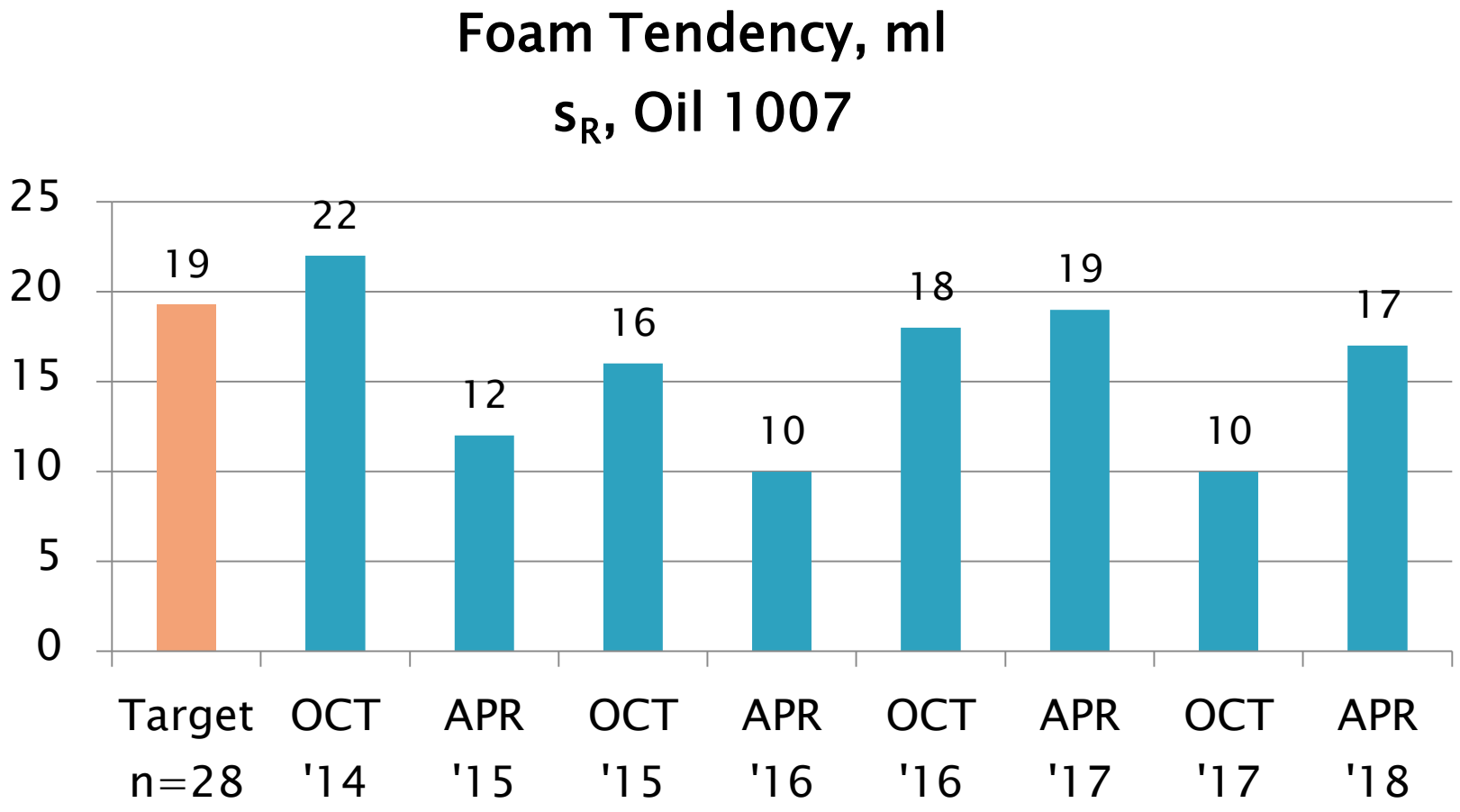
Period Precision and Severity Estimates Oil 1007

Foam Stability @ 1 min, ml	n	Mean	s
Current Targets	28	0.00	0.00
4/1/14 through 9/30/14	11	No non-zero occurrences	
10/1/14 through 3/31/15	10	No non-zero occurrences	
4/1/15 through 9/30/15	11	No non-zero occurrences	
10/1/15 through 3/31/16	8	No non-zero occurrences	
4/1/16 through 9/30/16	12	No non-zero occurrences	
10/1/16 through 3/31/17	14	No non-zero occurrences	
4/1/17 through 9/30/17	12	No non-zero occurrences	
10/1/17 through 3/31/18	14	No non-zero occurrences	

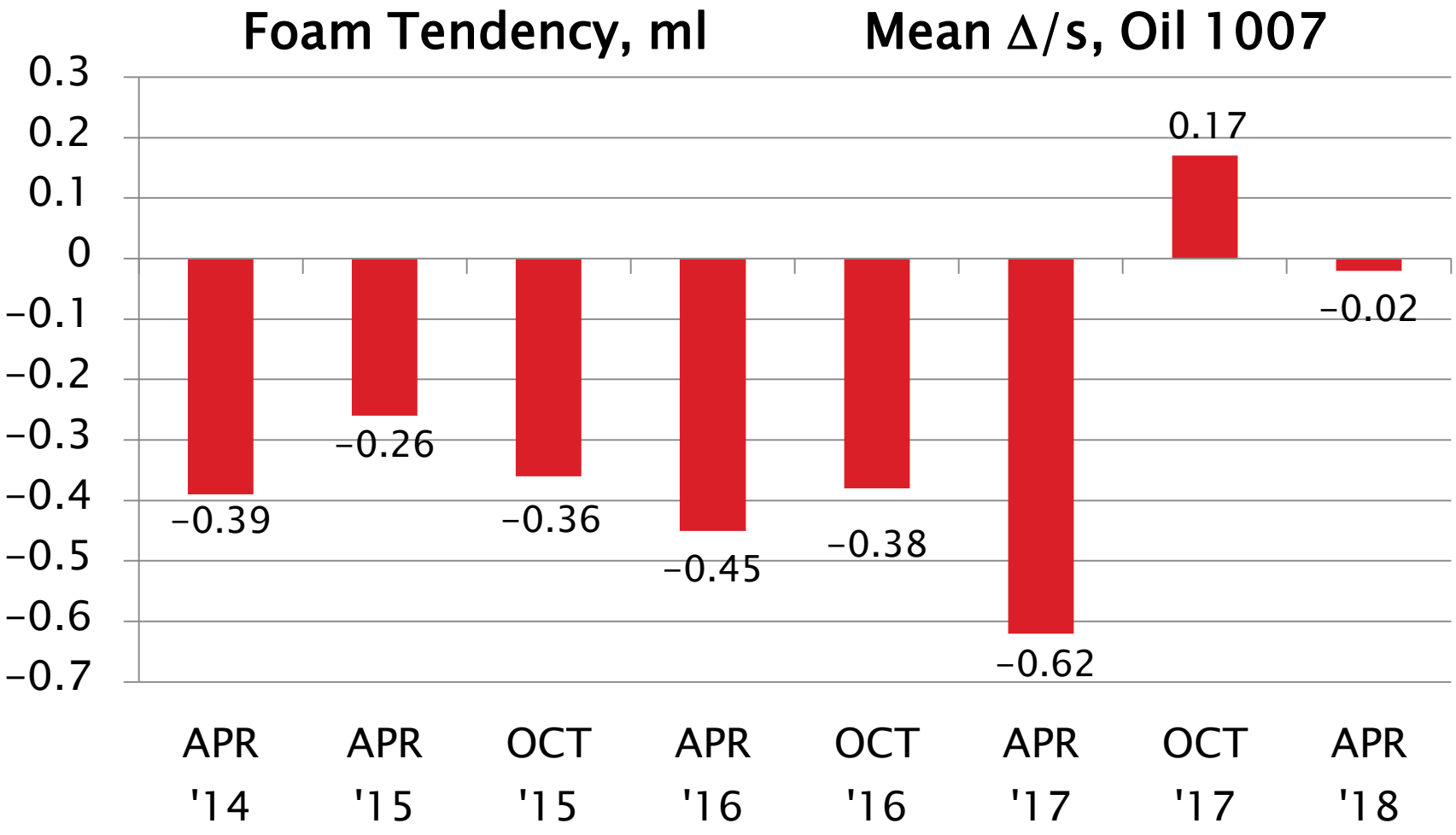
D6082: High Temperature Foam



D6082: High Temperature Foam



D6082: High Temperature Foam

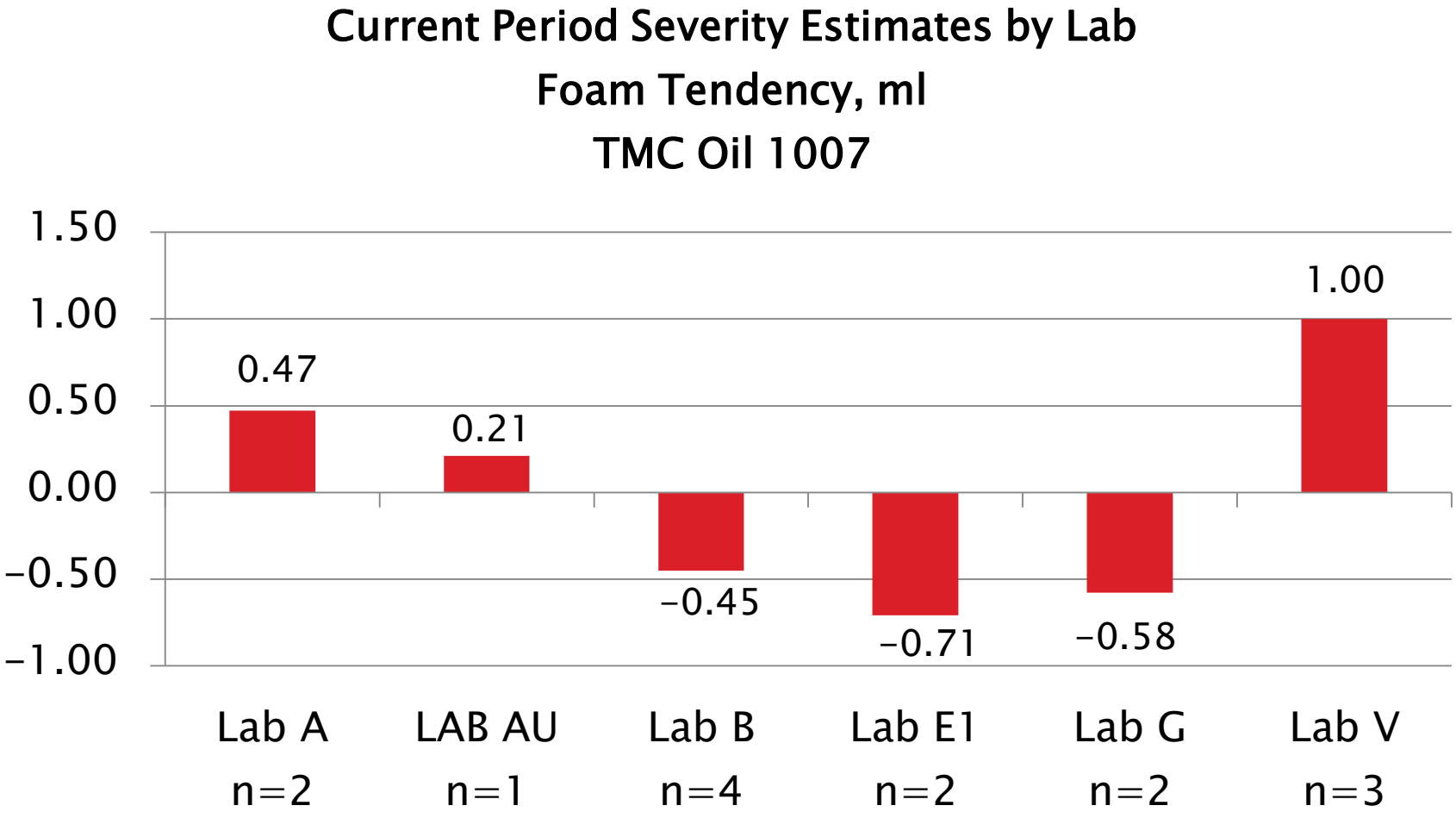


D6082: High Temperature Foam

Current Period Severity Estimates by Lab
Foam Tendency, ml
TMC Oil 1007

	n	Mean Δ/s
Lab A	2	0.47
Lab AU	1	0.21
Lab B	4	-0.45
Lab E1	2	-0.71
Lab G	2	-0.58
Lab V	3	1.00

D6082: High Temperature Foam



D6082: High Temperature Foam

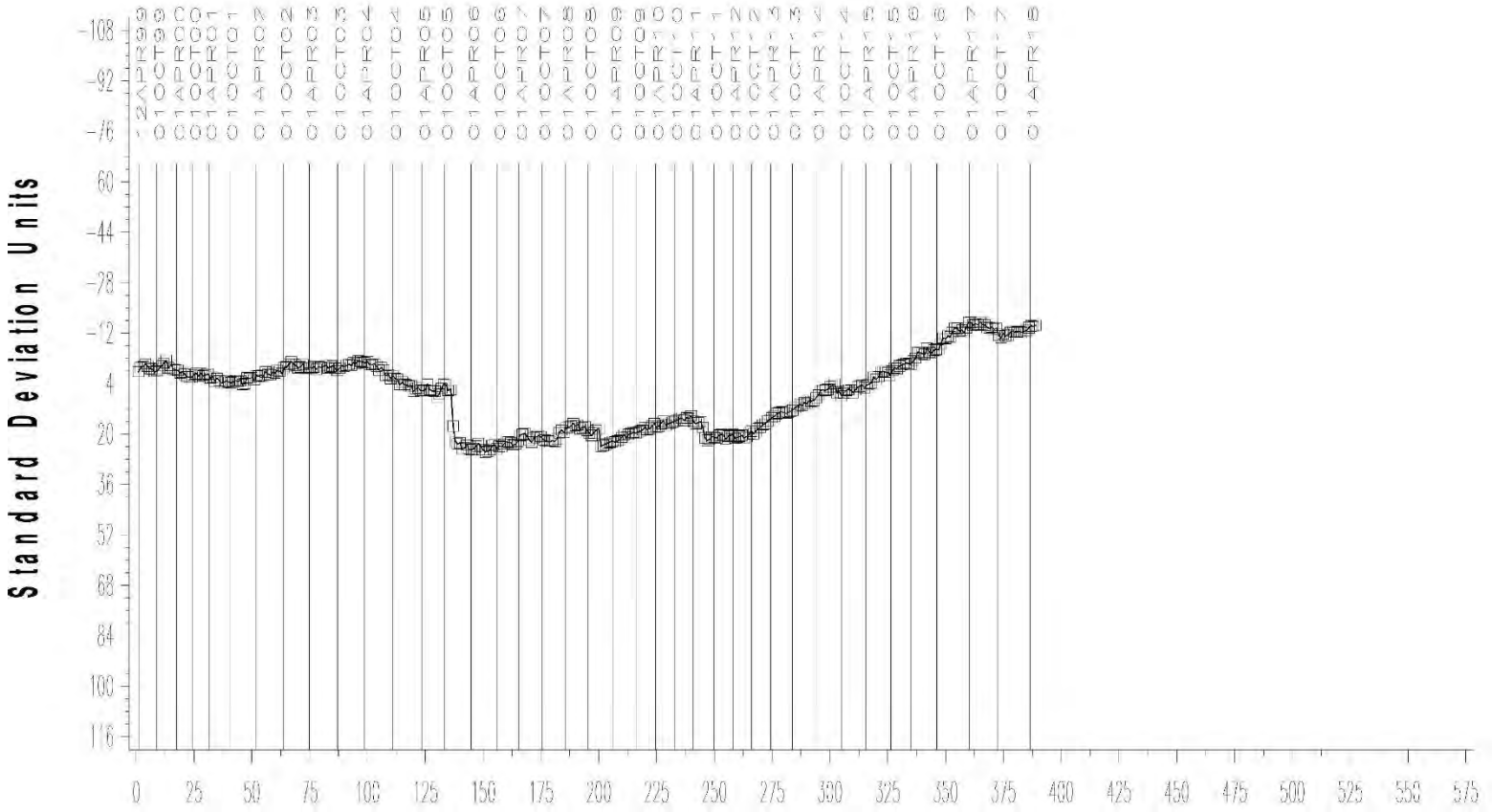
- Foam Tendency Precision (Pooled s) is degraded compared to the prior period
  - But, comparable to prior period, and much more precise than target precision, with one OC failing result excluded (Yi = 2.3 s, Lab V)
- Performance (Mean Δ/s) is on target (slightly mild with one result excluded)
- No non-zero occurrences of Foam Stability (on operationally valid tests)
- All severe oil discrimination runs demonstrated acceptable discrimination.

D6082 HIGH TEMPERATURE FOAM INDUSTRY OPERATIONALLY VALID DATA

IND= '1007'

FOAM TENDENCY

CUSUM Severity Analysis



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Return to Executive Summary

D874: Sulfated Ash

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	8
Failed Calibration Test	OC	0
Operationally Invalidated by Lab	LC, XC	0
Operationally Invalidated After Initially Reported as Valid	RC	0
Total		**8**

Number of Labs Reporting Data: 4
Fail Rate of Operationally Valid Tests: 0%

D874: Sulfated Ash

Statistically Unacceptable Tests (OC)	No. Of Tests
Sulfated Ash Mild	0
Sulfated Ash Severe	0

- No operationally or statistically invalid tests reported this period
- No TMC technical updates issued this period

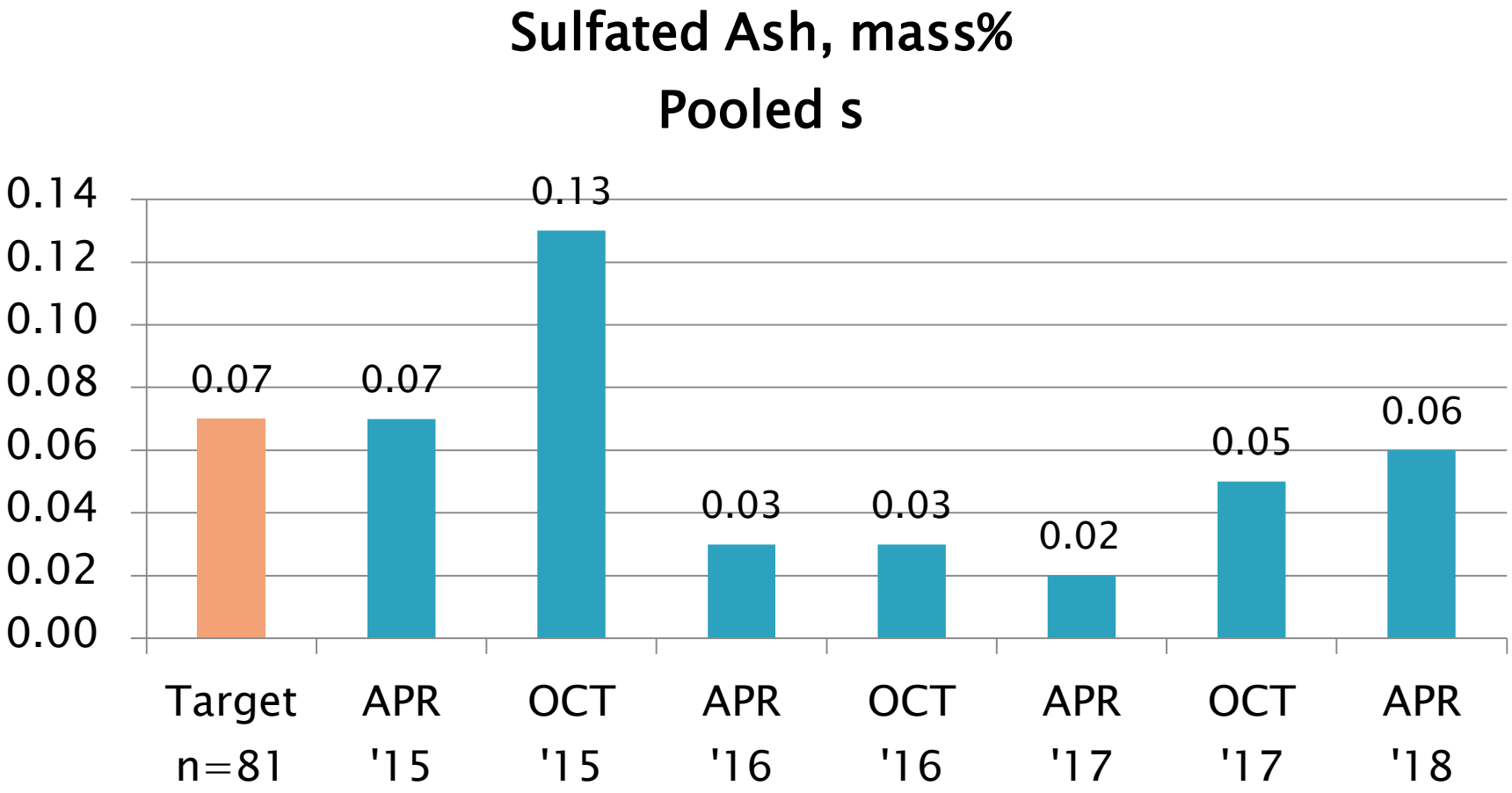
D874: Sulfated Ash

Period Precision and Severity Estimates

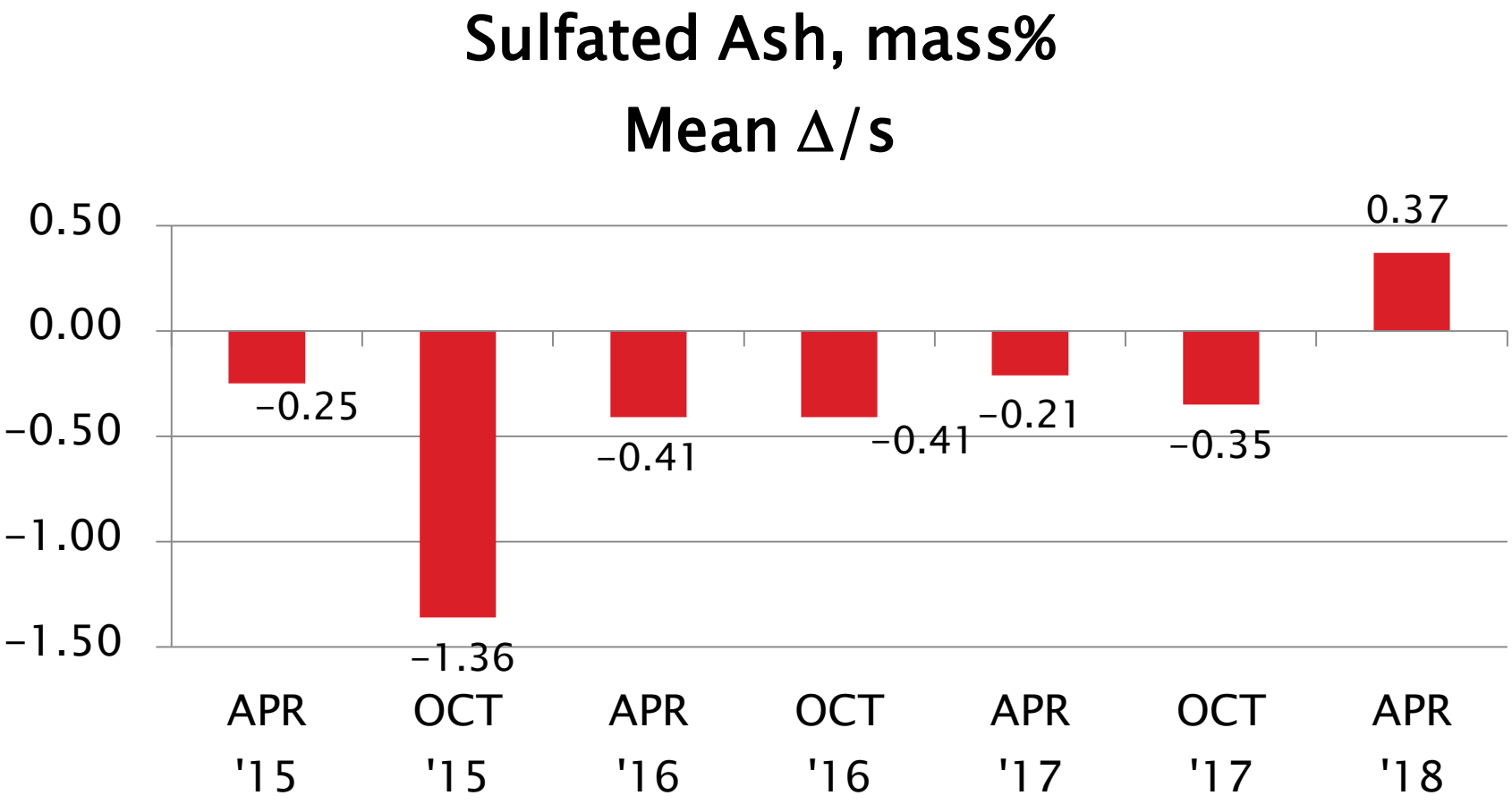
Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Current Targets	81	78	0.07	-----
10/1/14 through 3/31/15	6	4	0.07	-0.25
4/1/15 through 9/30/15*	8	5	0.13	-1.36
4/1/15 through 9/30/15*	7	4	0.05	-0.36
10/1/15 through 3/31/16	7	4	0.03	-0.41
4/1/16 through 9/30/16	6	3	0.03	-0.41
10/1/16 through 3/31/17	7	4	0.02	-0.21
4/1/17 through 9/30/17	8	5	0.05	-0.35
10/1/17 through 3/31/18	8	5	0.06	0.37

*Period statistics with and without extreme result included

D874: Sulfated Ash



D874: Sulfated Ash

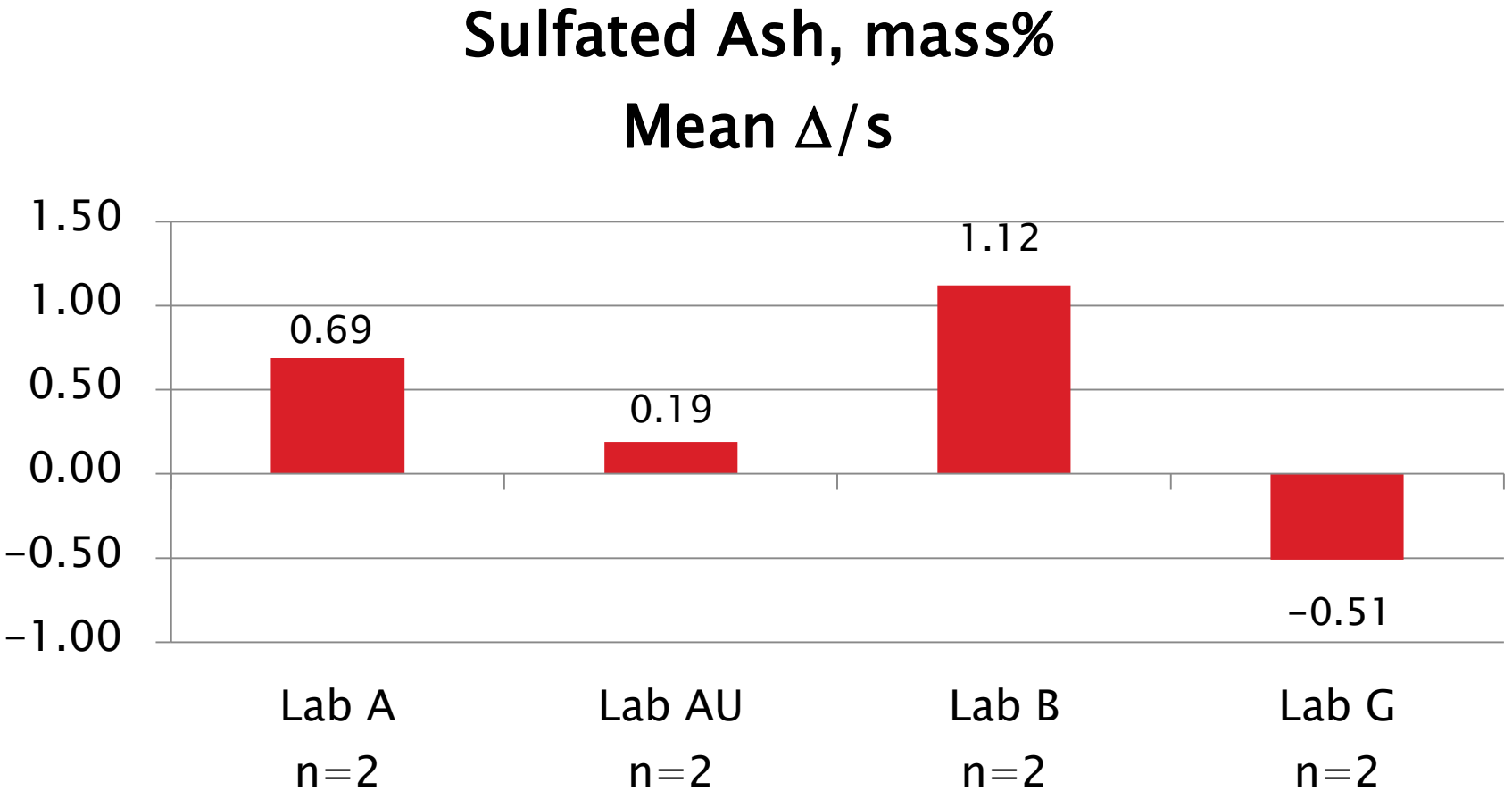


D874: Sulfated Ash

Current Period Severity Estimates by Lab
Sulfated Ash, mass%

	n	Mean Δ/s
Lab A	2	0.69
Lab AU	2	0.19
Lab B	2	1.12
Lab G	2	-0.51

D874: Sulfated Ash



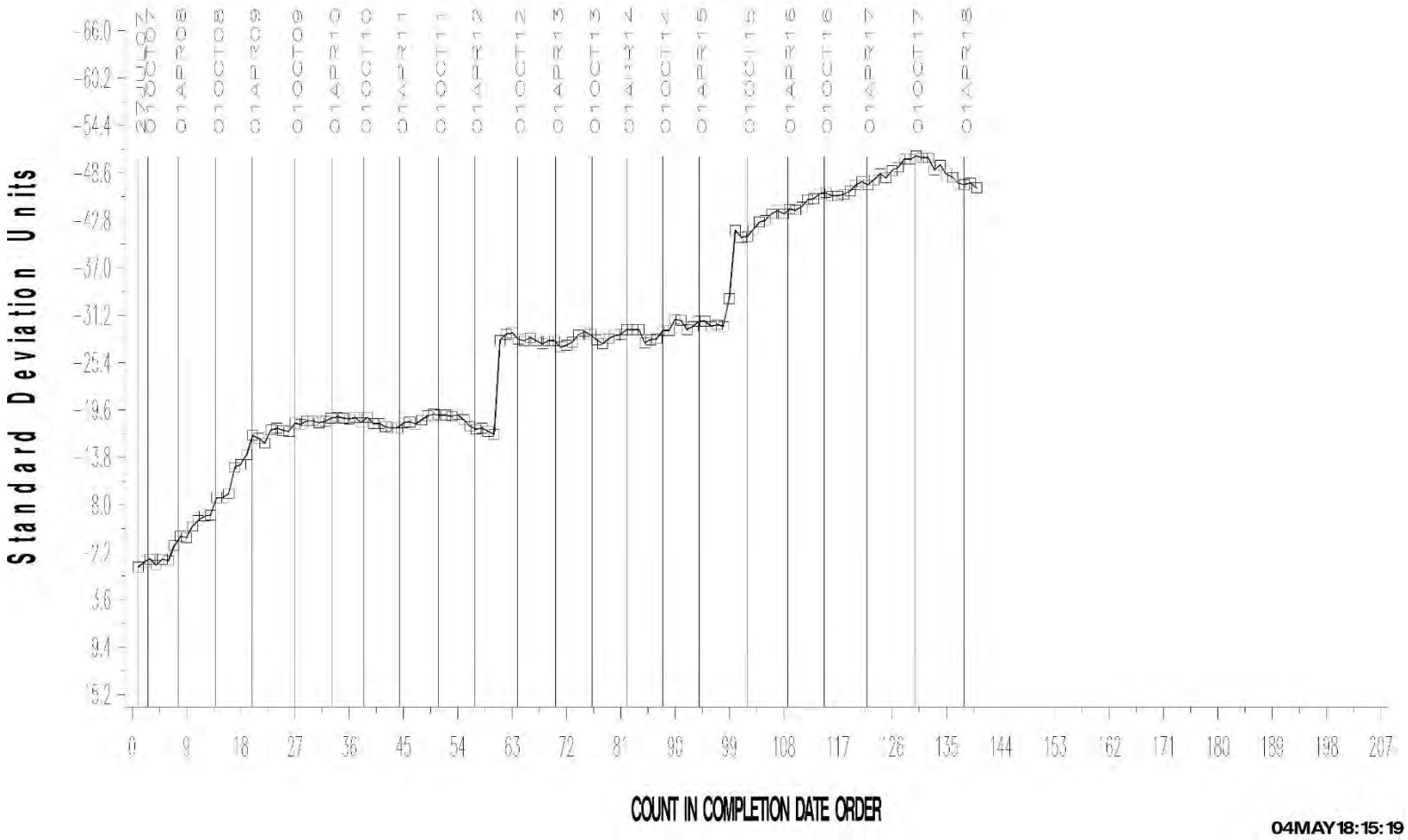
D874: Sulfated Ash

- Precision (Pooled s) is comparable to the prior period (which was less precise than the prior three periods)
  - Comparable to the target precision
- Performance (Mean Δ/s) is 0.37 s severe

D874 INDUSTRY OPERATIONALLY VALID DATA

TEST SAMPLE PERCENT SULFATED ASH

CUSUM Severity Analysis



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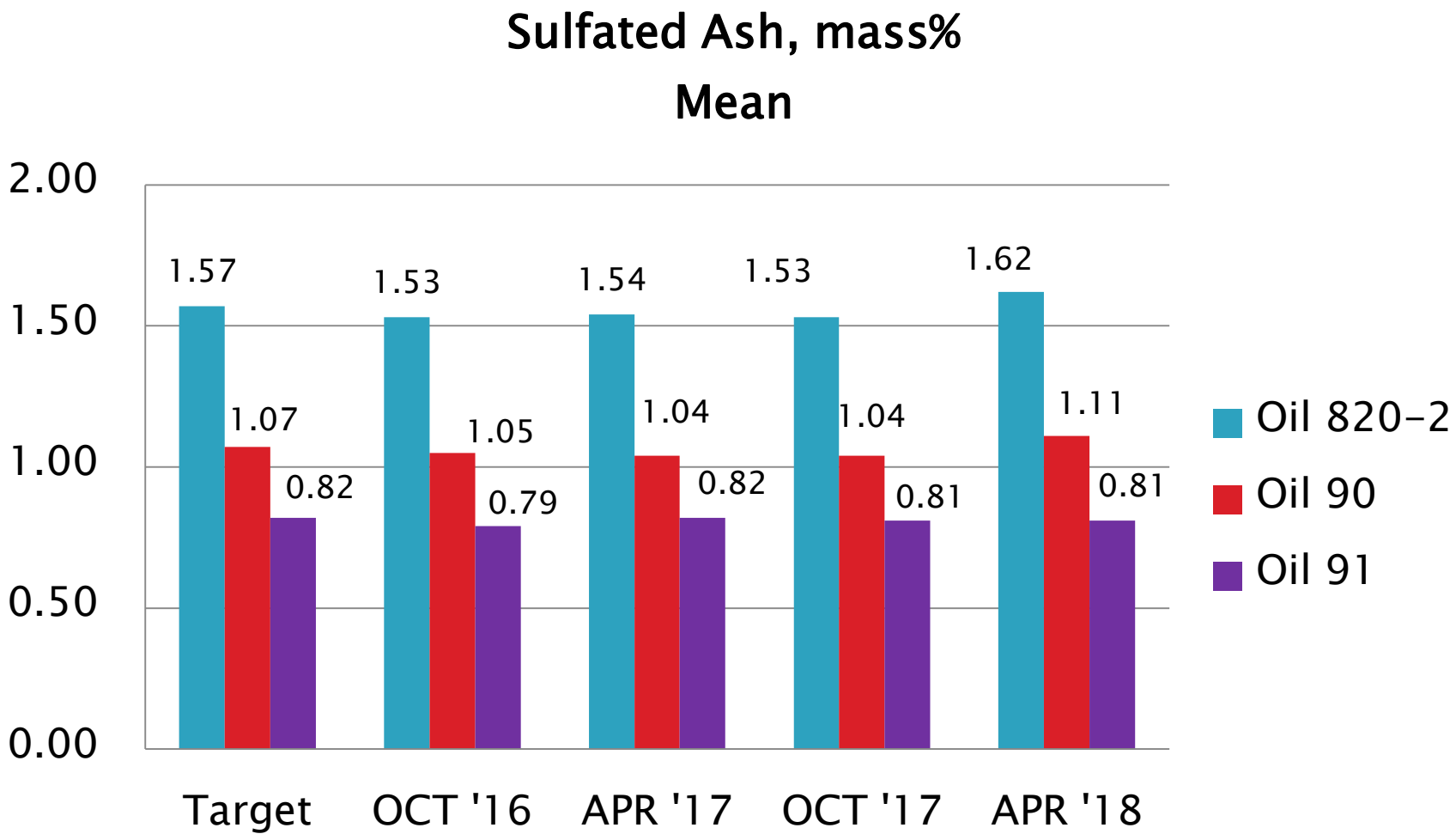
D874: Sulfated Ash

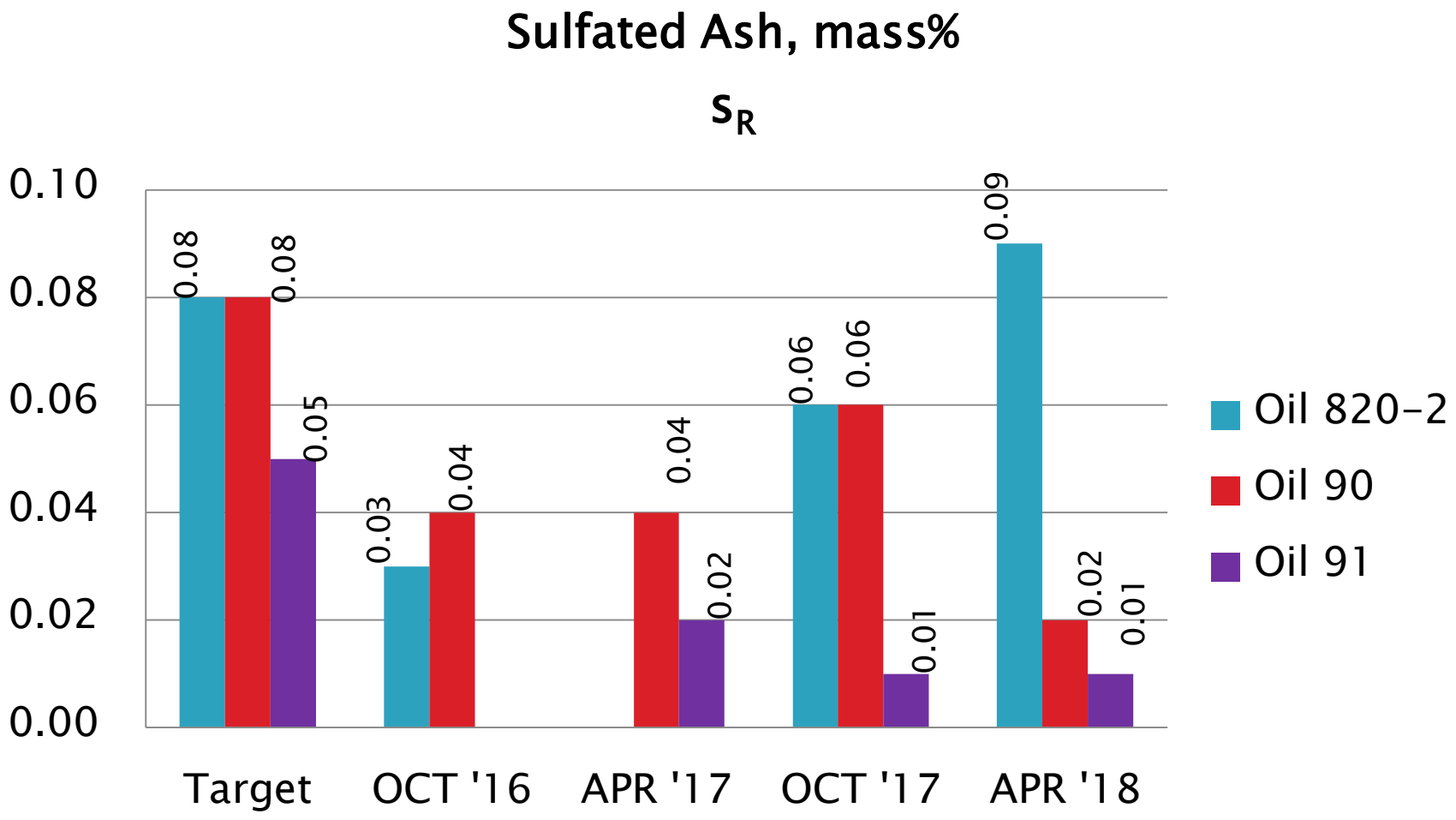
Performance by Oil
Sulfated Ash, mass%

	Targets			10/1/16 – 3/31/17				4/1/17 – 9/30/17				10/1/17 – 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
820-2	27	1.57	0.08	1	1.54	---	-0.38	3	1.53	0.06	-0.46	3	1.62	0.09	0.67
90	27	1.07	0.08	2	1.04	0.04	-0.44	3	1.04	0.06	-0.33	3	1.11	0.02	0.46
91	27	0.82	0.05	4	0.82	0.02	-0.05	2	0.81	0.01	-0.20	2	0.81	0.01	-0.20

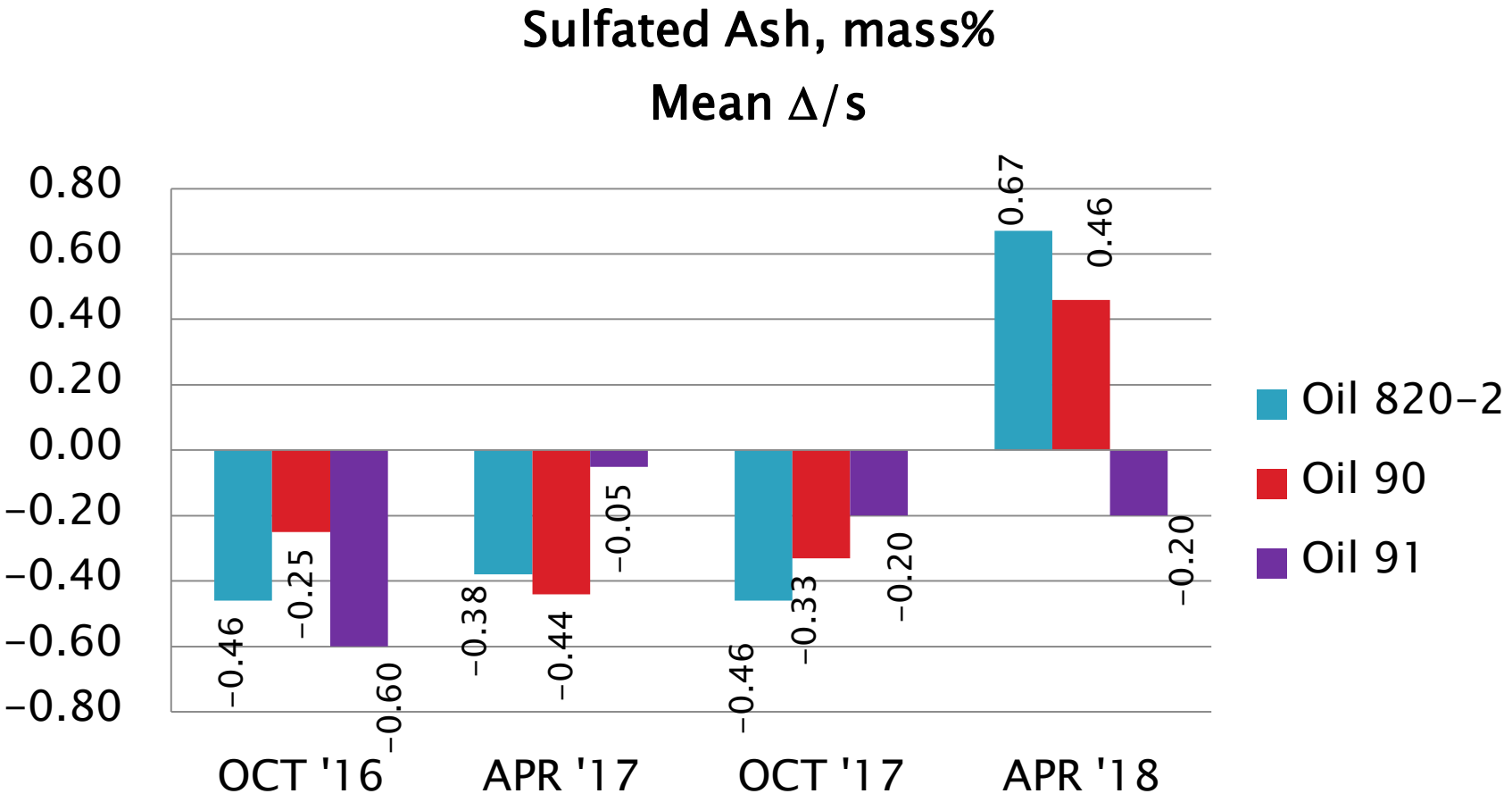
D874: Sulfated Ash



D874: Sulfated Ash



D874: Sulfated Ash



Return to Executive Summary

D7528: Oxidation by ROBO

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	79
Failed Calibration Test	OC	11
Operationally Invalidated by Lab	LC, XC	18
Operationally Invalidated After Initially Reported as Valid	RC	0
Rig Shakedown Runs	NN	12
Total		**120**

Number of Labs Reporting Data: 7
Fail Rate of Operationally Valid Tests: 12%

D7528: Oxidation by ROBO

Operationally Invalid Tests

- 9 tests vacuum failure, vacuum or air leak (LC, XC)
- 5 tests NO_2 flow off-spec (LC, XC)
- 1 test heater or heater control failure (XC)
- 1 test thermocouple failure (XC)
- 1 test stirrer failure (XC)
- 1 test power failure

Other Tests

- 6 required rig shakedown runs on three new rigs (NN)
- 6 requested rig shakedown runs to troubleshoot established rigs (NN)

D7528: Oxidation by ROBO

Statistically Unacceptable Tests (OC)	No. Of Tests
Natural Log (MRV Viscosity) Mild	10
Natural Log (MRV Viscosity) Severe	1

- 4 tests mild on oil 435-1
- 4 tests mild on oil 434-2
- 1 test severe on oil 434-2
- 2 tests mild on 438

- One ROBO technical memo was issued after the end of this report period:
  - Report Packet Revision Notice ROBO-20180323, issued April 24, 2018, effective May 25, 2018

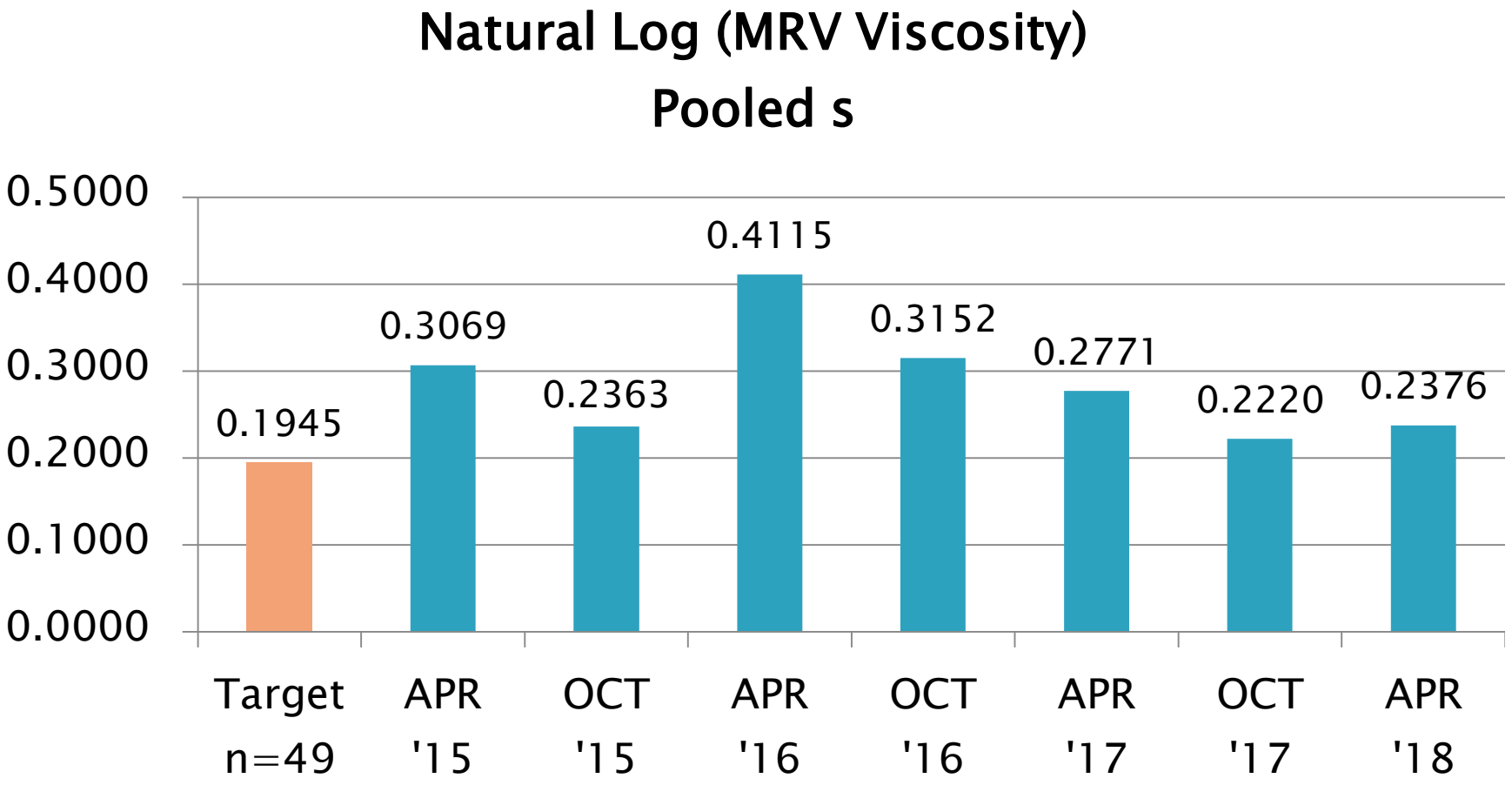
D7528: Oxidation by ROBO

Period Precision and Severity Estimates

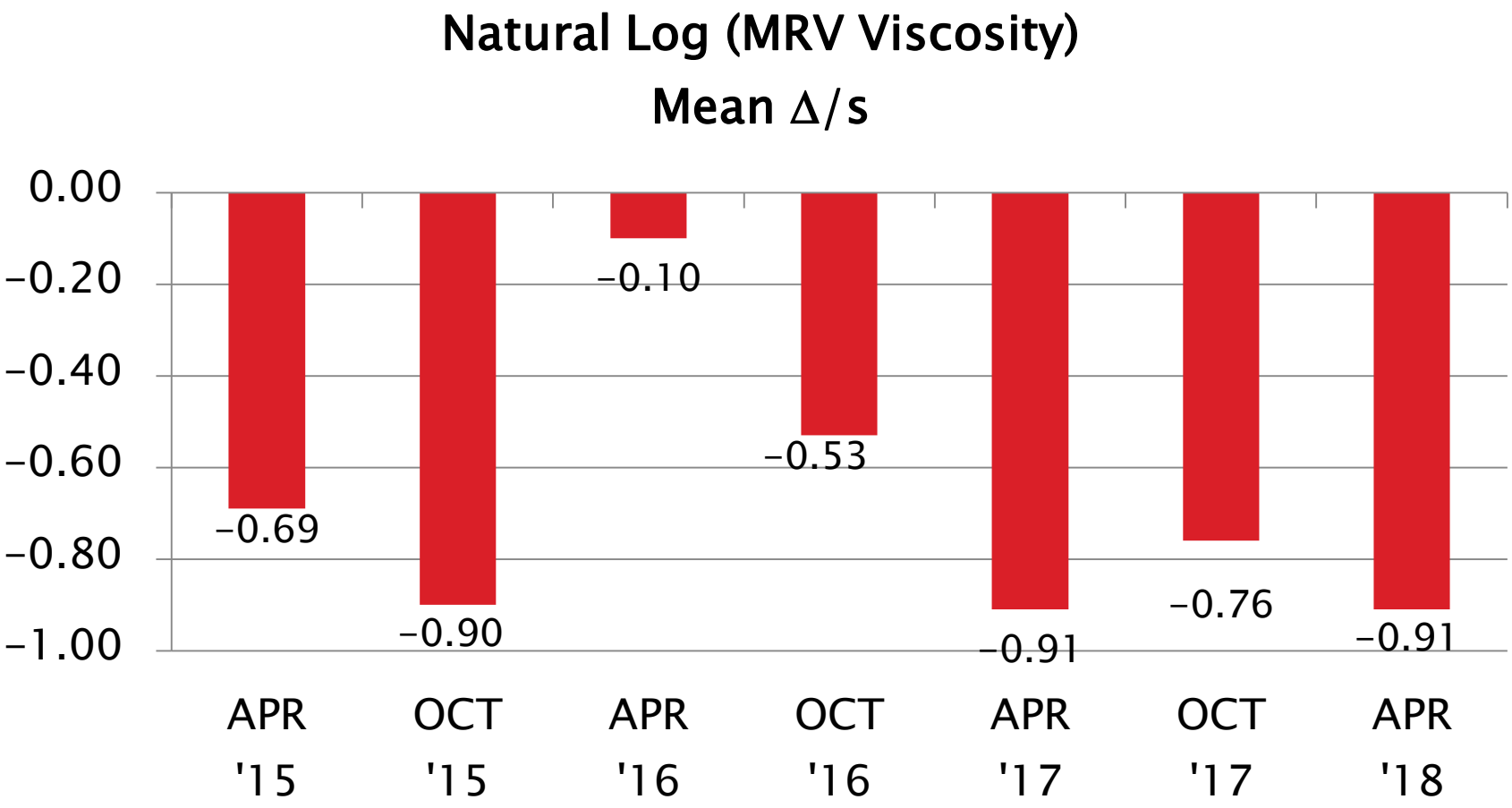
Natural Log (MRV Viscosity)	n	df	Pooled s	Mean Δ/s
Current Targets	49	46	0.1945	-----
4/1/15 through 9/30/15	85	82	0.2363	-0.90
10/1/15 through 3/31/16*	92	89	0.4115	-0.10
10/1/15 through 3/31/16*	91	88	0.3661	-0.20
4/1/16 through 9/30/16	74	71	0.3152	-0.53
10/1/16 through 3/31/17	78	75	0.2771	-0.91
4/1/17 through 9/30/17	99	95	0.2220	-0.76
10/1/17 through 3/31/18**	90	86	0.2376	-0.91
10/1/17 through 3/31/18**	83	79	0.2076	-0.74

*Period statistics with and without one extreme result included
**Period statistics with and without seven suspect results from two rigs

D7528: Oxidation by ROBO



D7528: Oxidation by ROBO

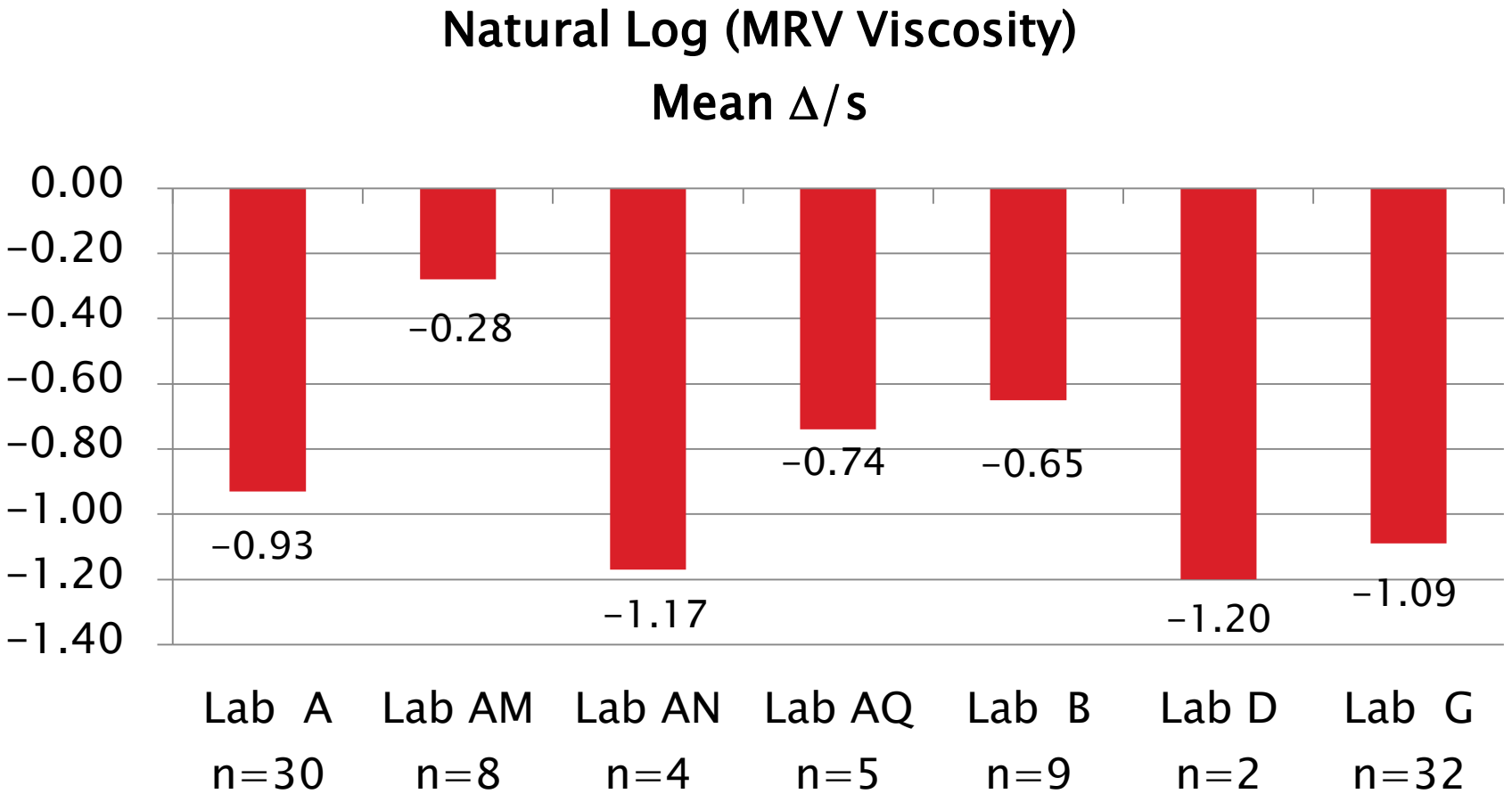


D7528: Oxidation by ROBO

Current Period Severity Estimates by Lab
Natural Log (MRV Viscosity)

	n	Mean Δ/s
Lab A	30	-0.93
Lab AM	8	-0.28
Lab AN	4	-1.17
Lab AQ	5	-0.74
Lab B	9	-0.65
Lab D	2	-1.20
Lab G	32	-1.09

D7528: Oxidation by ROBO



D7528: Oxidation by ROBO

- As with last period, Lab G, has a few issues of note affecting the period statistics:
  - Eight of the eleven OC fails this period are from Lab G. (Lab A, with a similar number of test, had 3 OC fails.)
  - Three tests exceed 4 s mild this period: (-4.4, -5.5, -6.0), all from Lab G, with the two exceeding -5 s being consecutive runs on the same rig (G7). Rig G7 subsequently passed calibration, but Lab G never reported an operational cause for the two consecutive extreme mild results on that rig.
  - As of this report, rig G6 reports 17 calibration attempts and 4 shakedown runs since the last successful calibration expired on 20161020. Of the 17 calibration runs, 3 are AC, 4 OC (all mild), 9 XC or LC and 1 MC (not acceptable for calibration). The 3 AC test failed to calibrate under the two-test calibration requirements, and, to date, the rig has failed to calibrate, but the lab continues to troubleshoot the instrument's performance.

D7528: Oxidation by ROBO

- Because of the influence of the two consecutive very mild results from rig G7 (subsequently passing on two tests), and the unusual number of failing attempts to calibrate rig G6, the period statistical estimates are shown on slide 121 with these results included and excluded for comparison. Subsequent slides show only estimates to include all results on these two rigs reported as operationally valid.

- Precision (Pooled s) is less precise than last period
  - Continues to be less precise than target precision
  - However, with identified results from rigs G6 and G7 excluded, for reasons as explained above, precision is more precise than all prior periods since at least October 2014.

- Performance (Mean Δ/s) is -0.91 s mild with all labs mild to some degree and all four oils performing overall mild (the same as prior periods)
  - Overall performance is -0.74 s mild with identified results excluded from rigs G6 and G7

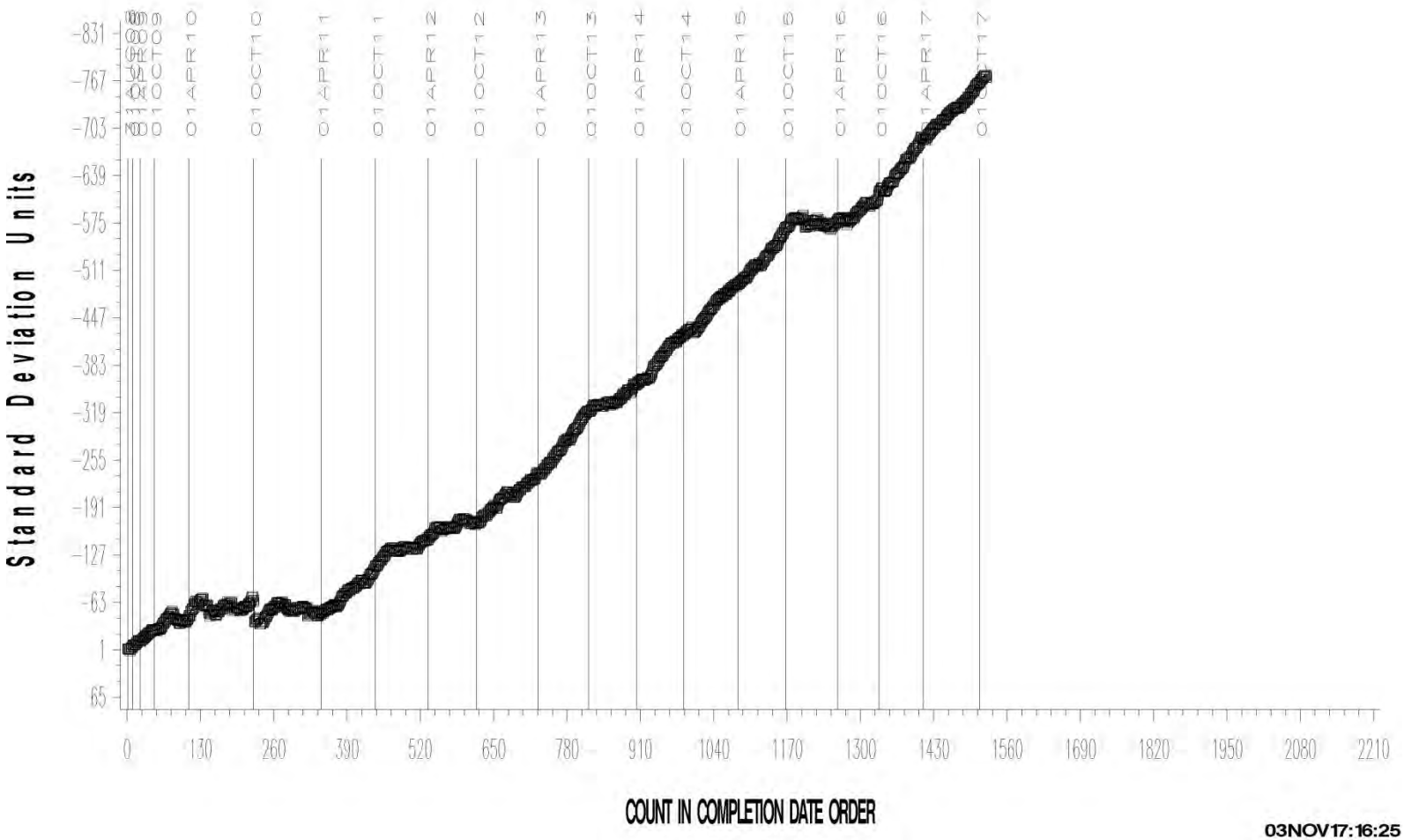
D7528: Oxidation by ROBO

- Oil 434-1 is depleted at the TMC, reblend 434-2 has been introduced with preliminary targets set by round robin.
  - Any 434-1 in current lab inventories is still being assigned.
  - 434-2 is running –0.88 s mild overall on 26 tests (excepting identified tests from G6 and G7), and –0.72 s mild for the period (with same exceptions). However, targets were set with consideration of preserving (or not canceling out) the mild trend on oil 434-1, and the 434-2 performance reflects that ongoing mild trend.
- CUSUM Severity Plot shows an overall mild trend since the 01APR11 timeline (following a 2011 ROBO workshop) with a brief leveling coincident with the October 2015 ROBO workshop held in San Antonio, TX, but the mild trend returns following the April 2016 timeline.

ROBO TEST INDUSTRY OPERATIONALLY VALID DATA

AGED OIL MRV APPARENT VISCOSITY

CUSUM Severity Analysis



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Test Monitoring Center

http://astmtmc.cmu.edu

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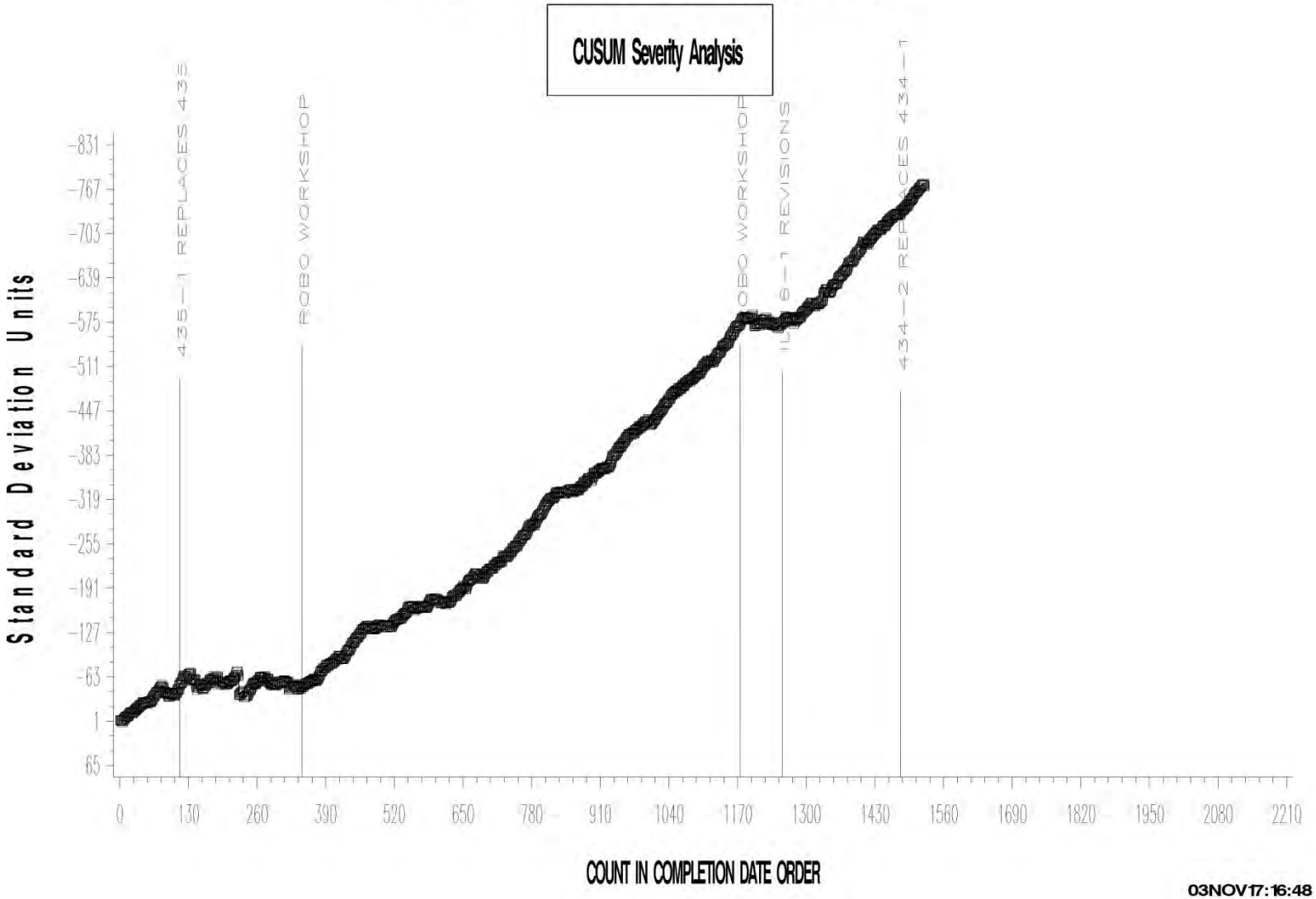
ROBO TEST INDUSTRY OPERATIONALLY VALID DATA

AGED OIL MRV APPARENT VISCOSITY



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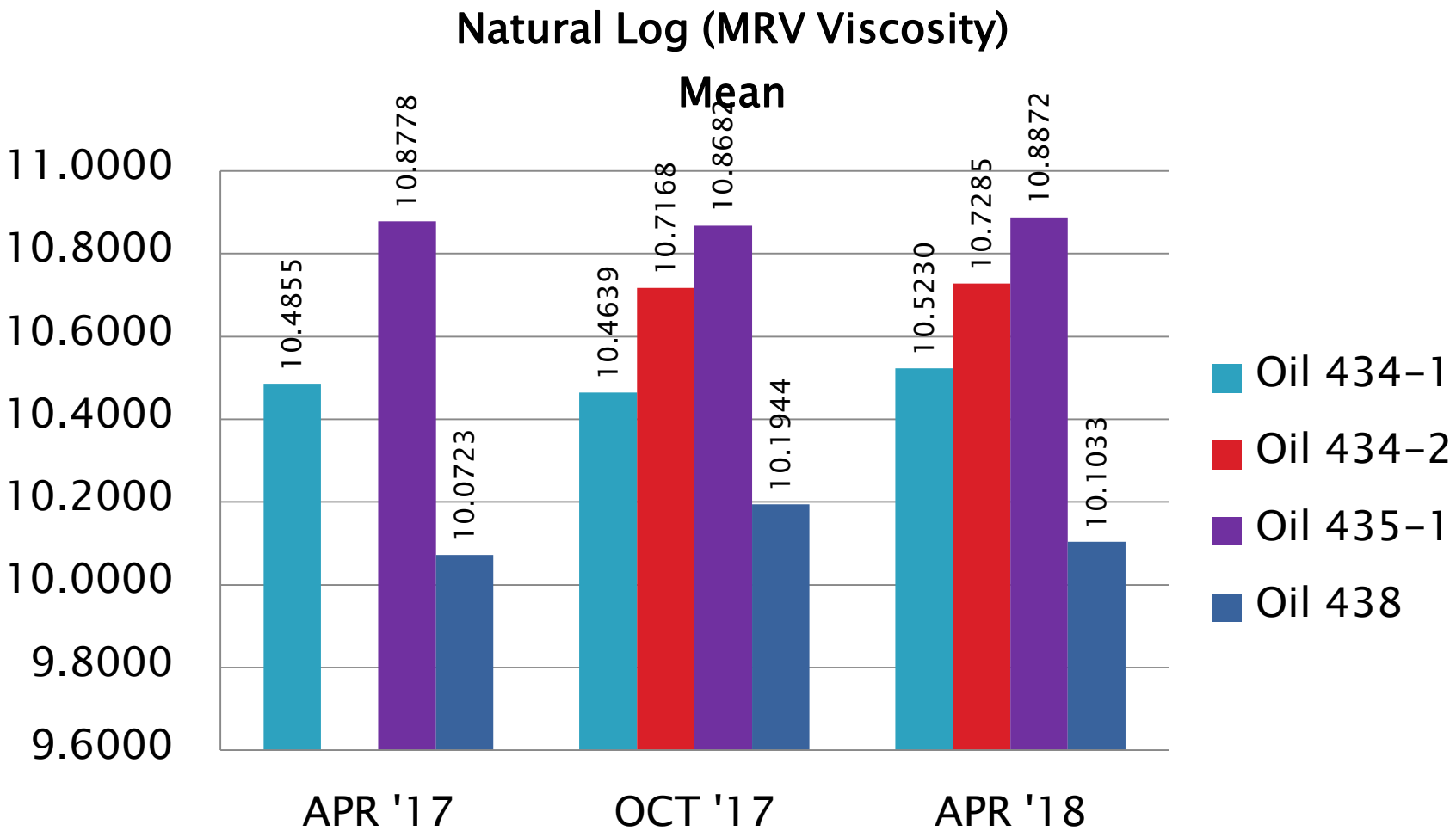
D7528: Oxidation by ROBO

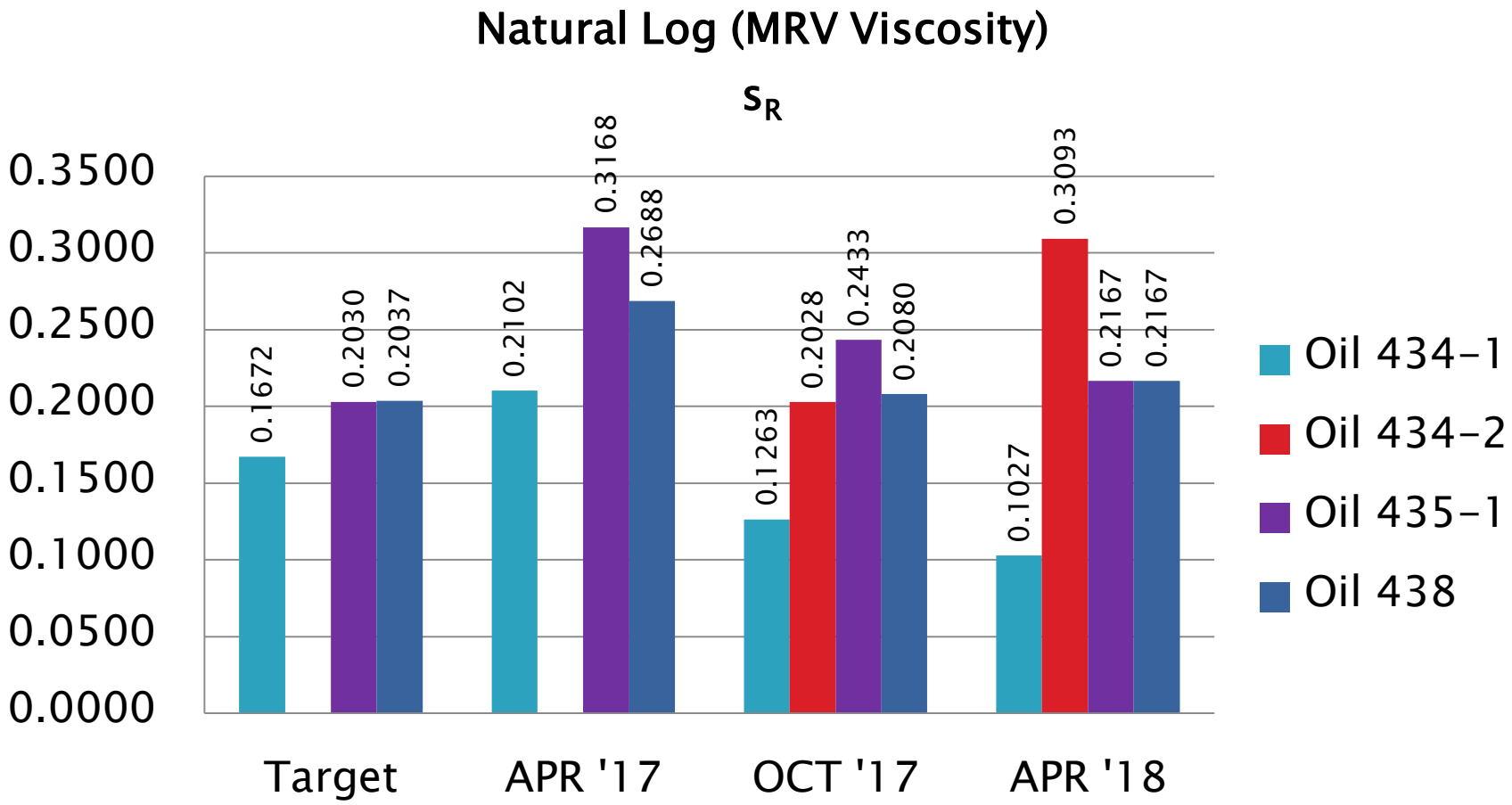
Performance by Oil
Natural Log (MRV Viscosity)

	Targets			10/1/16 - 3/31/17				4/1/17 - 9/30/17				10/1/17 - 3/31/18			
Oil Code	n	Mean	s_R	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s	n	Mean	s_R	Mean Δ/s
434-1	13	10.6599	0.1672	23	10.4855	0.2102	-1.04	8	10.4639	0.1263	-1.17	8	10.5230	0.1027	-0.82
434-2	--	-----	-----	--	-----	-----	-----	9	10.7168	0.2028	-1.34	23	10.7285	0.3093	-1.27
435-1	22	11.0416	0.2030	38	10.8778	0.3168	-0.81	50	10.8682	0.2433	-0.85	40	10.8872	0.2167	-0.76
438	14	10.2676	0.2037	17	10.0723	0.2688	-0.96	32	10.1944	0.2080	-0.36	19	10.1033	0.2167	-0.81

D7528: Oxidation by ROBO



D7528: Oxidation by ROBO



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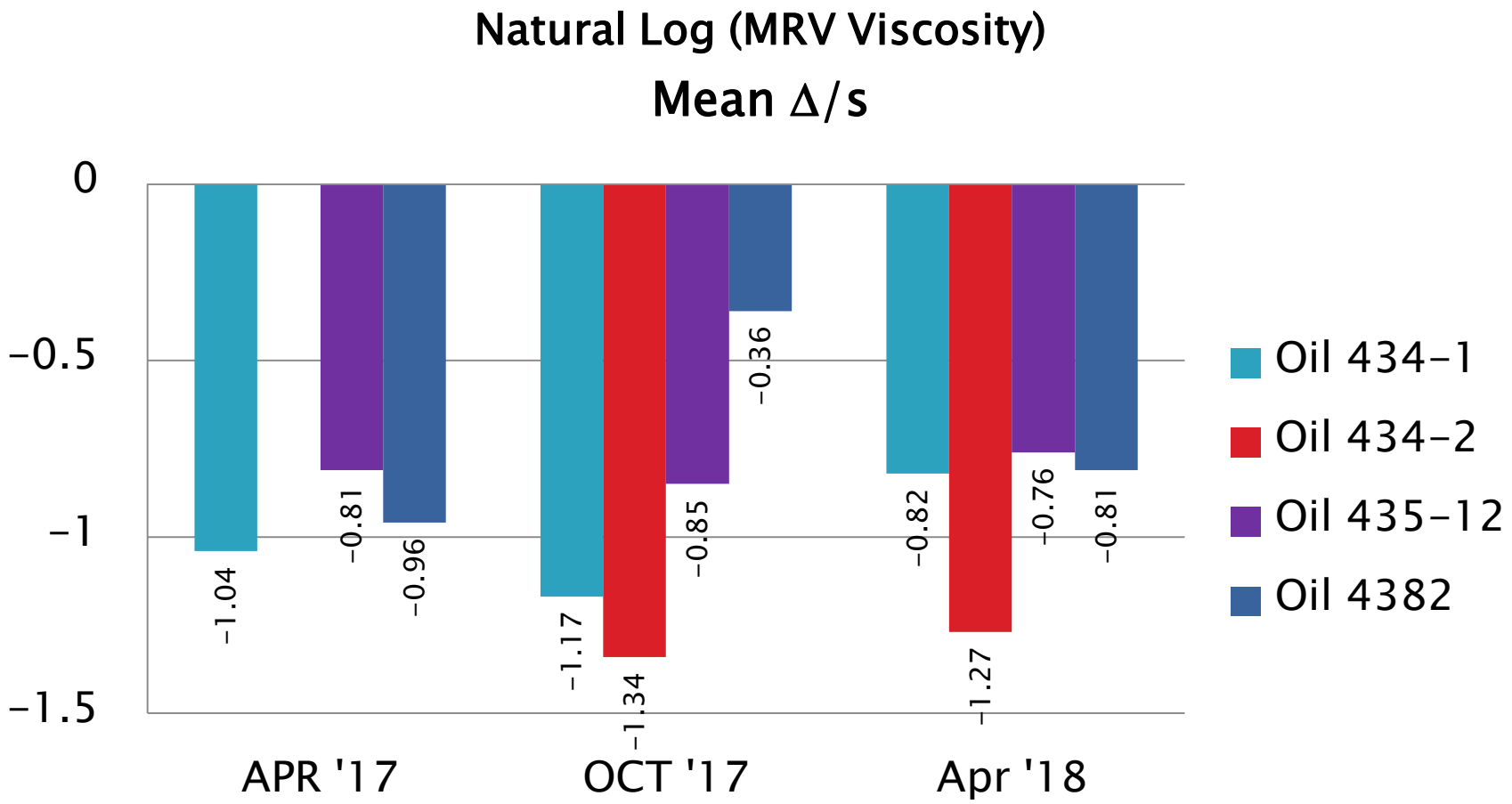
D7528: Oxidation by ROBO



Return to Executive Summary

Reference Oil Inventory

- As of 3/31/2018

Reference Oil Inventory

D5800, D6417, GI

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
VOLC12	2013	D5800	39.5	2.7
VOLD12	2013	D5800	41.9	2.7
VOLE12	2013	D5800	40.5	2.9
VOLD14	2014	D5800QC	93.2	74.8
52	1995	D6417	58.9	0.2
55	1995	D6417	66.0	0.1
58	1998	D6417, GI	115.6	0.4

Reference Oil Inventory

GI

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
62	1996	GI	0.4	0.3
GIA17*	2017	GI (proposed)	9.9	0.1
GIB17*	2017	GI (proposed)	9.9	0.1
1009**	2002	GI	34.2	6.2

*GIA17 & GIB17 are currently being evaluated to replace oil 62

**Multi-test oil; estimated aliquot reserved for bench testing.

Reference Oil Inventory

TEOST, MTEOS & ROBO

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
432	1998	MTEOS	107.5	0.7
434	2003	MTEOS	2.0	0.6
75	2010	TEOST	1.8	0.4
75-1*	2016	TEOST (proposed)	9.3	0.7
435-2**	2010	TEOST	43.2	0.0
434-2	2014	ROBO	21.5	8.6
435-1	2008	ROBO	425.9	11.4
438***	2003	ROBO	3.6	4.8

*75-1 is currently being evaluated to replace oil 75

**Multi-test oil; estimated aliquot reserved for bench testing.

***438 resupplied from Seq. III inventory as is available.

Reference Oil Inventory

D6082 & D874

Oil	Year Rec'd By TMC	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
1007	1998	D6082	12 samples	22 samples
FOAMA18*	2018	D6082 (proposed)	101.5	2.5
FOAMB18*	2018	D6082 (proposed)	99.5	2.5
66	2002	D6082	83.8	0.6
820-2	2001	D874	10.1	0.1
90*	2005	D874/D874QC	20.1	3.2
91	2006	D874	3.9	0.1

*FOAMA18 & FOAMB18 are currently being evaluated to replace oil 1007

**Oil 90 is also used as a D874 QC Check Oil

Additional Information

Additional Information

- Available on the TMC's Website:
  - CUSUM Severity Plots
  - Reference Data, Period Statistics and Timelines
  - Information Letters and Technical Memos
  - Report Forms & Data Dictionaries
  - Online Store, and more…

- www.astmtmc.cmu.edu

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