Test Monitoring Center

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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)

Spring 2021

Calibrated Labs and Stands*

Test	Labs	Stands
D6417	7	9
D5800	10	25
D5133 (GI)	9	60
D6335 (TEOST)	7	9
D7097 (MTEOS)	8	40
D6082	6	7
D874	4	--
D7528 (ROBO)	6	19

*As of 3/31/2021

B0.07 Bench Testing Executive Summary

- D6417 (Volatility by GC)

- Precision (Pooled s) is less precise than prior period
  - Less precise than target precision
  - Primarily due to results from two rigs at one lab (D5 & D6). Precision is comparable to target with suspect rig results excluded.

- Performance (Mean Δ/s) is -0.81 s mild.
  - -0.43 s mild excluding two very mild results from lab D

- CUSUM severity plot shows a mild trend developing last period, with a sharp increase (mild) this period.
  - Five of seven labs performing mild to some extent.

B0.07 Bench Testing Executive Summary

- D5800 (Volatility by Noack)

- Precision (Pooled s) is less precise than the updated target precision (in natural log transformed units).
  - But more precise than prior two periods since application of transformed units
  - Procedure B rigs are less precise, Procedure D rigs are more precise than target

- Performance (Mean Δ/s) is 0.53 s severe.
  - Procedure B rigs are trending 0.77 s severe while Procedure D rigs are trending −0.15 s mild.

- CUSUM severity plots shows a continuing overall severe trend with reference testing, completely attributable (this period) to procedure B tests. Procedure D tests are, overall, only slightly mild for the period.

B0.07 Bench Testing Executive Summary

- D5133 (Gelation Index)
  - GI was formally added to the LTMS effective October 1, 2020 (coincident with the start of this report period).
    - Test monitoring changed from a bath-based calibration scheme to a head-based calibration (where 'stand' was redefined from bath to the head/rotor/stator combinations).
    - Low/non-gelling oil 58 was reclassified as a mild performing discrimination oil with only a maximum performance limit.
    - Stand calibration period changed from 60 days to 180 days, with a coinciding discrimination run required with every other calibration.
    - GI Report Packet Revision Version 20200807 became effective October 1, 2020 to accommodate these significant test monitoring changes.

B0.07 Bench Testing Executive Summary

- D5133 (Gelation Index)
- Fail rate of operationally valid tests is 18% this period
  - Fail rate of (new) discrimination runs reported as operationally valid was also 18%
  - Fail rate is comparable to last period (17%).
  - Historic period fail rates have ranged between 6% and 26%
- Precision (Pooled s) is much less precise than last period
  - Much less precise than updated target precision
  - Target precision is updated to current reference oils GIA17 and 1009 only
    - Oil 62 excluded from updated target precision as nearly depleted (n=9 this period)
    - Oil 58 also excluded as imprecise (low to non-gelling oil), now a discrimination oil only with no target mean or precision)
- Performance (Mean Δ/s) is -0.86 s mild
  - Eight of nine reporting labs performing overall mild
  - Lab B is the only lab performing on target (n=11)
    - All Lab B results reported as operationally valid passed calibration
- A round robin is underway to evaluate a calibration oil that performs closer to the GF-5/6 pass/fail limit of 12 GI
  - To replace oil 58 that was reclassified as a discrimination oil

B0.07 Bench Testing Executive Summary

D6335 (TEOST-33C)

- Precision (Pooled s) is improved over the prior period (also highly imprecise), but remains imprecise compared to other periods.
  - Much less precise than target precision
  - Target precision updated this period to current reference oils 75-1 and 435-2 (oil 75 removed from target precision calculation)
    - Only two tests this period were oil 75; oil is nearly depleted
- Performance (Mean Δ/s) is unusually severe this period (0.42 s)
- Period fail rate of 23% on test reported as operationally valid
  - Fail rates continue to be high.
  - Compared to 39% fail rate last period, 0% two periods back, but 20% and 23% before that, and similarly high in prior periods
- All tests this period report using Rod Batch M or N.

B0.07 Bench Testing Executive Summary

- D7097 (MHT-4 TEOST)

- Precision (Pooled s) is significantly less precise than prior report periods
  - Less precise than target precision
- Performance (Mean Δ/s) is 0.17 s severe
- All operationally valid tests this period report using Rod Batch M
- All operationally valid calibration tests this period report using Catalyst Batch 18AB (n=3) or 19BA (n=101)
  - Lab P continues to report using prior catalyst batch 18AB
- Overall severity on catalyst batch 19BA (n=217) appears to be on-target, and on target for both reference oils.

B0.07 Bench Testing Executive Summary

- D6082 (High Temperature Foam)
- Foam Tendency Precision (Pooled s) is more precise than the prior report period
  - More precise than updated target precision
  - Target precision updated this period to current reference oil FOAMB18 only (oil 1007 removed from target precision calculation, replaced by oil FOAMB18)
    - Only one test this period was oil 1007; oil is nearly used up
- Performance (Mean Δ/s) is -0.48 s mild
  - Replacement reference oil FOAMB18 performing at -0.55 s mild (n=11)
  - Fourth consecutive period of mild performance on FOAMB18.
    - Target performance, set on 18 runs in a RR, may need revisited.
- No non-zero occurrences of Foam Stability
- All five severe oil discrimination runs (on TMC oil 66) demonstrated acceptable discrimination.

B0.07 Bench Testing Executive Summary

- D874 (Sulfated Ash)
- Precision (Pooled s) is more precise than prior periods
  - More precise than target precision
- Performance (Mean Δ/s) is -0.35 s mild

B0.07 Bench Testing Executive Summary

- D7528 (ROBO)
- Precision (Pooled s) is less precise than last period
  - Less precise than all periods since at least April 2018
  - Continues to be less precise than target
  - Target precision update to include primary period reference oils 434-2, 434-3, 435-1 and 438-2
- Performance (Mean Δ/s) is -0.11 s mild for this report period
- CUSUM severity plot shows variable performance the past three report period

D02.B0.07
TMC Monitored Tests

- October 1, 2020 –
  March 31, 2021

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D6417: Estimation of Engine Oil Volatility by Capillary GC

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	19
Failed Calibration Test	OC	2
Operationally Invalidated by Lab	LC, XC	0
Operationally Invalidated After Initially Reported as Valid	RC	0
Total		**21**

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

D6417: Estimation of Engine Oil Volatility by Capillary GC

Statistically Unacceptable Tests (OC)	No. Of Tests
Volatility Loss Mild	2
Volatility Loss Severe	0

- One mild result, -3.8 s mild, was on rig (D5). That same rig had two OC fails last period, a column was changed in between, failed on a two-test calibration this period, followed by a passing two-test calibration. The other mild failing result this period, -5 s mild, was by the same lab, separate column (rig D6).

- There were no operationally invalid tests reported this period

- No D6417 TMC technical updates were issued this report period.

- D6417 calibration requirement updates are issued as LTMS document updates

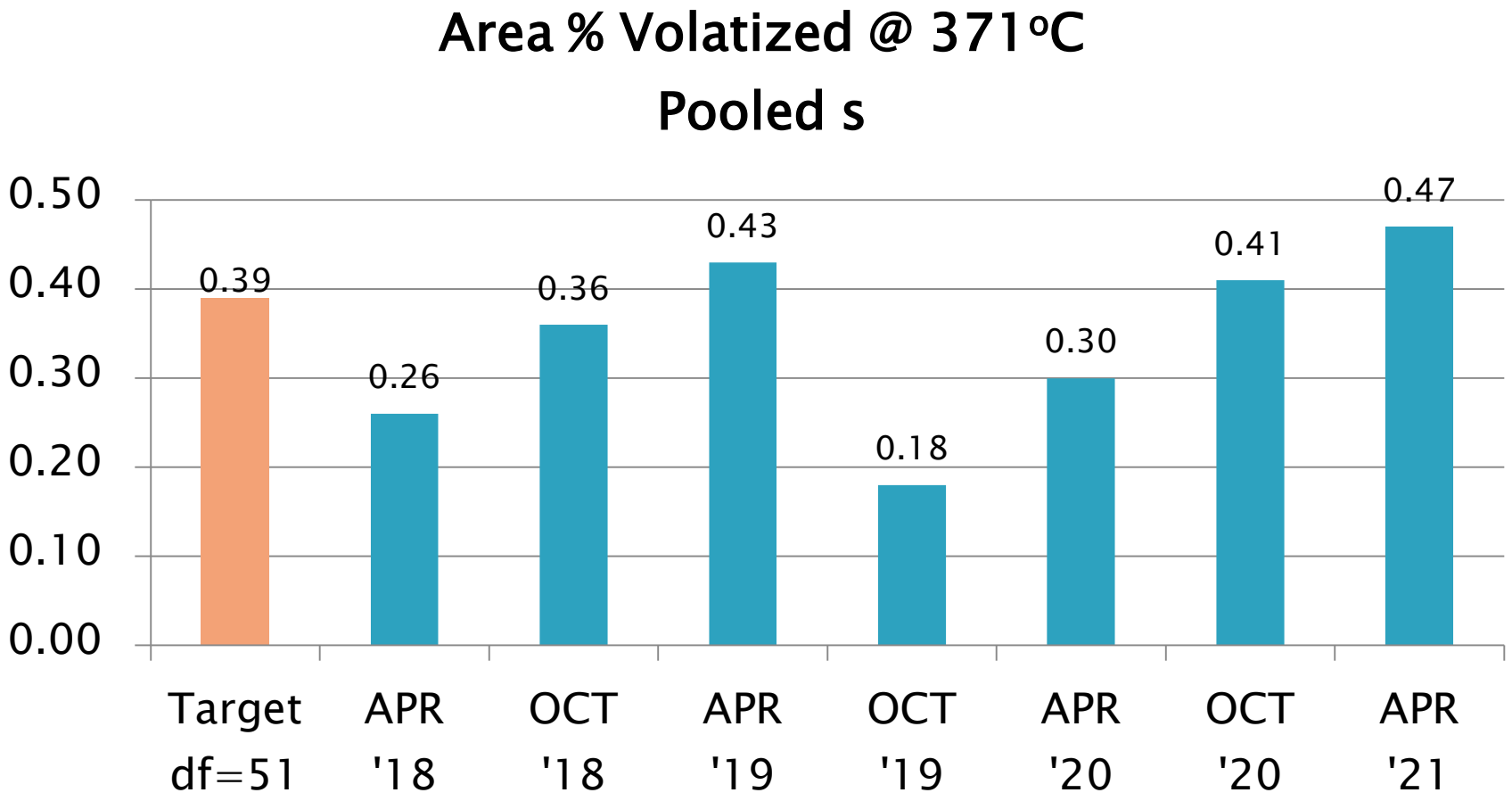
D6417: Estimation of Engine Oil Volatility by Capillary GC

Period Precision and Severity Estimates

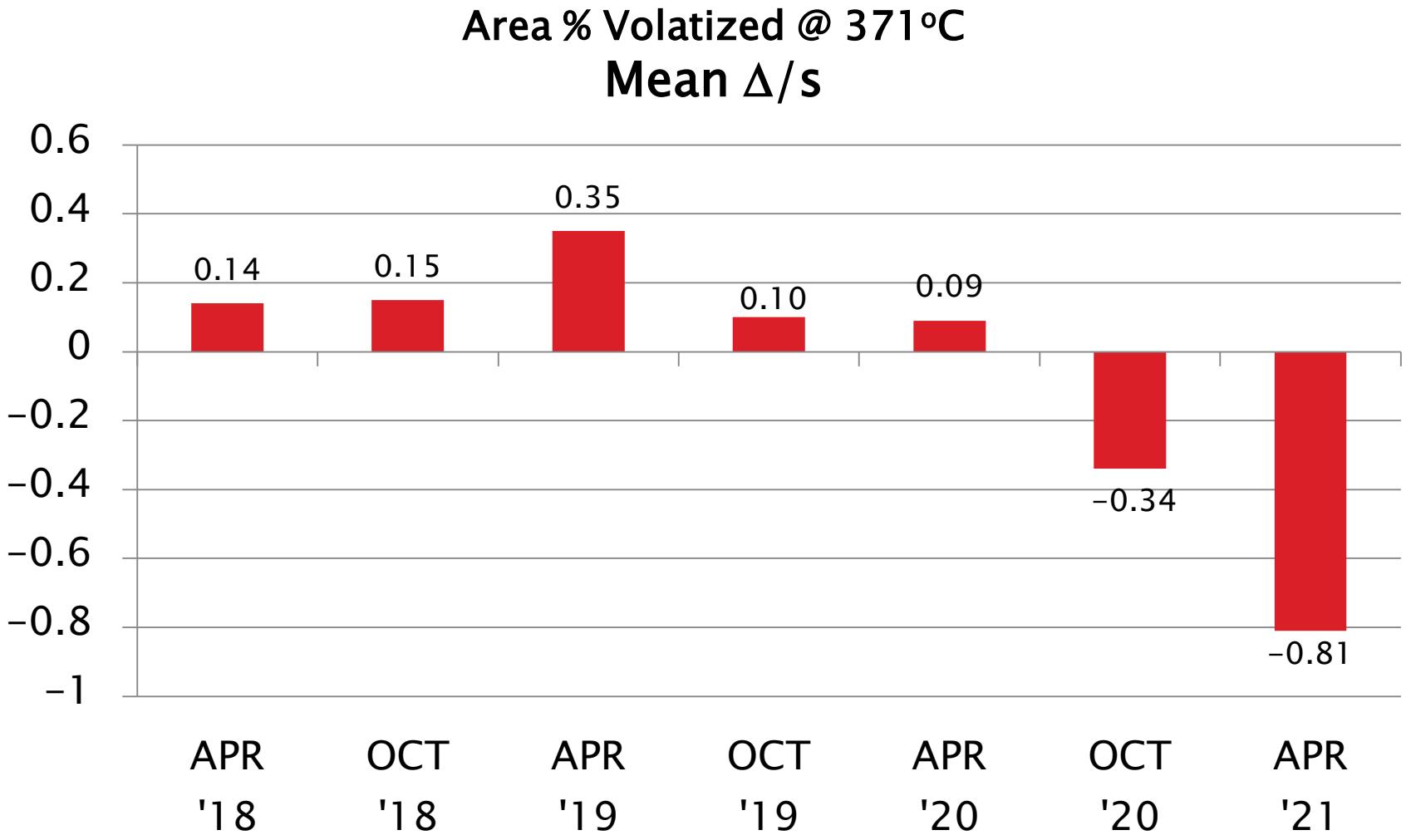
Area % Volatized @ 371°C	n	df	Pooled s	Mean Δ/s
Initial Selected Oils from RR	54	51	0.39	-----
4/1/18 through 9/30/18	16	13	0.36	0.15
10/1/18 through 3/31/19	19	16	0.43	0.35
4/1/19 through 9/30/19	19	16	0.18	0.10
10/1/19 through 3/31/20	17	14	0.30	0.09
4/1/20 through 9/30/20*	16	13	0.41	-0.34
4/1/20 through 9/30/20*	14	11	0.31	0.01
10/1/20 through 3/31/21*	21	18	0.47	-0.81
10/1/20 through 3/31/21*	19	16	0.37	-0.43

*Period statistics with two mild results from rigs D5/D6 included and excluded (operational problem suspected but lab never confirmed)

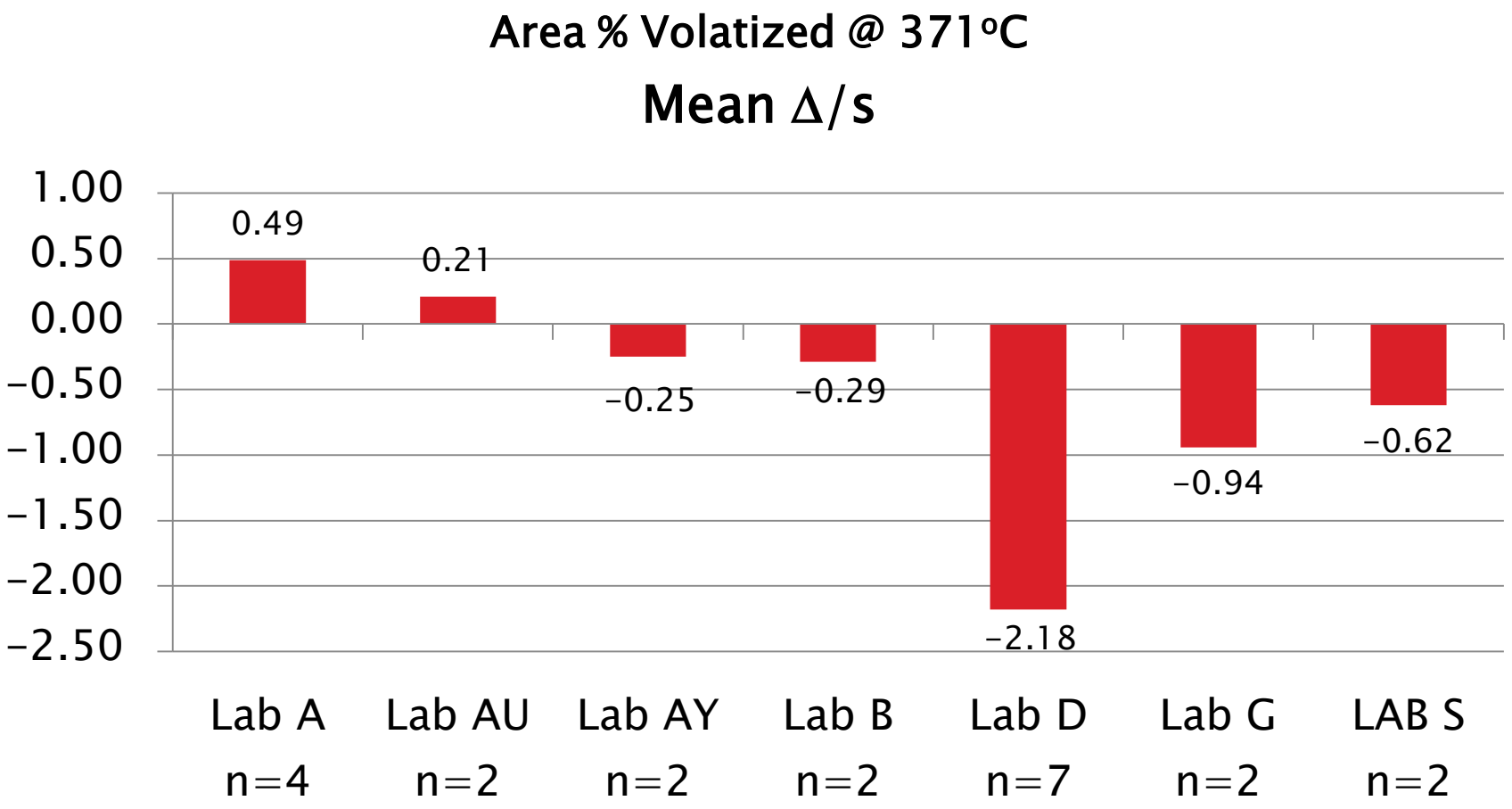
D6417 Precision Estimates



D6417 Severity Estimates



D6417 Lab Severity Estimates



D6417: Estimation of Engine Oil Volatility by Capillary GC

- Precision (Pooled s) is less precise than prior period
  - Less precise than target precision
  - Primarily due to results from two rigs at one lab (D5 & D6). Precision is comparable to target with suspect rig results excluded.

- Performance (Mean Δ/s) is -0.81 s mild.
  - -0.43 s mild excluding two very mild results from lab D

- CUSUM severity plot shows a mild trend developing last period, with a sharp increase (mild) this period.
  - Five of seven labs performing mild to some extent.

D6417 VOLATILITY BY GC INDUSTRY OPERATIONALLY VALID DATA

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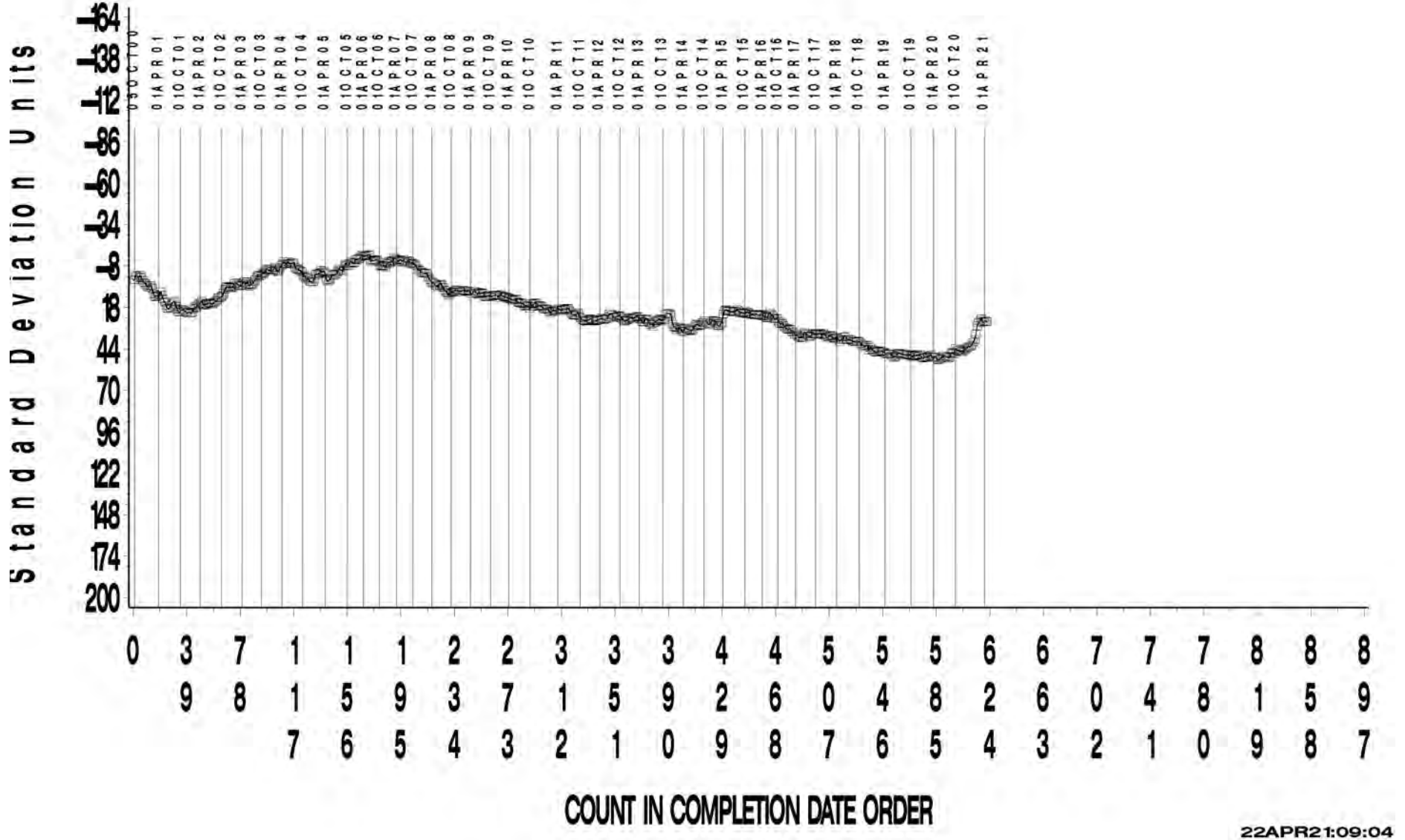
SAMPLE AREA % VOLATIZED

CUSUM Severity Analysis



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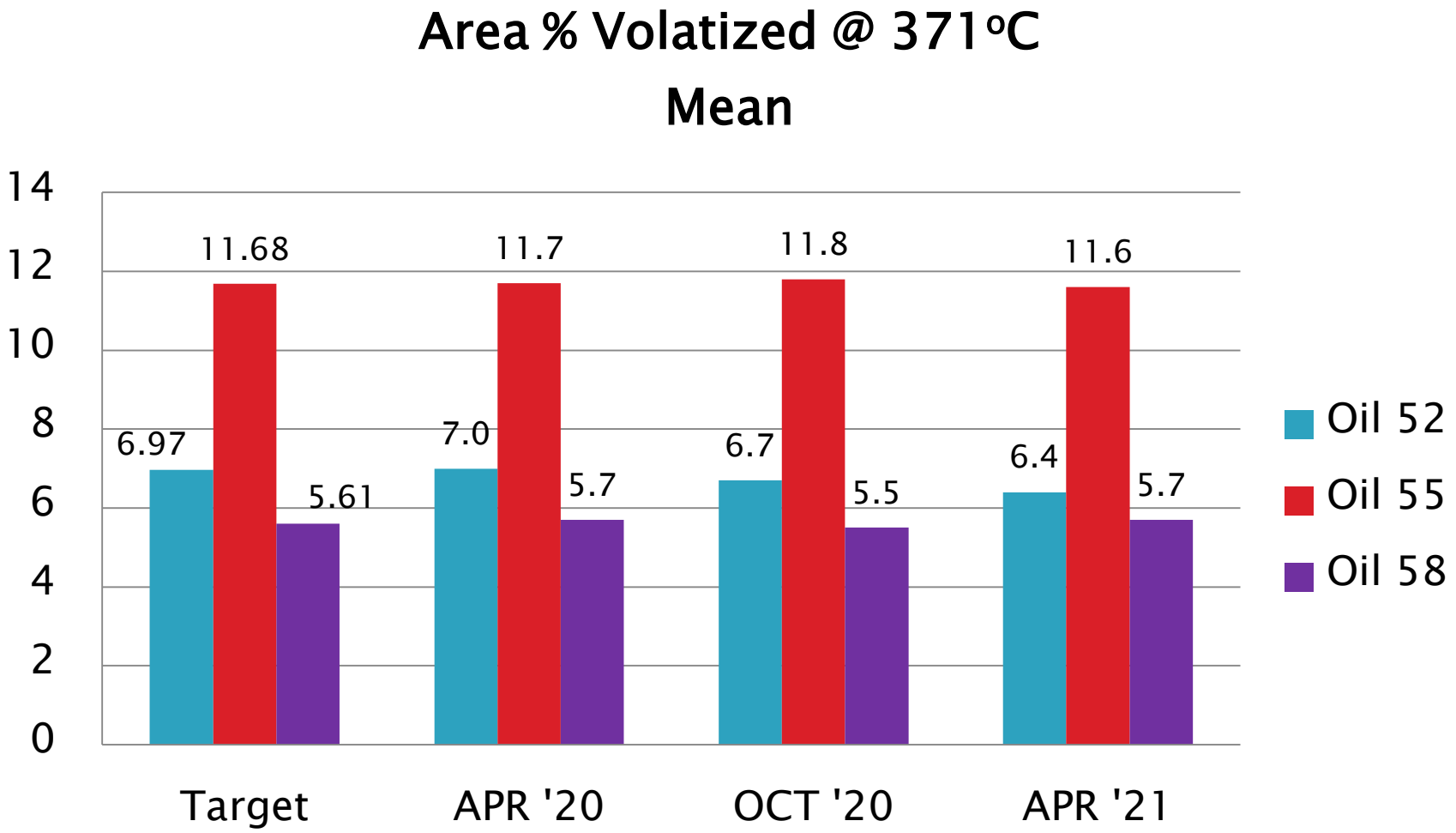
D6417 Performance by Oil



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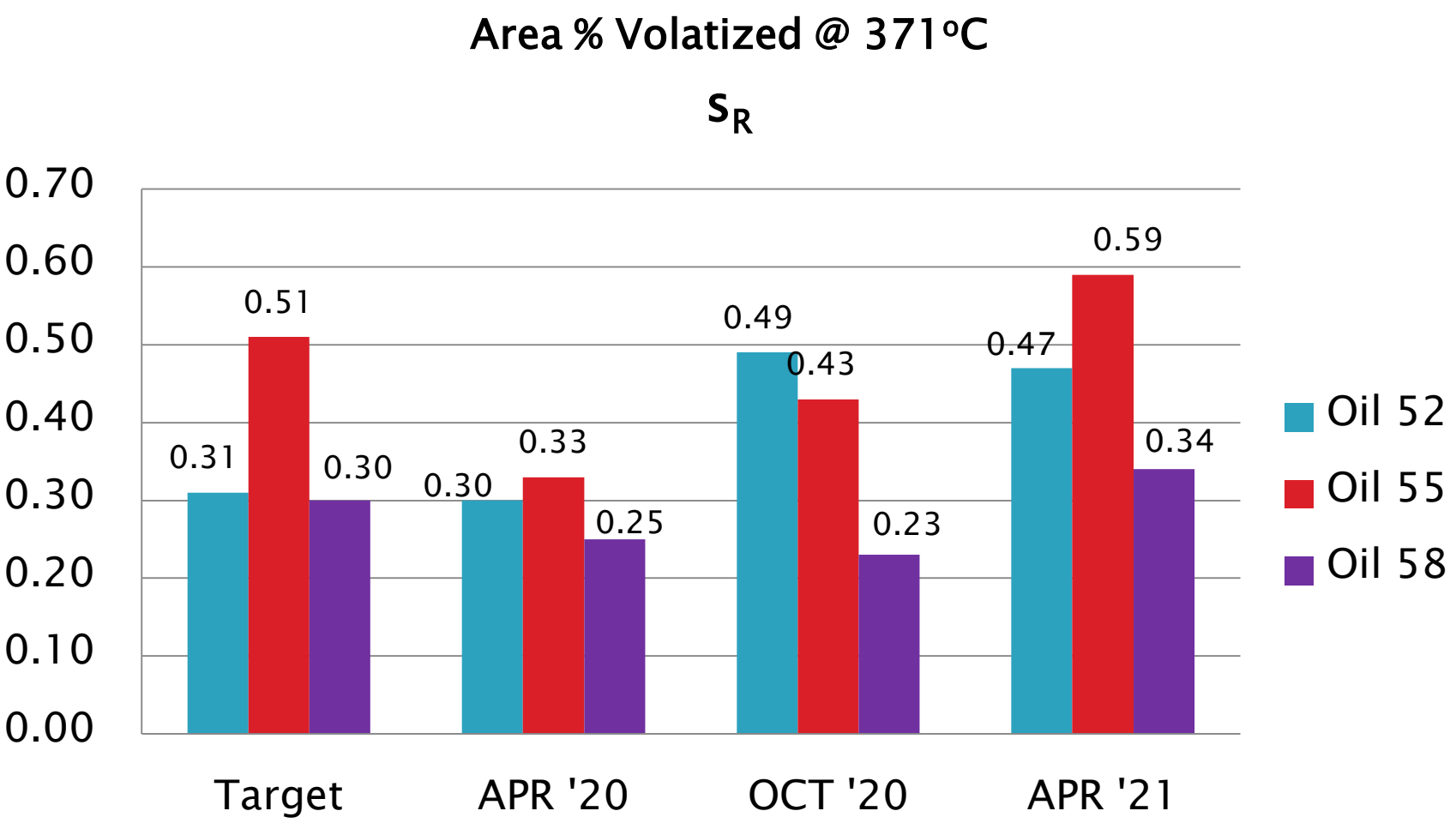
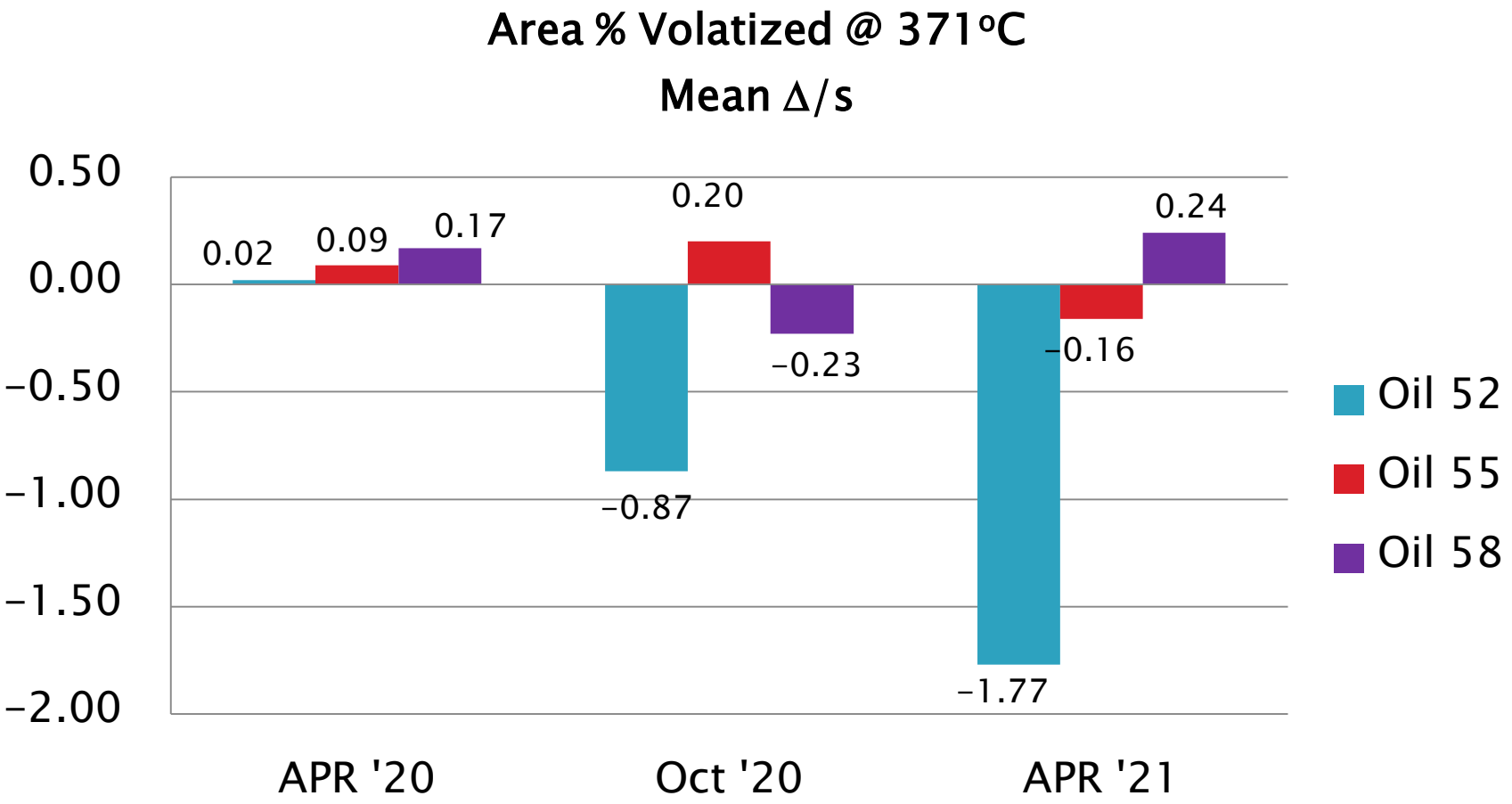
D6417 Performance by Oil



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	131
Failed Calibration Test	OC	9
Operationally Invalidated by Lab	LC, XC	2
Operationally Invalidated After Initially Reported as Valid	RC	1
Total		**143**

Number of Labs Reporting Data: 11
Fail Rate of Operationally Valid Tests: 6%

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	1
Zi Level 2 Severity Alarm Severe	7
Zi Level 2 Severity Alarm Mild	0

- The 9 OC tests were on five different rigs at four labs.
  - Four on rig G6, two on rig J7.
  - One test (rig G6) triggered both Ei L3 and Zi L2 alarms (both severe)

- Rig G6 had two consecutive Zi L2 (severe) alarms before alarm cleared on the third attempt, repeated later in the report period (four OC fails total on the rig for the period).
  - Same lab had a similar severe failing pattern on rig G8 last period and into this period.

- Two tests exceed ±3 s this period (+3.8 s rig G6 and +3.3 s rig J7)

D5800: Evaporation Loss of Lubricating Oil by Noack Method

- Three operationally invalid calibration runs were reported this period:
  - Vacuum leak discovered post-test after being informed of failing calibration (RC)
  - One test invalidated by lab due to failing QC result (LC)
  - One test where the test sample was spilled (XC)

- No D5800 technical memos were issued by the TMC this period.

- D5800 calibration requirement updates are issued as LTMS document updates.

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 02/07/20[1]	78	75	0.0465	-----
4/1/18 through 9/30/18[2]	149	146	0.82	0.40
4/1/18 through 9/30/18[2]	148	145	0.76	0.44
10/1/18 through 3/31/19	151	148	0.81	0.51
4/1/19 through 9/30/19	164	161	0.81	0.65
10/1/19 through 3/31/20[1]	146	143	0.0503	0.54
4/1/20 through 9/30/20[1]	136	133	0.0659	0.35
10/1/20 through 3/31/21[1]	140	137	0.0495	0.53

[1]Began monitoring natural log transformed test results on 20200207 making logarithmic scale changes for target and period precision estimates starting April 2020 report period.

[2]Extreme OC result included and excluded

D5800: Evaporation Loss of Lubricating Oil by Noack Method

Performance Comparison by Procedure & Model

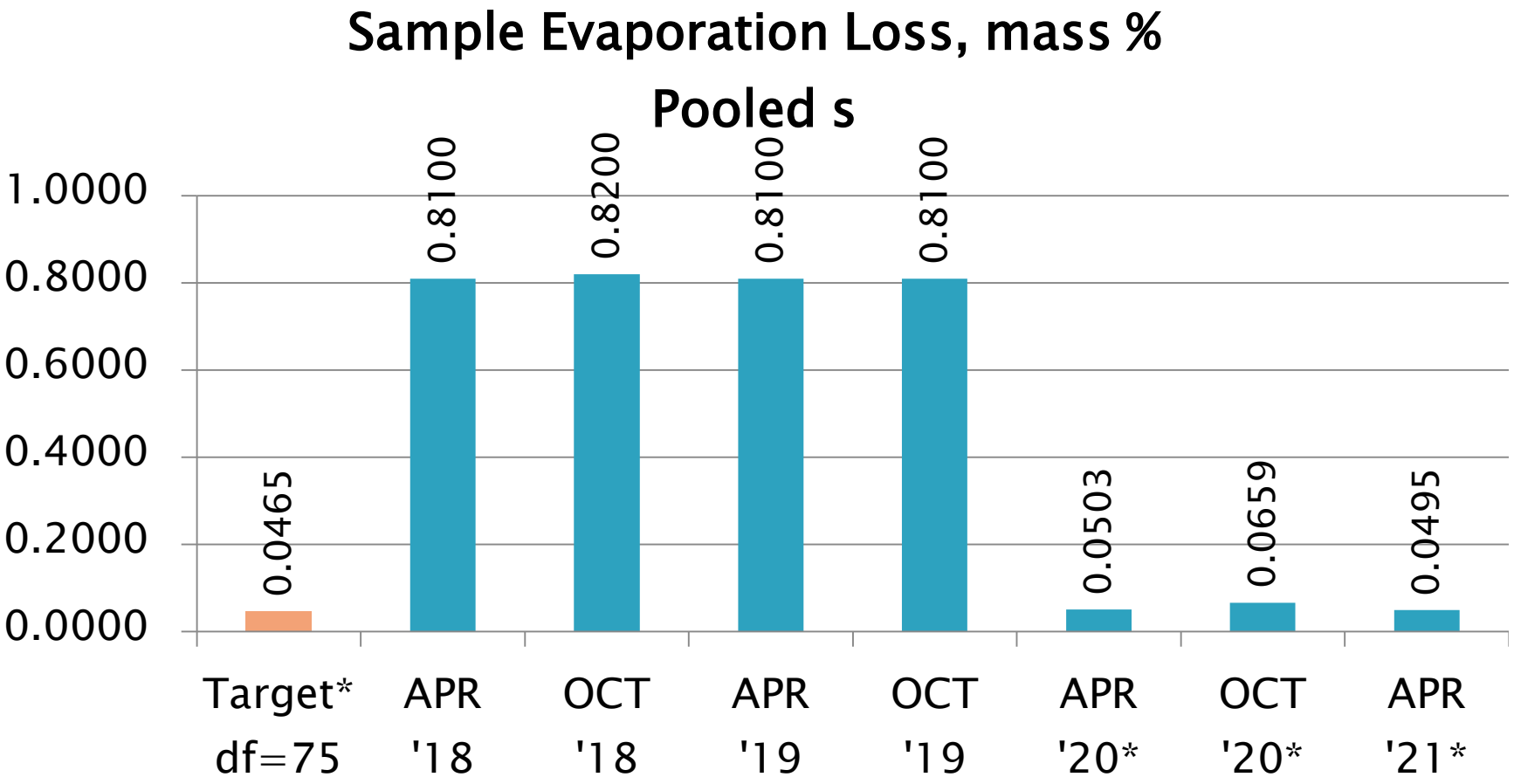
Sample Evaporation Loss, Mass %

Procedure	n	df	Pooled s	Mean Δ/s
Procedure B	104	101	0.0477	0.77
Procedure C	No Procedure C tests reported this period.			
Procedure D	36	33	0.0376	-0.15

Model	n	df	Pooled s	Mean Δ/s
NCK2	6	3	0.0042	0.71
NCK25G	98	95	0.0490	0.77
NS2	36	33	0.0376	-0.15

1 Procedure B NCK2 Rig
19 Procedure B NCK25G Rigs
7 Procedure D NS2 Rigs

D5800 Precision Estimates



*Began monitoring natural log transformed test results on 20200207 making logarithmic scale changes for target and period precision estimates starting April 2020 report period.

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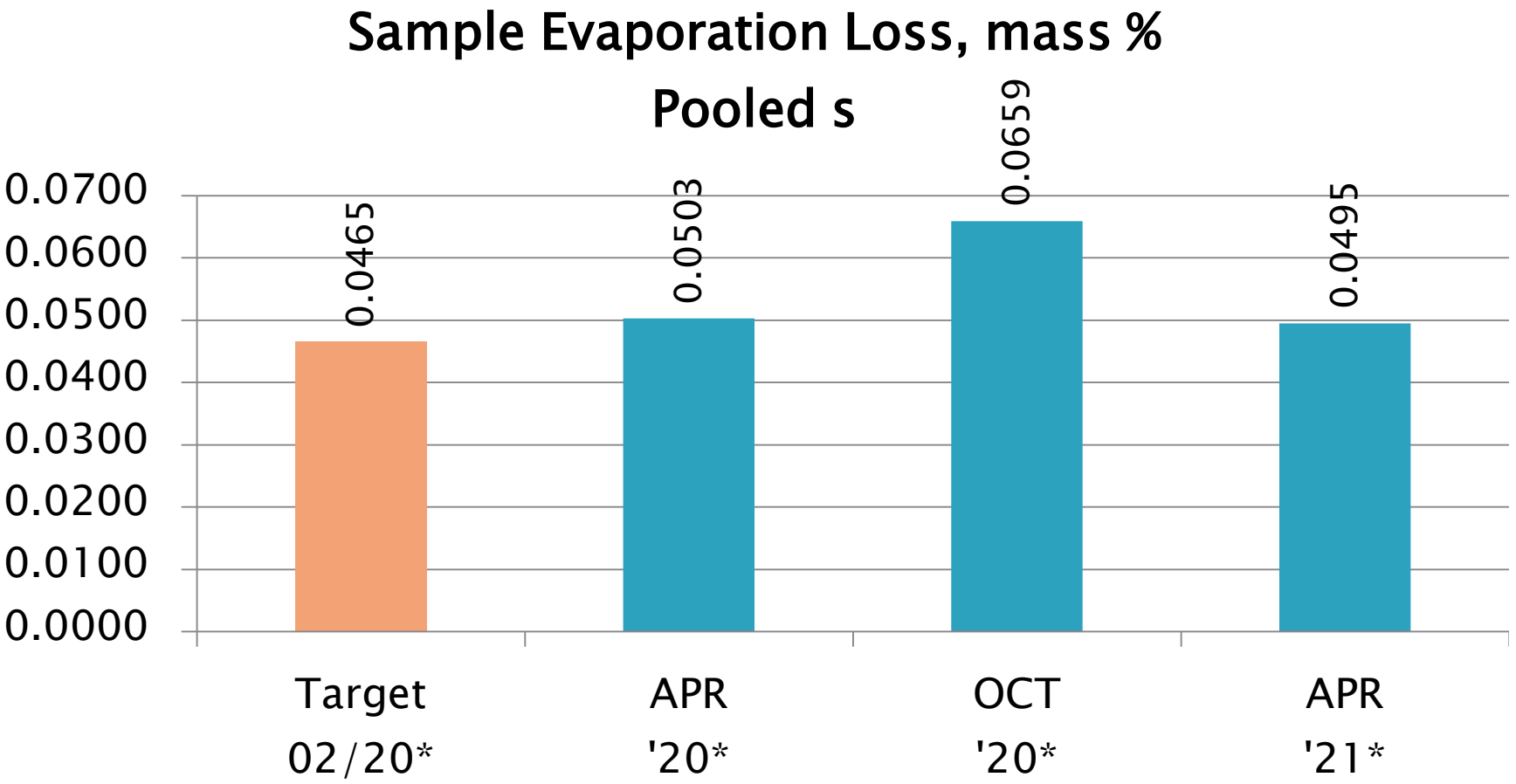
D5800 Precision Estimates



*Began monitoring natural log transformed test results on 20200207 making logarithmic scale changes for target and period precision estimates starting April 2020 report period.

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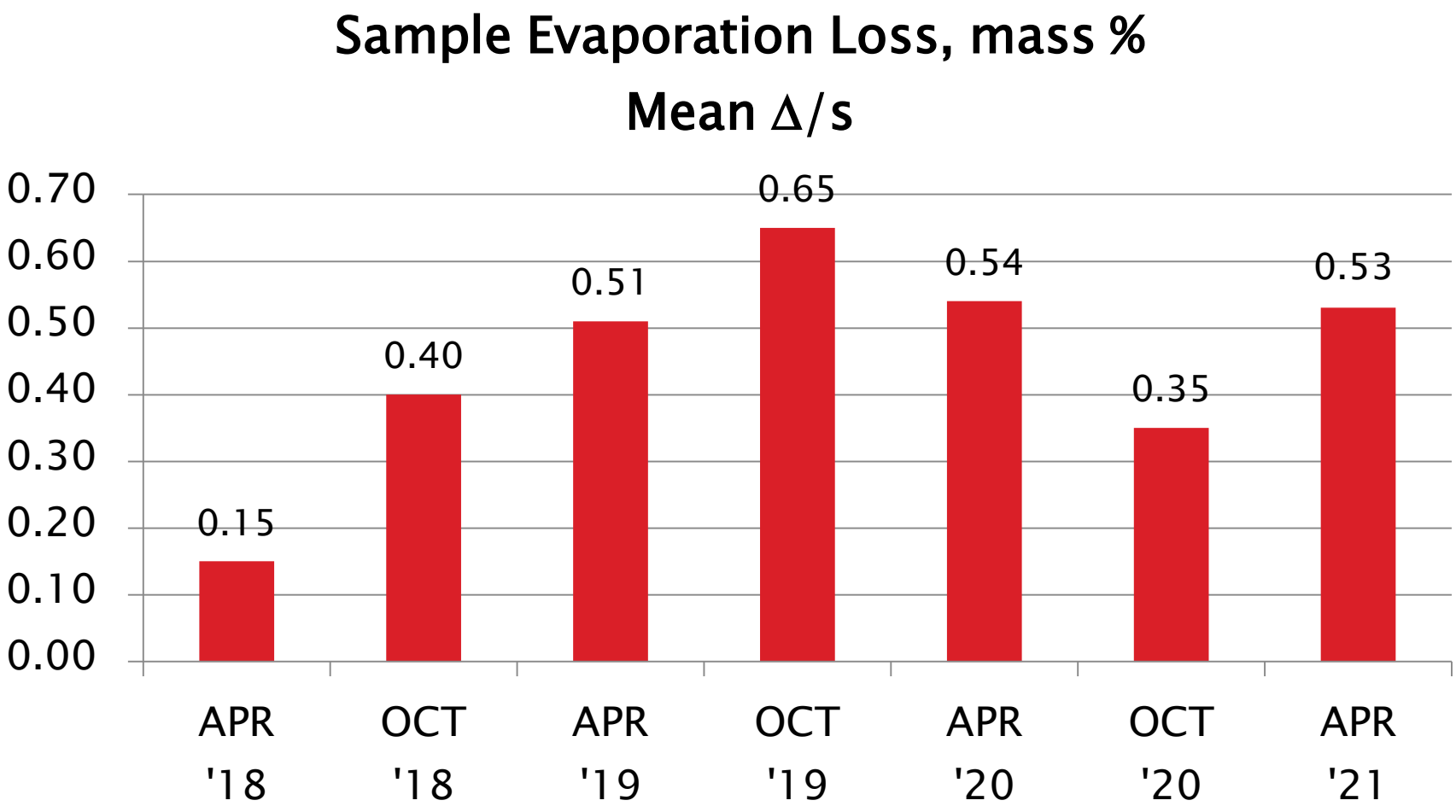
D5800 Severity Estimates



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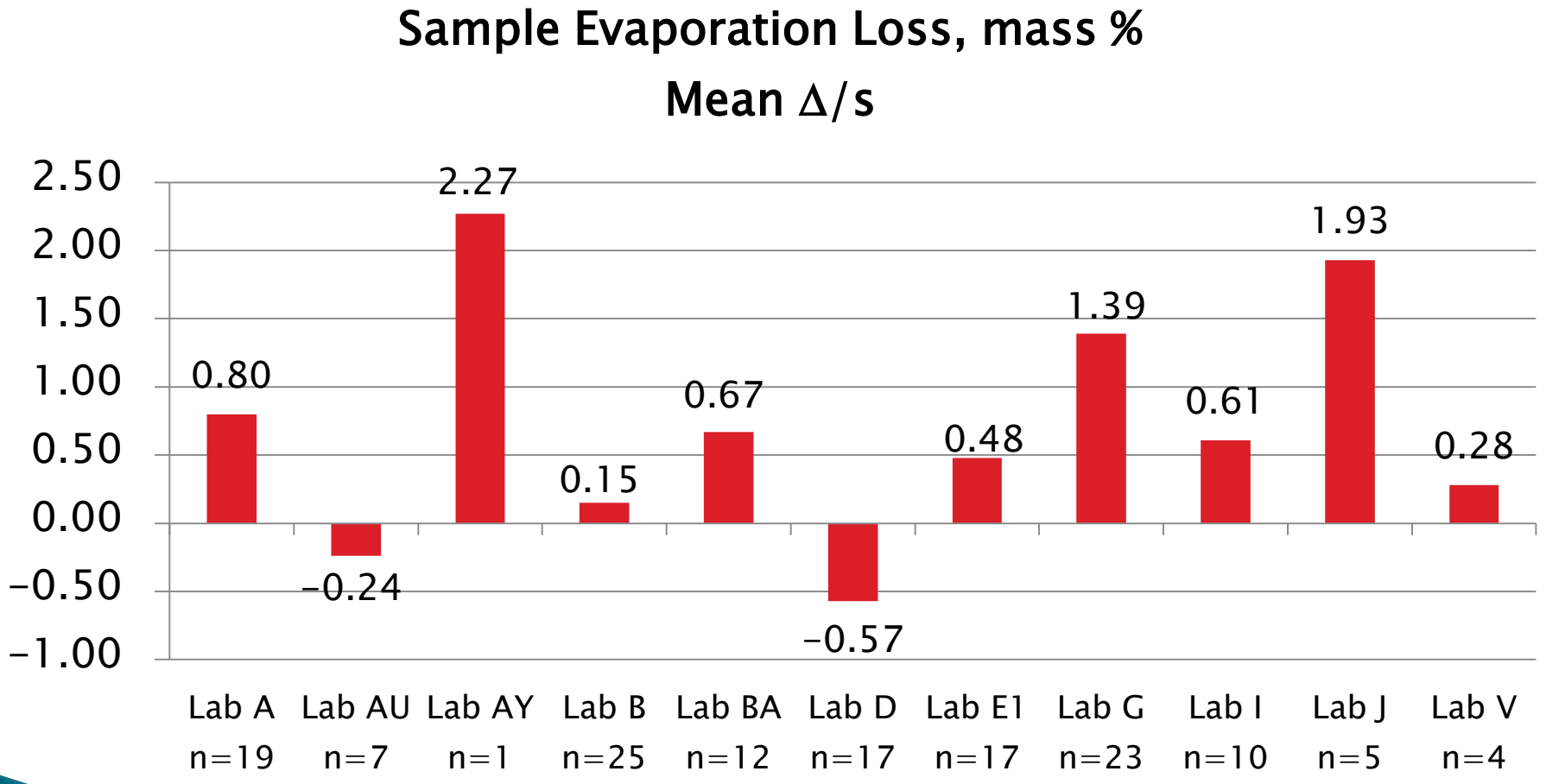
D5800 Lab Severity Estimates



D5800: Evaporation Loss of Lubricating Oil by Noack Method

- Precision (Pooled s) is less precise than the updated target precision (in natural log transformed units).
  - But more precise than prior two periods since application of transformed units
  - Procedure B rigs are less precise, Procedure D rigs are more precise than target
- Performance (Mean Δ/s) is 0.53 s severe.
  - Procedure B rigs are trending 0.77 s severe while Procedure D rigs are trending −0.15 s mild.
- CUSUM severity plots shows a continuing overall severe trend with reference testing, completely attributable (this period) to procedure B tests. Procedure D tests are, overall, only slightly mild for the period.

D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA

EVAPORATION LOSS, MASS%

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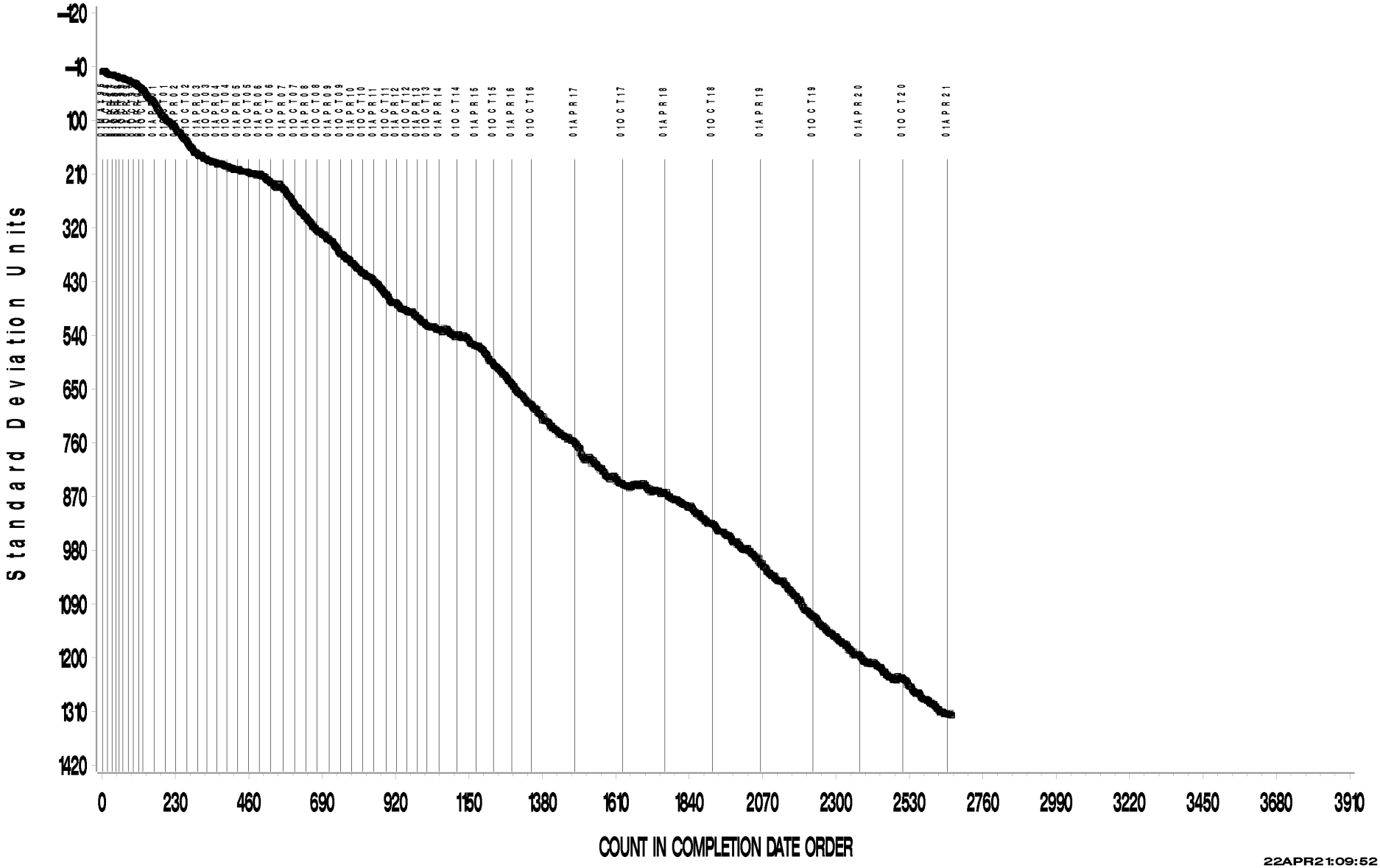
CUSUM Severity Analysis



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D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA

EVAPORATION LOSS, MASS%

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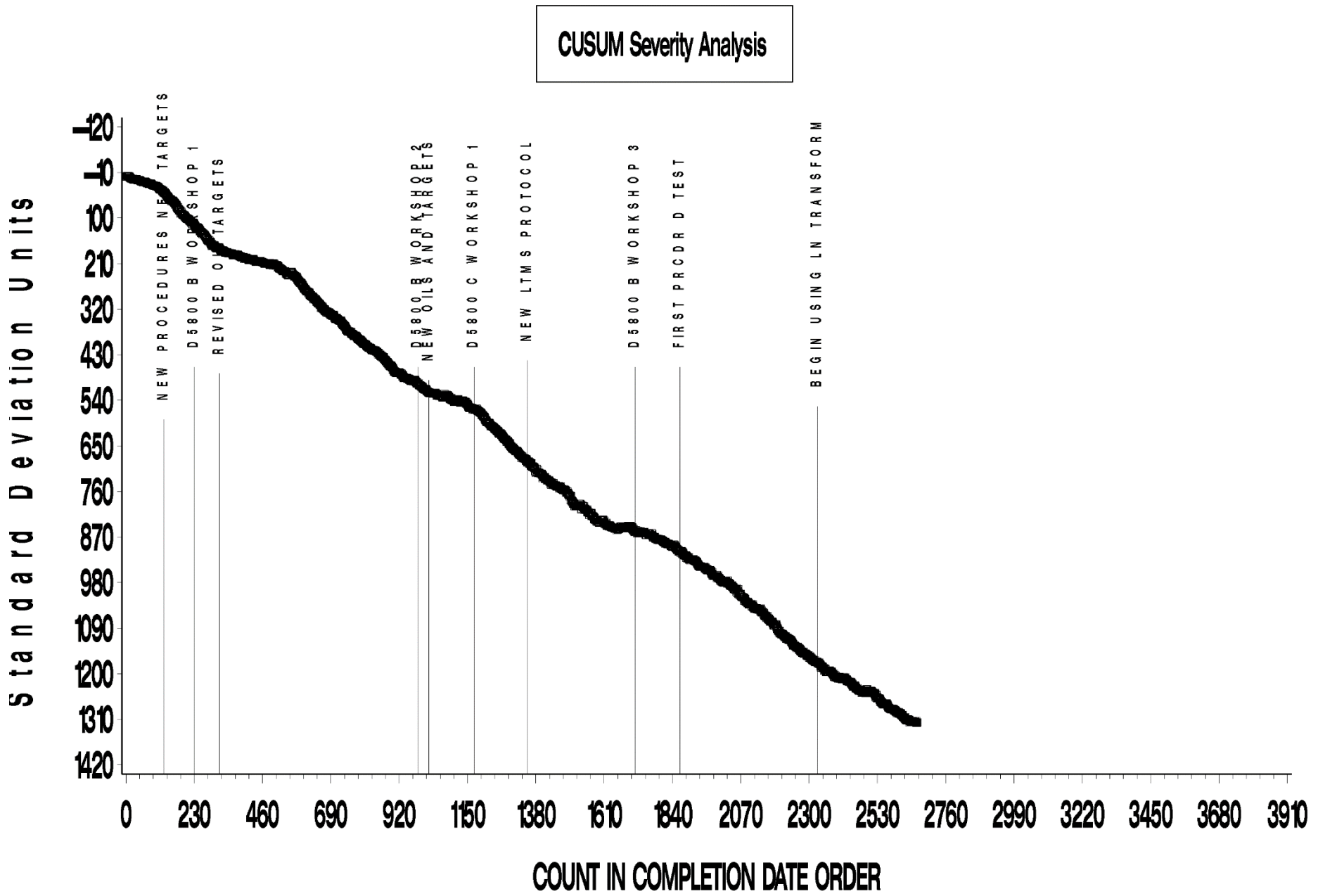

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D5800 VOLATILITY BY NOACK INDUSTRY OPERATIONALLY VALID DATA
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EVAPORATION LOSS, MASS%

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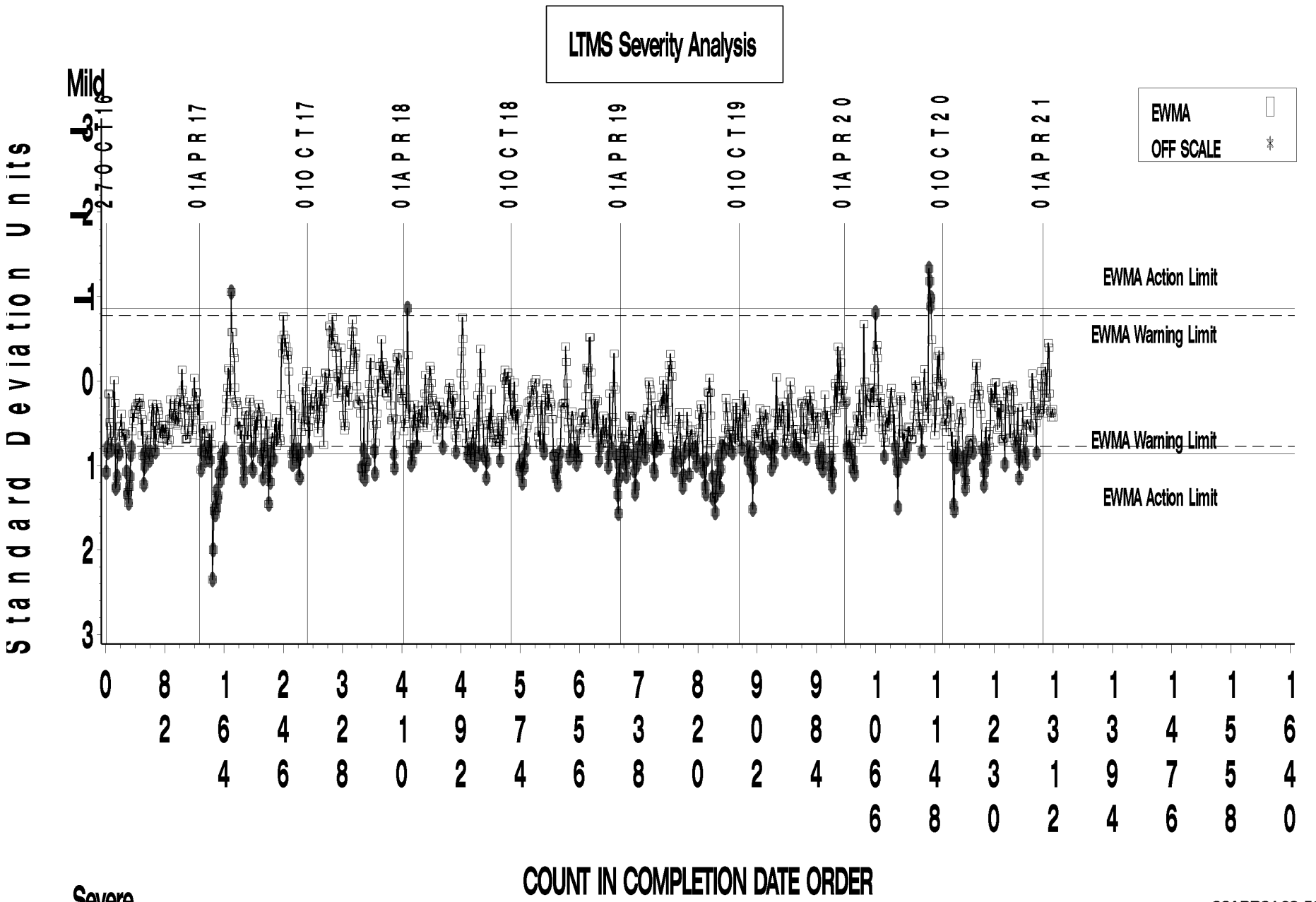

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EVAPORATION LOSS, MASS%

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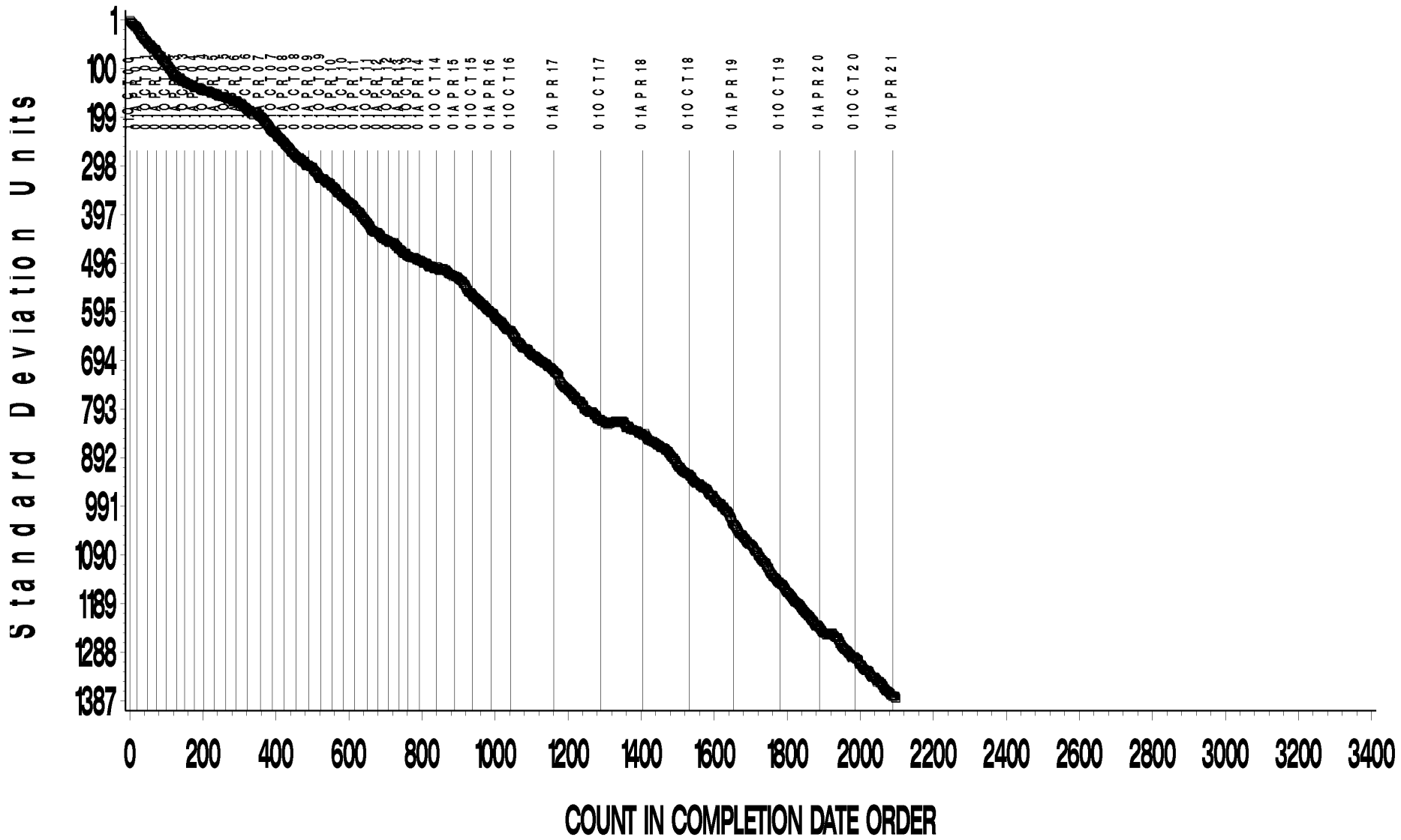
CUSUM Severity Analysis



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

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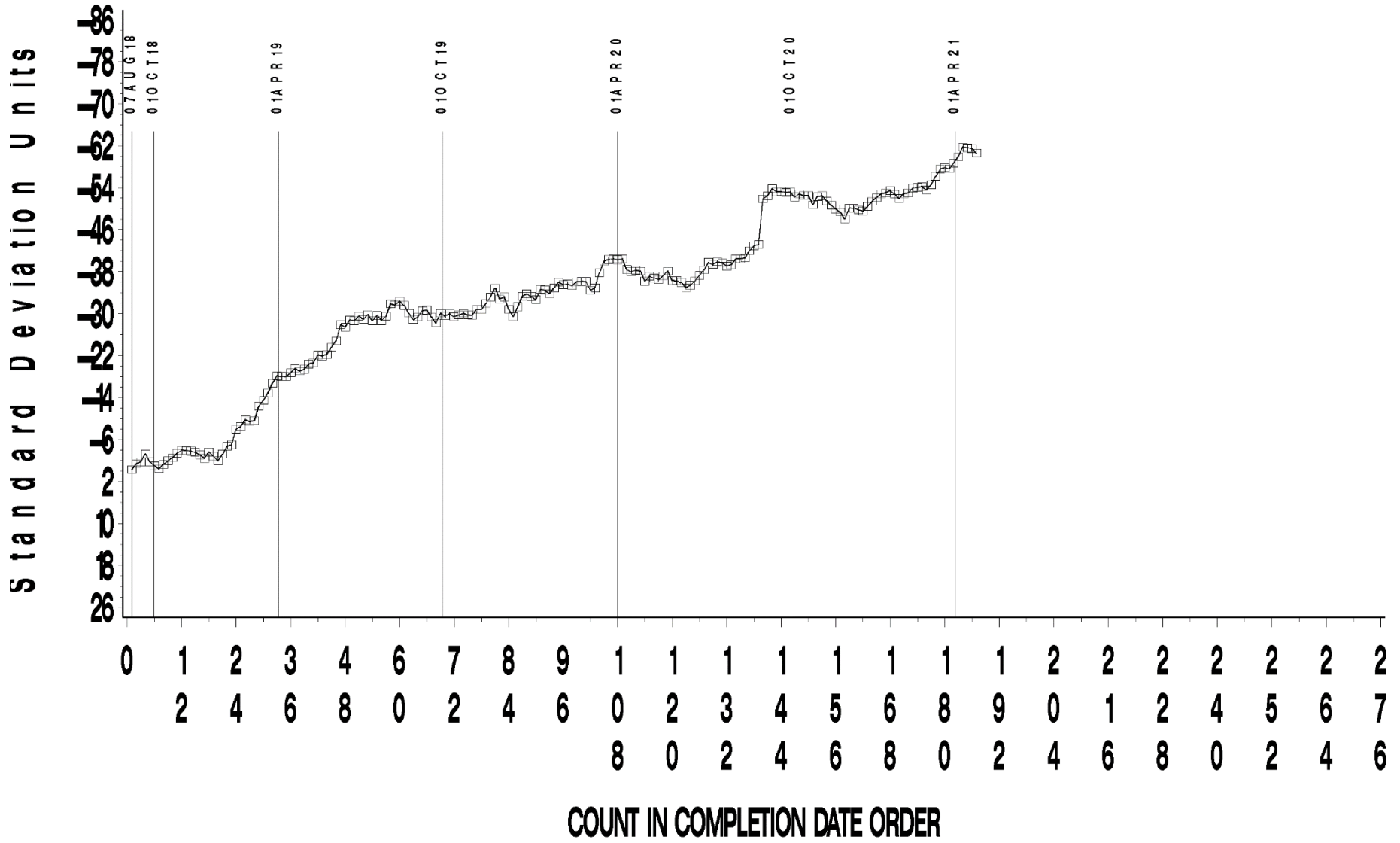
CUSUM Severity Analysis



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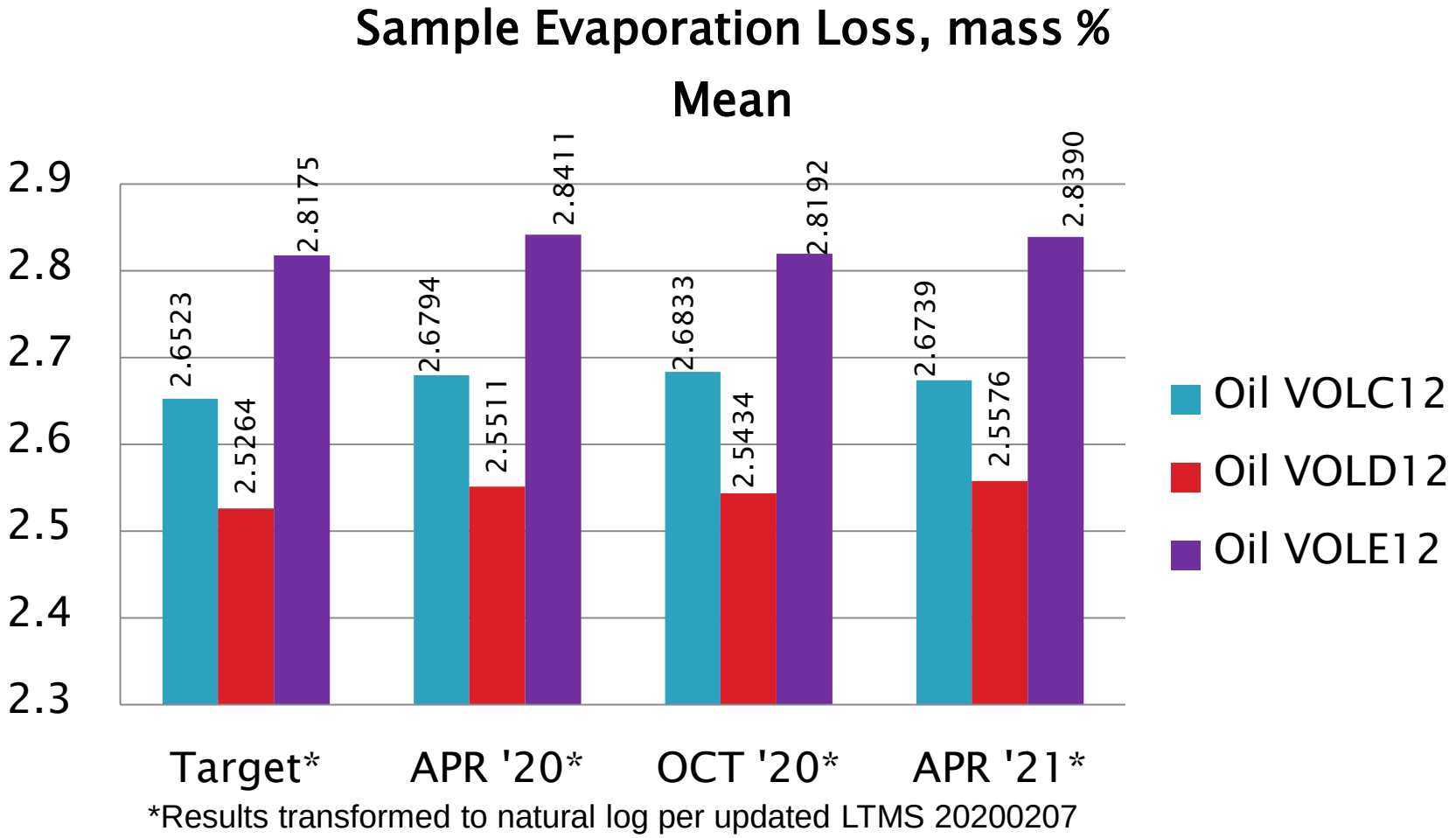
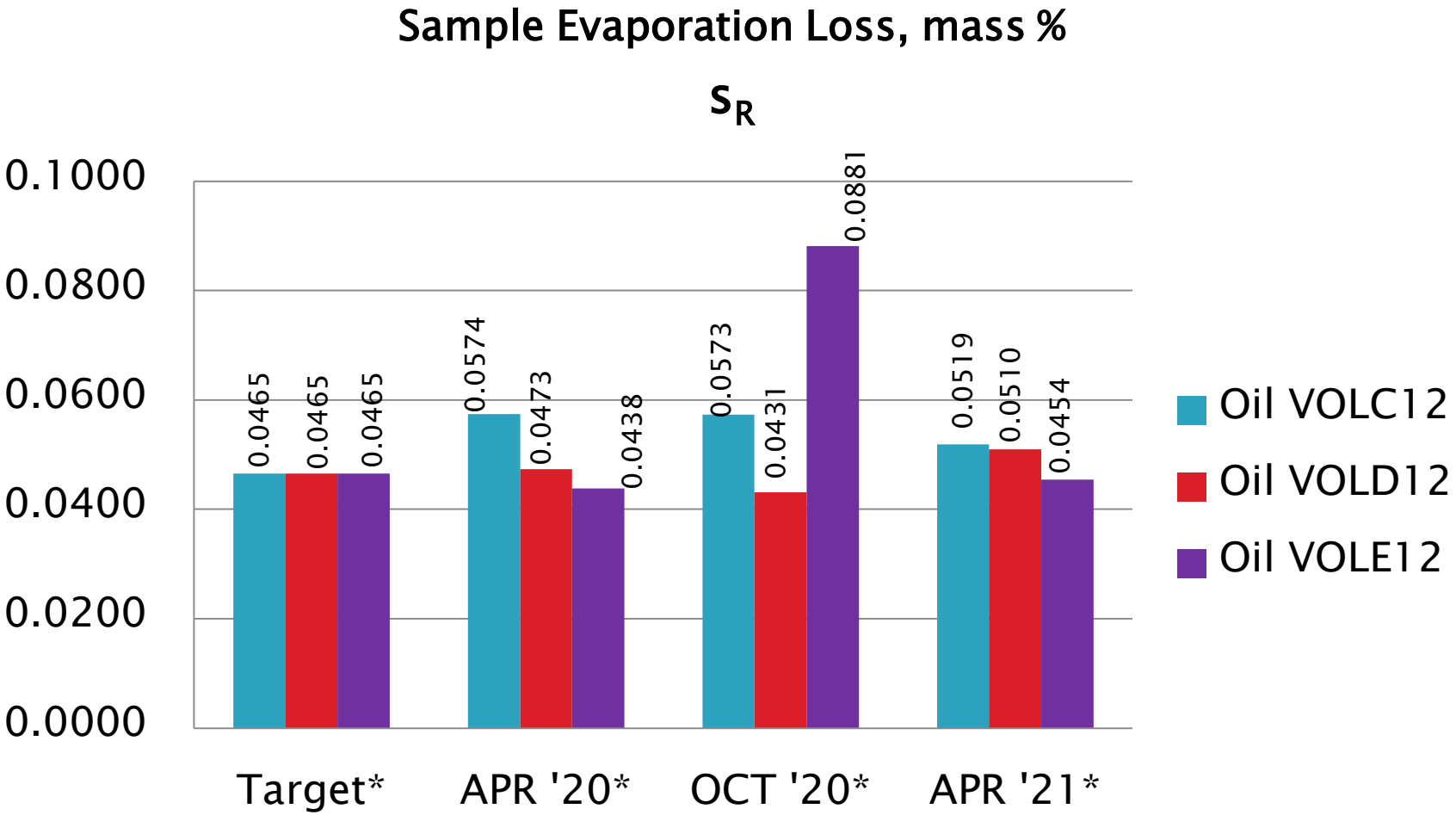
D5800 Performance by Oil



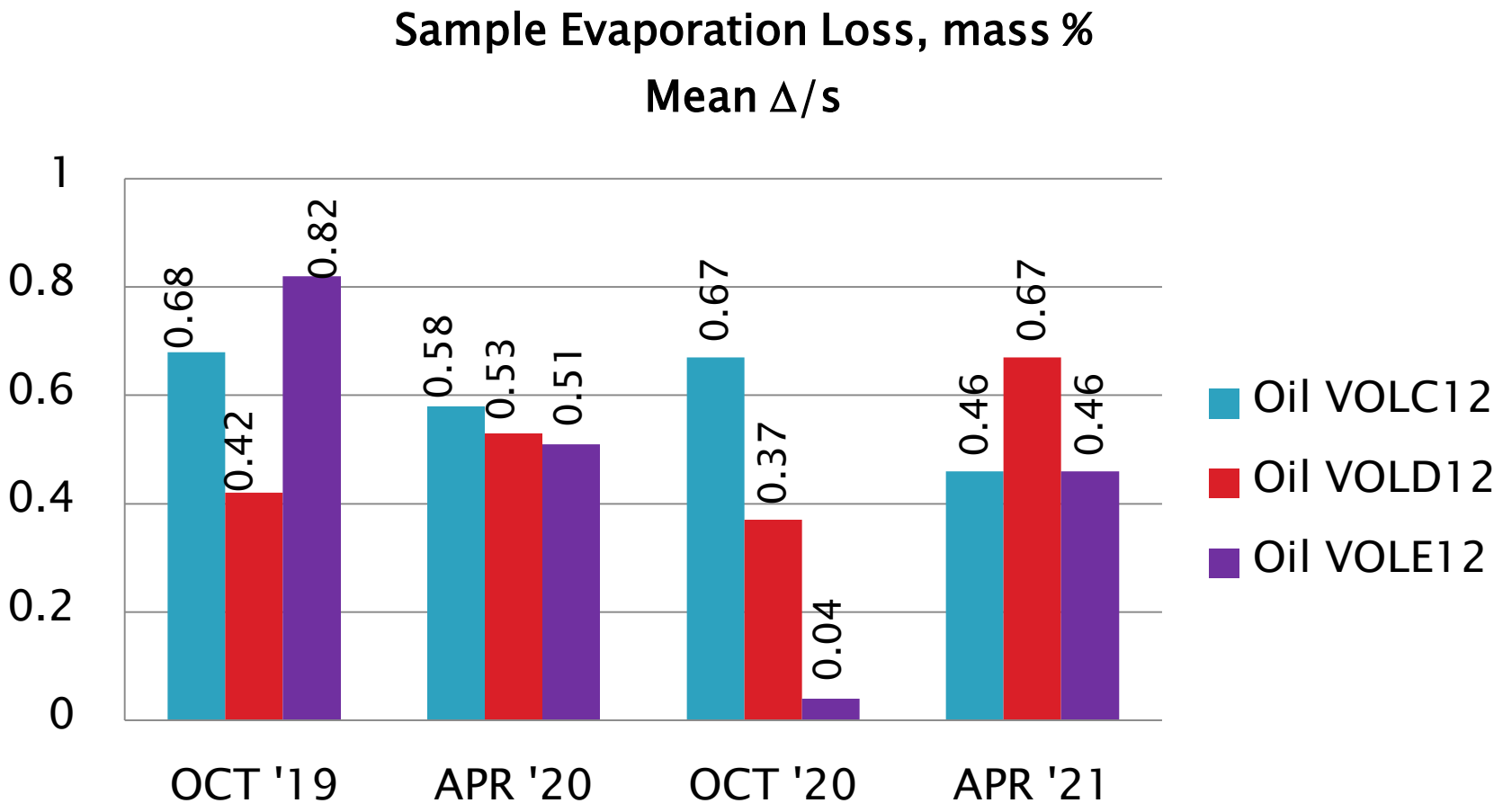
*Results transformed to natural log per updated LTMS 20200207

D5800 Performance by Oil



*Results transformed to natural log per updated LTMS 20200207

D5800 Performance by Oil



Return to Executive Summary

D5133: Gelation Index

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	95
Failed Calibration Test	OC	21
Operationally Invalidated by Lab	LC, LS, XC, XS	29
Operationally Invalidated After Initially Reported as Valid	RC	0
Acceptable Discrimination Tests	AS	72
Failed Discrimination Tests	OS	16
Excluded From Statistics	MC, MS	6
Industry Donated Run	AG	11
Instrument Shakedown	AN, ON	7
Total		**257**

Number of Labs Reporting Data: 9
Fail Rate of Operationally Valid Calibration Tests: 18%
Fail Rate of Operationally Valid Discrimination Tests: 18%

D5133: Gelation Index

Statistically Unacceptable Calibration Tests (OC)	No. Of Tests
Gelation Index Mild	17
Gelation Index Severe	4

- There were also 16 severe failing discrimination runs this period, out of 88 reported as operationally valid.

- Of the 21 OC tests:
  - Four were between ±2-3 s from targets
  - Five were between ±3-4 s from targets
  - Three were between ±4-5 s from targets
  - Five were between ±5-6 s from targets
  - Two were between ±7-8 s from targets
  - One was between ±8-9 s from target
  - One was between ±9-10 s from target

D5133: Gelation Index

Tests Excluded From Statistics (Operationally or Otherwise)	Validity Code	No. Tests
New Stand, Failed to Calibrate Initially	MC, MS	6
Bad Head, Needing Maintenance/Repair	LC, XC, LS, XS	5
Computer or Software Failure	XC, XS	10
Bath Temperature Control Failure	LC, XS	7
Controller Connection Failure	XC	4
Incorrect Baseline Calibration	LC	1
Sample Mix-up, Wrong Stand Charged	LC	2
Stand Shakedown Run	AN, ON	7
Industry Donated Run (GIC18 RR)	AG	11
Total		**53**

D5133: Gelation Index

Period Precision and Severity Estimates

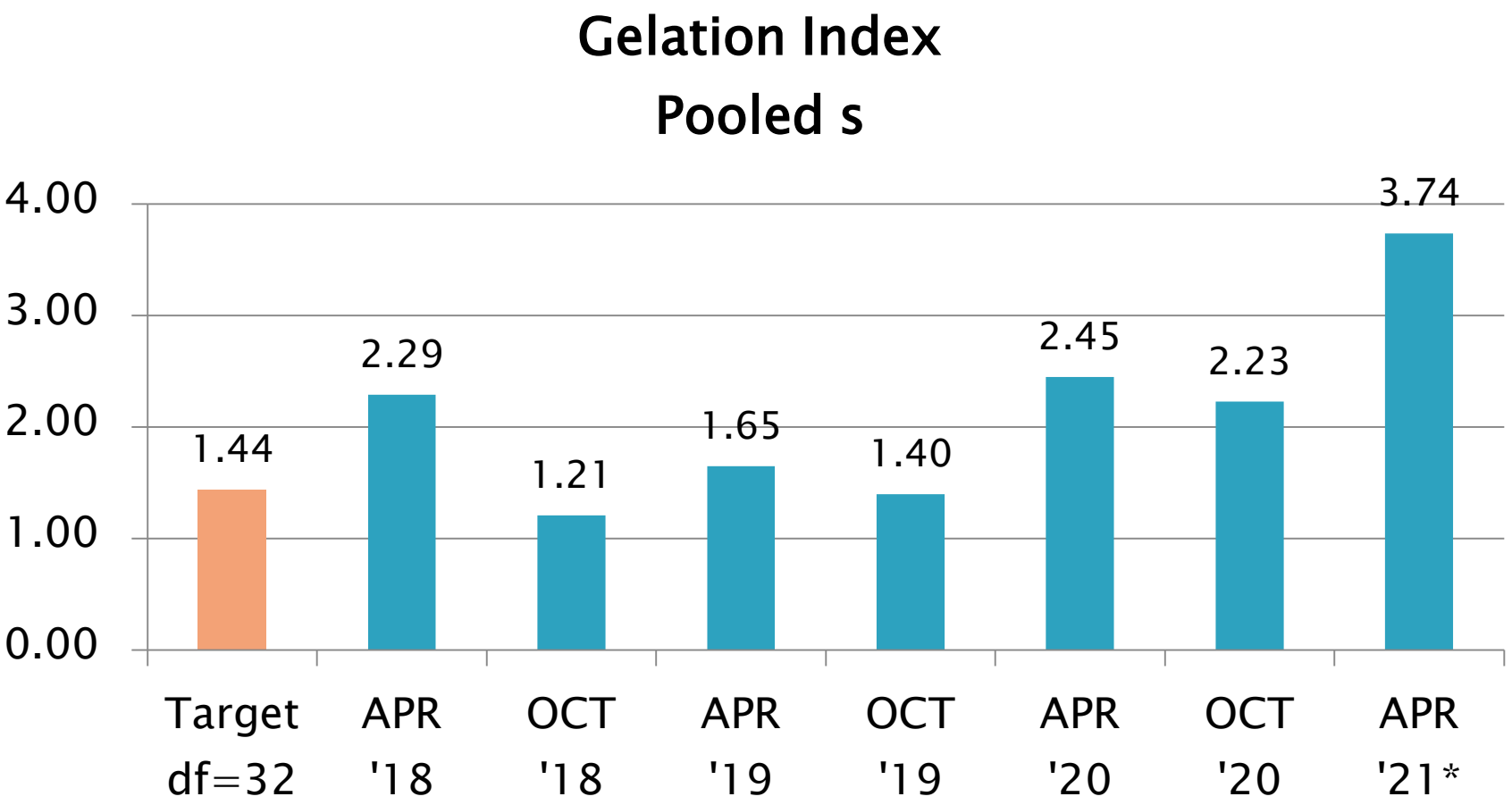
Gelation Index	n	df	Pooled s	Mean Δ/s
Targets Updated 20201001[1]	34	32	1.44	-----
10/1/17 through 3/31/18	36	33	2.29	0.16
4/1/18 through 9/30/18[2] 4/1/18 through 9/30/18[2]	32 31	29 28	1.21 1.03	0.15 -0.02
10/1/18 through 3/31/19	27	24	1.65	0.13
4/1/19 through 9/30/19	47	44	1.40	-0.25
10/1/19 through 3/31/20	41	37	2.45	-0.24
4/1/20 through 9/30/20	52	48	2.23	-0.11
10/1/20 through 3/31/21[3]	116	113	3.74	-0.86

[1]Target precision updated to current reference oils GIA17 and 1009 only

[2]Extreme OC results included and excluded

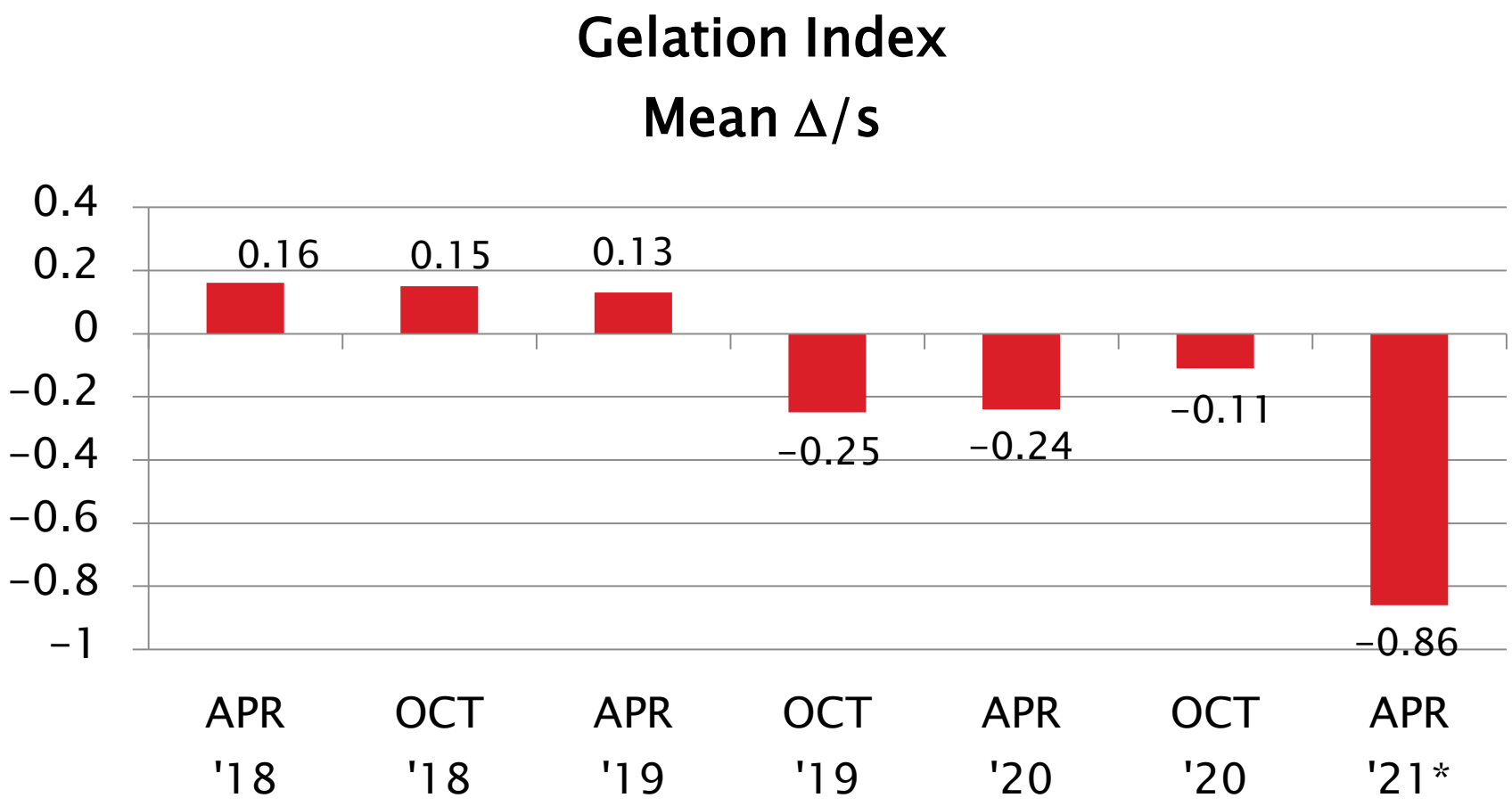
[3]Changed from bath to head based monitoring scheme

D5133 Precision Estimates



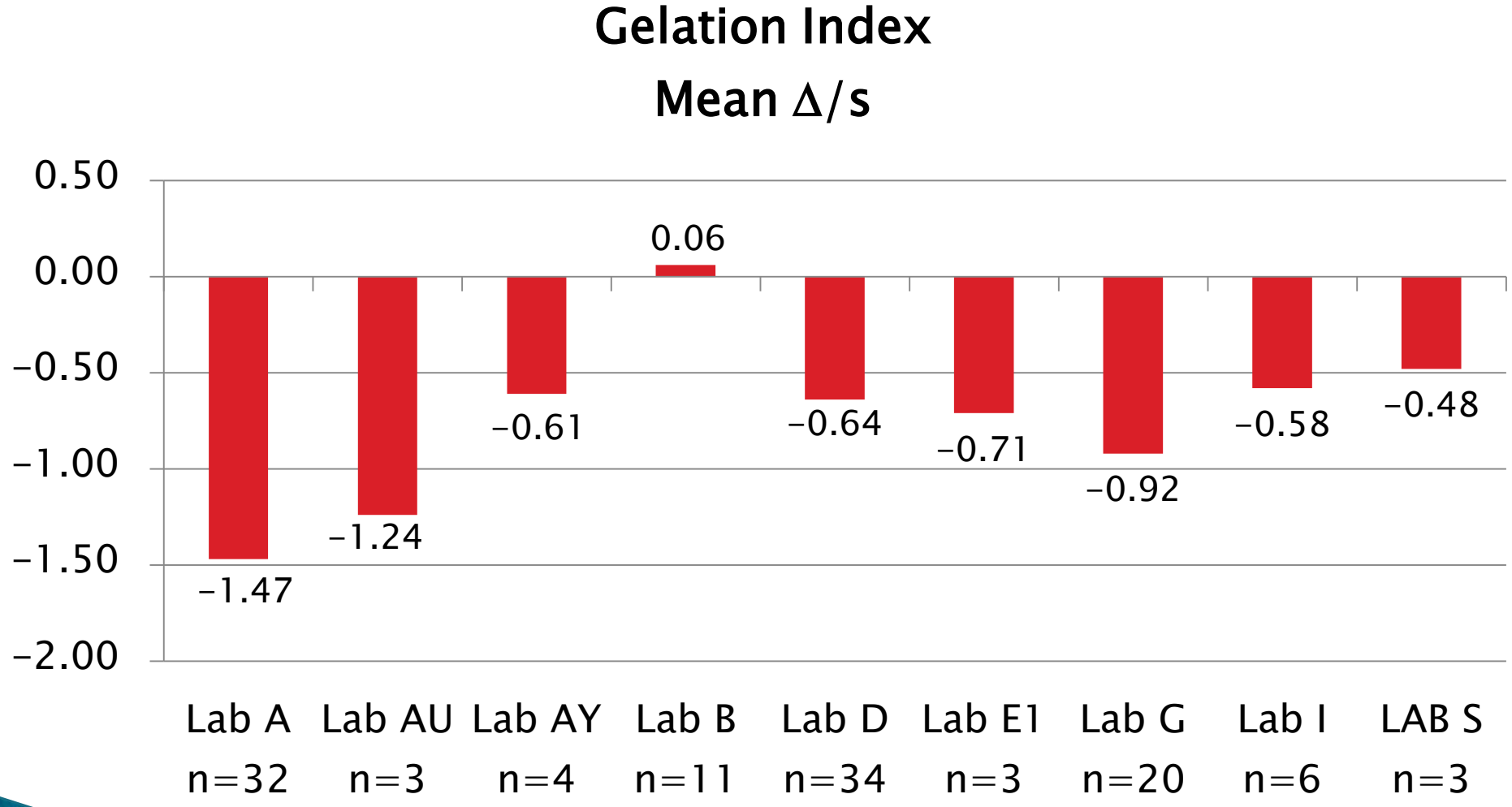
*Changed from bath to head based monitoring scheme

D5133 Severity Estimates



*Changed from bath to head based monitoring scheme

D5133 Lab Severity Estimates



D5133: Gelation Index

- GI was formally added to the LTMS effective October 1, 2020 (coincident with the start of this report period).
  - Test monitoring changed from a bath-based calibration scheme to a head-based calibration (where 'stand' was redefined from bath to the head/rotor/stator combination).
  - Low/non-gelling oil 58 was reclassified as a mild performing discrimination oil with only a maximum performance limit.
  - Stand calibration period changed from 60 days to 180 days, with a coinciding discrimination run required with every other calibration.
  - GI Report Packet Revision Version 20200807 became effective October 1, 2020 to accommodate these significant test monitoring changes.

D5133: Gelation Index

- Fail rate of operationally valid tests is 18% this period
  - Fail rate of (new) discrimination runs reported as operationally valid was also 18%
  - Fail rate is comparable to last period (17%).
  - Historic period fail rates have ranged between 6% and 26%
- Precision (Pooled s) is much less precise than last period
  - Much less precise than updated target precision
  - Target precision is updated to current reference oils GIA17 and 1009 only
    - Oil 62 excluded from updated target precision as nearly depleted (n=9 this period)
    - Oil 58 also excluded as imprecise (low to non-gelling oil), now a discrimination oil only with no target mean or precision)
- Performance (Mean Δ/s) is -0.86 s mild
  - Eight of nine reporting labs performing overall mild
  - Lab B is the only lab performing on target (n=11)
    - All Lab B results reported as operationally valid passed calibration
- A round robin is underway to evaluate a calibration oil that performs closer to the GF-5/6 pass/fail limit of 12 GI
  - To replace oil 58 that was reclassified as a discrimination oil

D5133: Gelation Index

- The high fail rate and very high number of invalidated runs this period emphasizes what the TMC has suspected for many years, that the GI baths themselves are not the primary contributing factor to unreliable GI results, but that the head/rotor/stator combinations (now defined as the stand) require closer scrutiny for accurately assessing, and hopefully improving, the overall reliability, accuracy and precision of this test.
- A number of issues have been brought to light this period concerning the performance of individual heads, leading to repairs, removal of heads from service, and even the purchasing of entirely new instruments by some labs.
- Once sufficient additional data has been collected under the new monitoring scheme, the panel should re-assess the statistical protocols for improving ongoing test monitoring. Perhaps looking at the applicability of transformations of test results and/or an EWMA based monitoring system. The frequency of calibrations should also be re-assessed, with the consideration of additional calibration data.

D5133 GELATION INDEX INDUSTRY OPERATIONALLY VALID DATA

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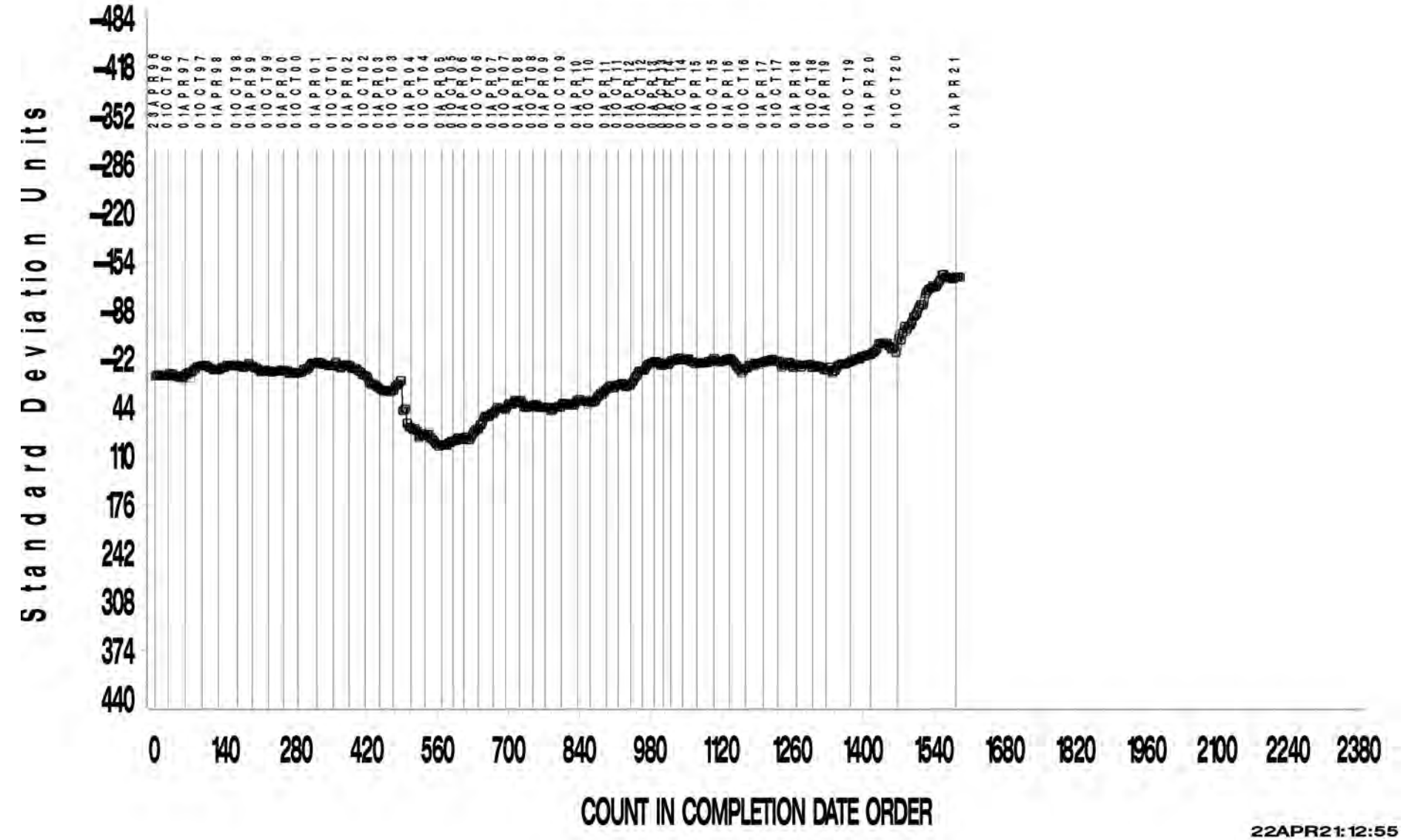
GELATION INDEX

CUSUM Severity Analysis



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D5133 GELATION INDEX INDUSTRY OPERATIONALLY VALID DATA

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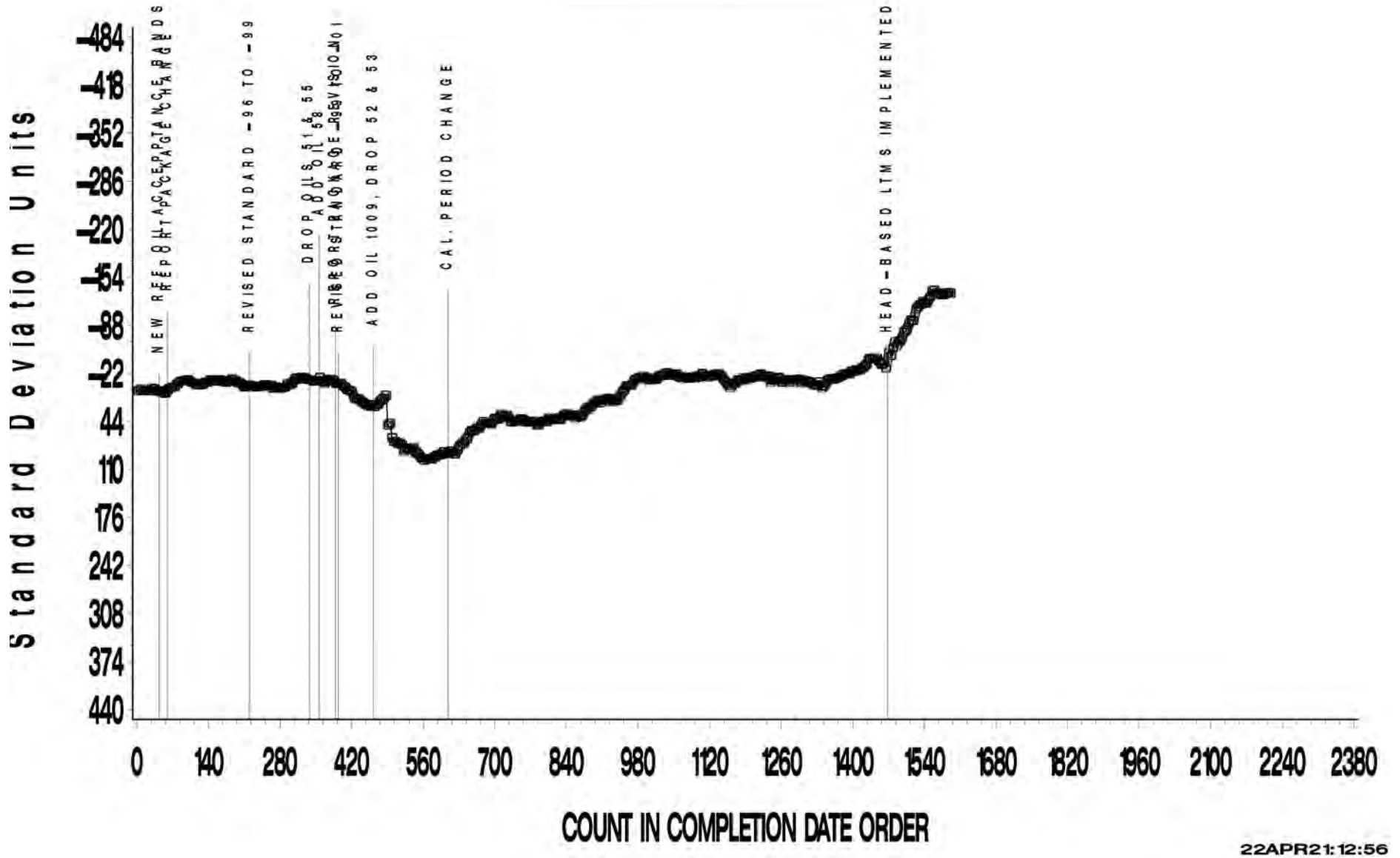
GELATION INDEX

CUSUM Severity Analysis



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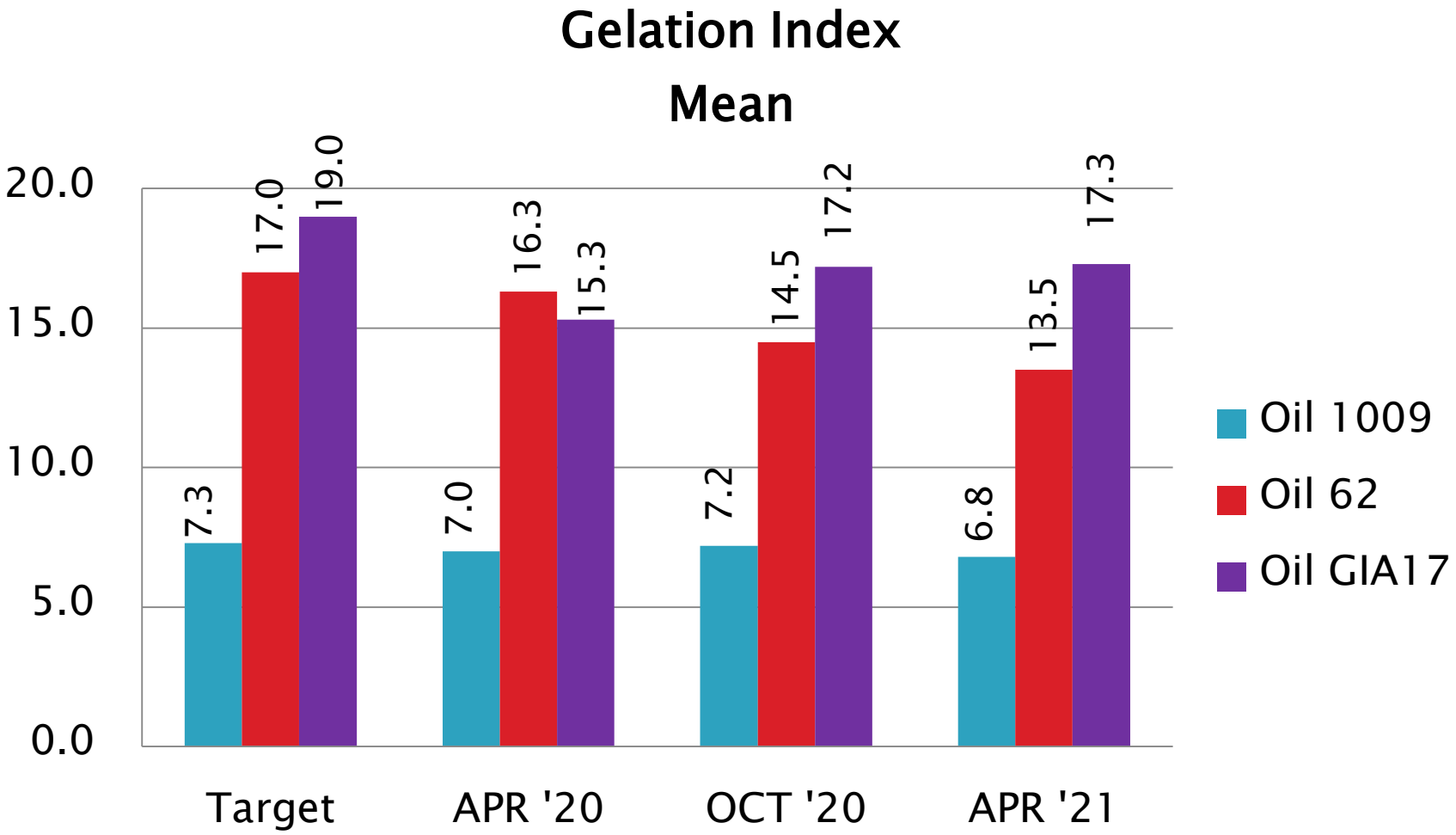
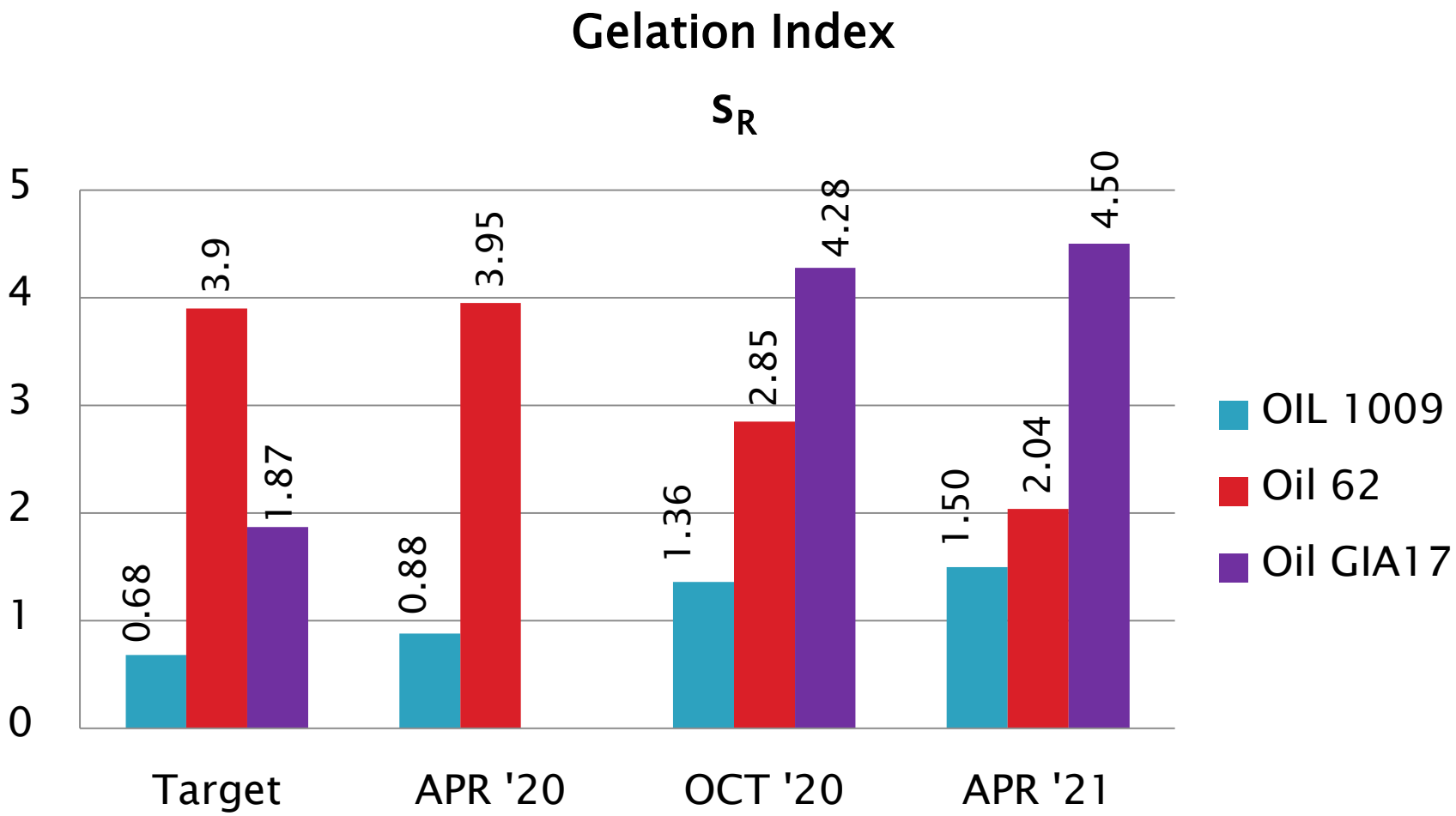
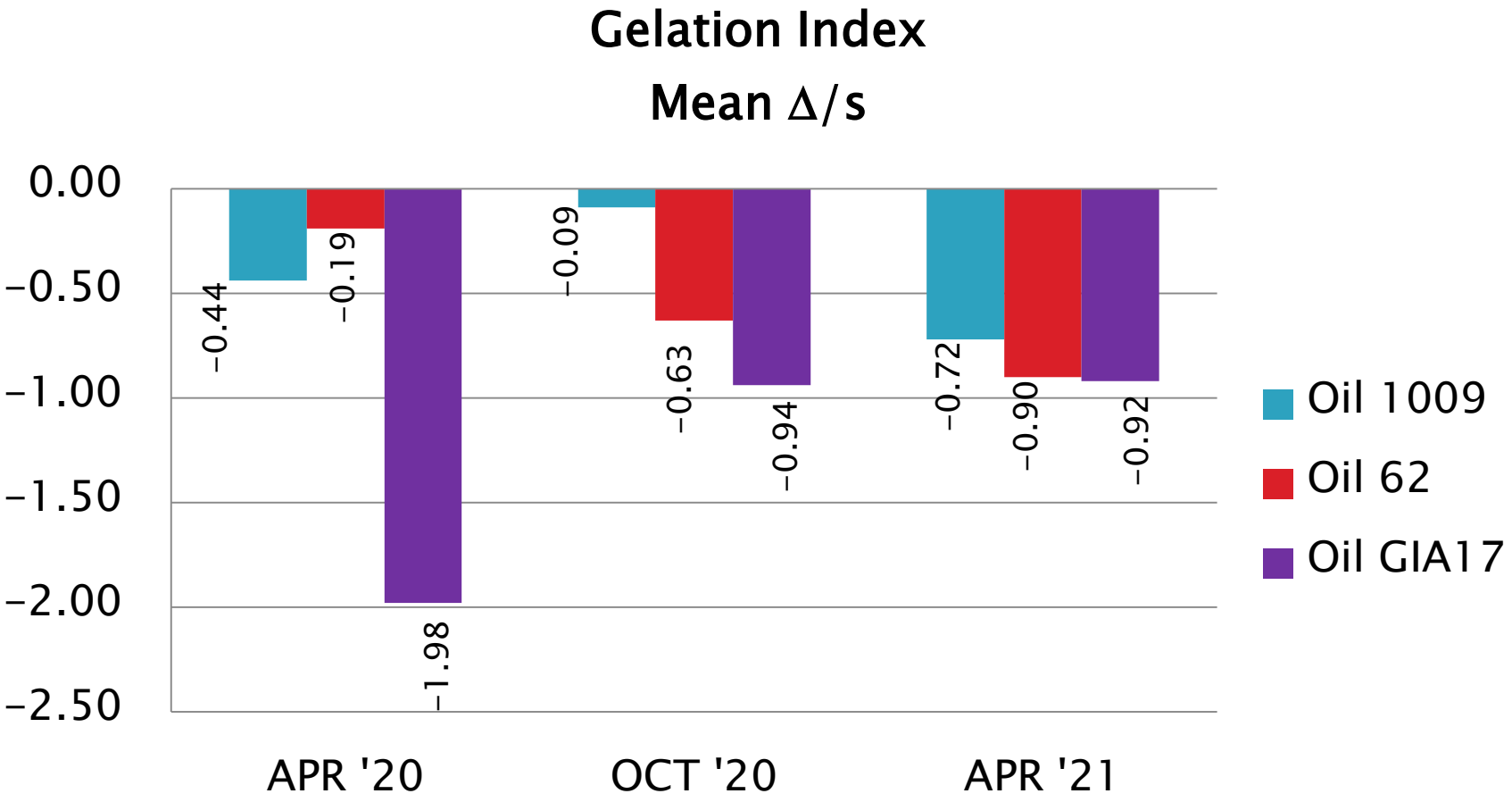
D5133 Performance by Oil



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	20
Failed Calibration Test	OC	6
Operationally Invalidated by Lab	LC, XC	3
Operationally Invalidated After Initially Reported as Valid	RC	0
Stand Shakedown Run	AN, ON	9
Total		**38**

Number of Labs Reporting Data: 8
Fail Rate of Operationally Valid Tests: 23%

D6335: Deposits by TEOST-33C

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

- Two stands (D5, B7) each reported two statistically unacceptable results this period, accounting for four of the six OC results reported this period.
- There were three operationally invalid tests reported this period:
  - Oil pump setting off-spec (one test, LC)
  - Temperature setting off-spec (one test, XC)
  - Test sample spilled (one test, XC)
- Nine shakedown runs to troubleshoot performance of a single rig.
- There were no TEOST technical update issued this report period.
- Calibration requirement updates are issued as LTMS document updates.

D6335: Deposits by TEOST-33C

Period Precision and Severity Estimates

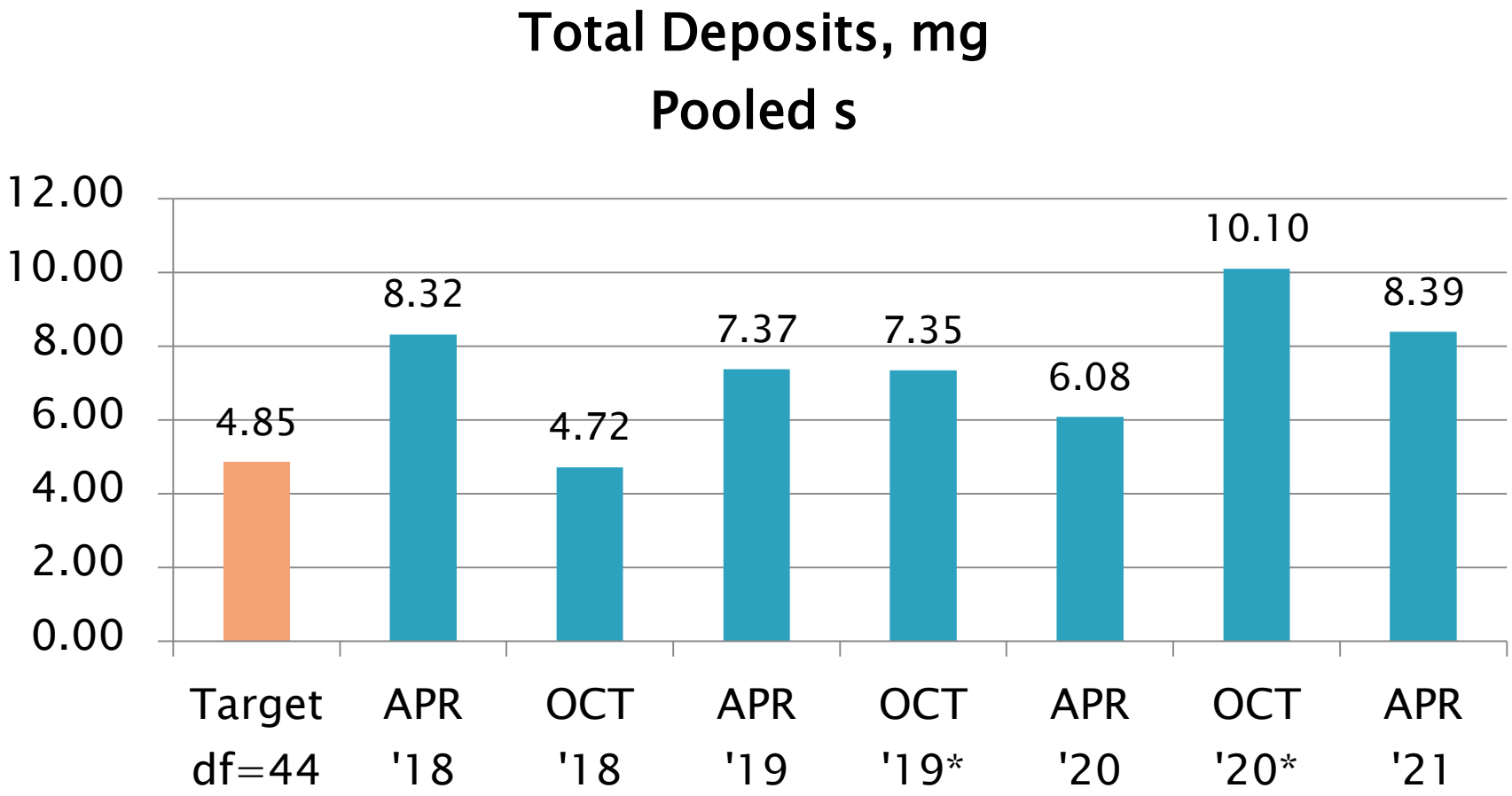
Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Updated Targets 20201001[1]	46	44	4.85	-----
4/1/18 through 9/30/18	21	19	4.72	-0.33
10/1/18 through 3/31/19	25	23	7.37	0.11
4/1/17 through 9/30/19[2] 4/1/17 through 9/30/19[2]	30 26	28 24	12.66 7.35	0.47 -0.23
10/1/19 through 3/31/20	32	30	6.08	0.28
4/1/20 through 9/30/20[3] 4/1/20 through 9/30/20[3]	33 26	30 23	11.44 10.10	0.02 -0.02
10/1/20 through 3/31/21	26	23	8.39	0.42

[1]Target precision updated to include only current oils 75-1 and 435-2

[2]Four consecutive OC results on same rig included and excluded.

[3]Rig with six OC results included and excluded.

D6335 Precision Estimates



*Multiple OC results from single excessively failing rig excluded.

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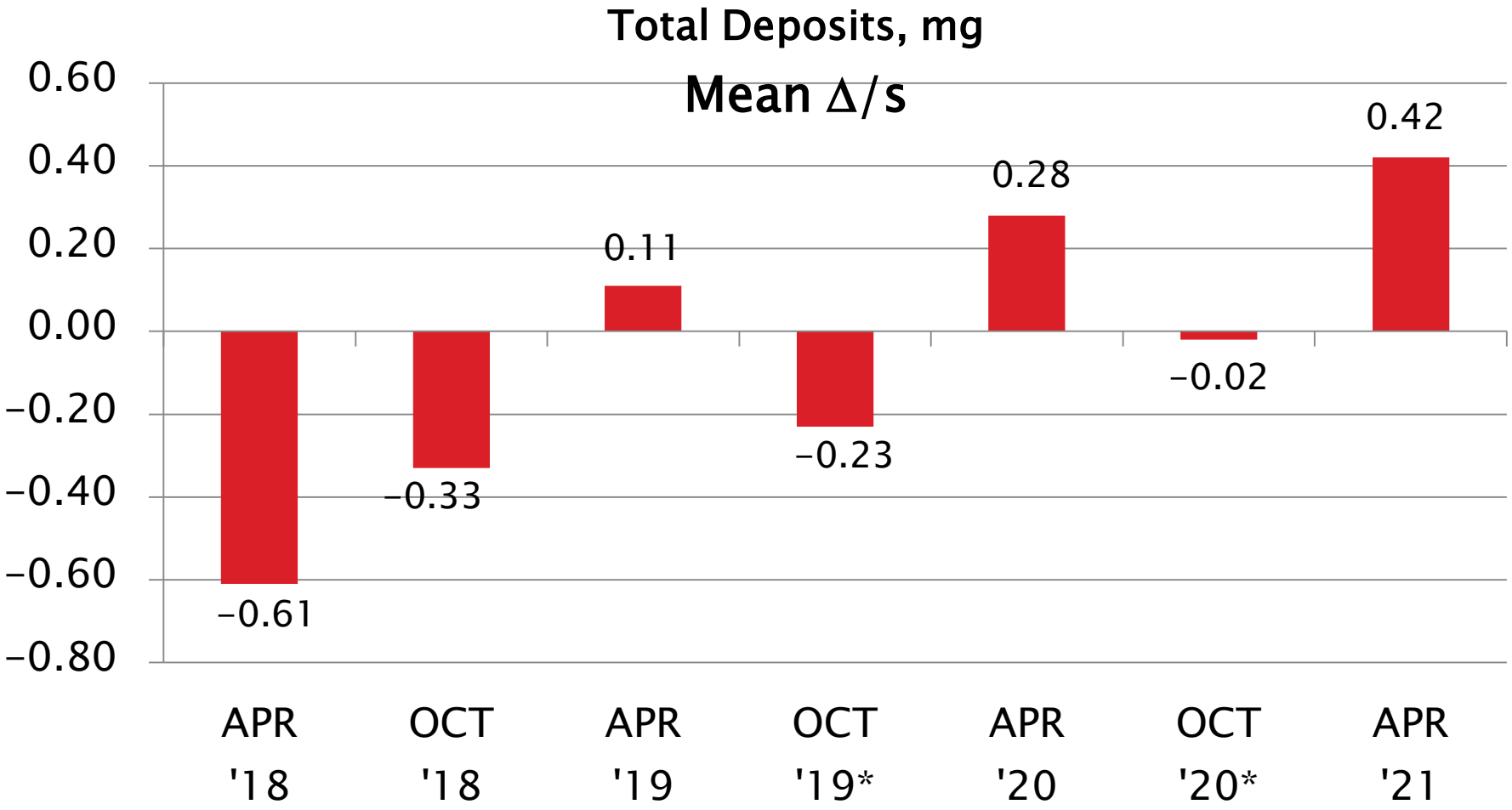
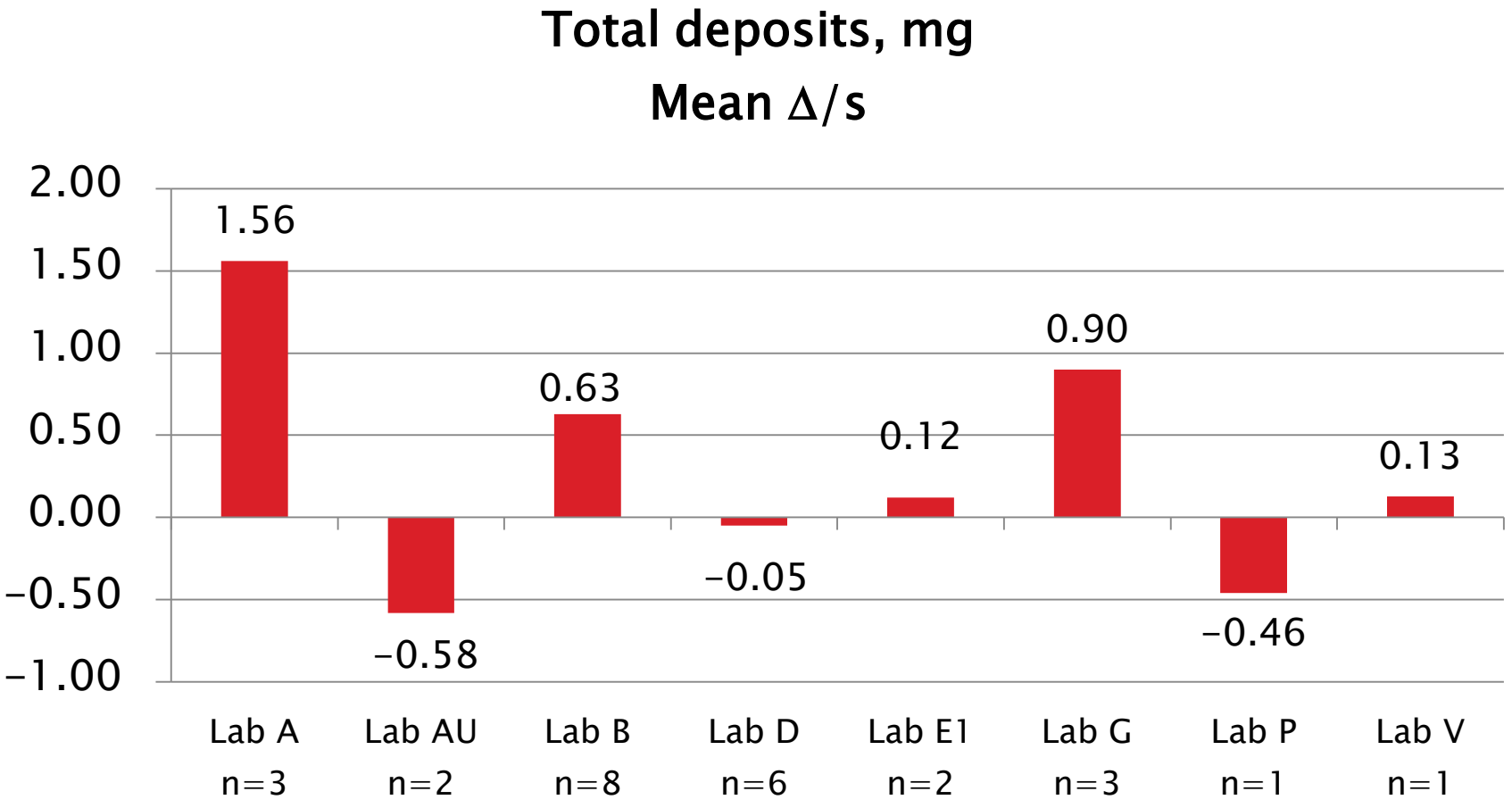
D6335 Severity Estimates



*Multiple OC results from single excessively failing rig excluded.

D6335 Lab Severity Estimates



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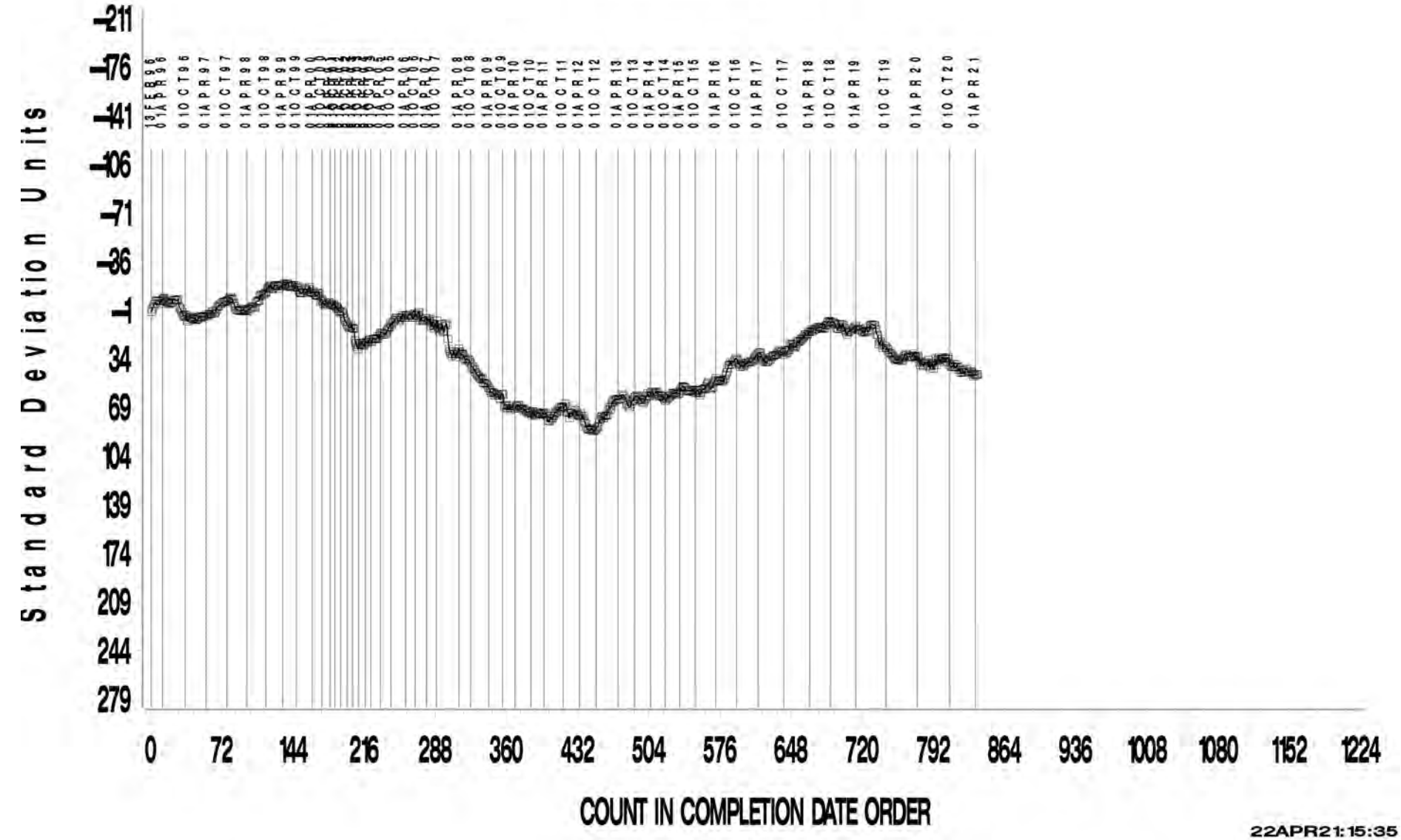
D6335: Deposits by TEOST-33C

- Precision (Pooled s) is improved over the prior period (also highly imprecise), but remains imprecise compared to other periods.
  - Much less precise than target precision
  - Target precision updated this period to current reference oils 75-1 and 435-2 (oil 75 removed from target precision calculation)
    - Only two tests this period were oil 75; oil is nearly used up
- Performance (Mean Δ/s) is unusually severe this period (0.42 s)
- Period fail rate of 23% on test reported as operationally valid
  - Fail rates continue to be high.
  - Compared to 39% fail rate last period, 0% two periods back, but 20% and 23% before that, and similarly high in prior periods
- All tests this period report using Rod Batch M or N.

TEOST –33C INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

CUSUM Severity Analysis



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TEOST –33C INDUSTRY OPERATIONALLY VALID DATA

TMC
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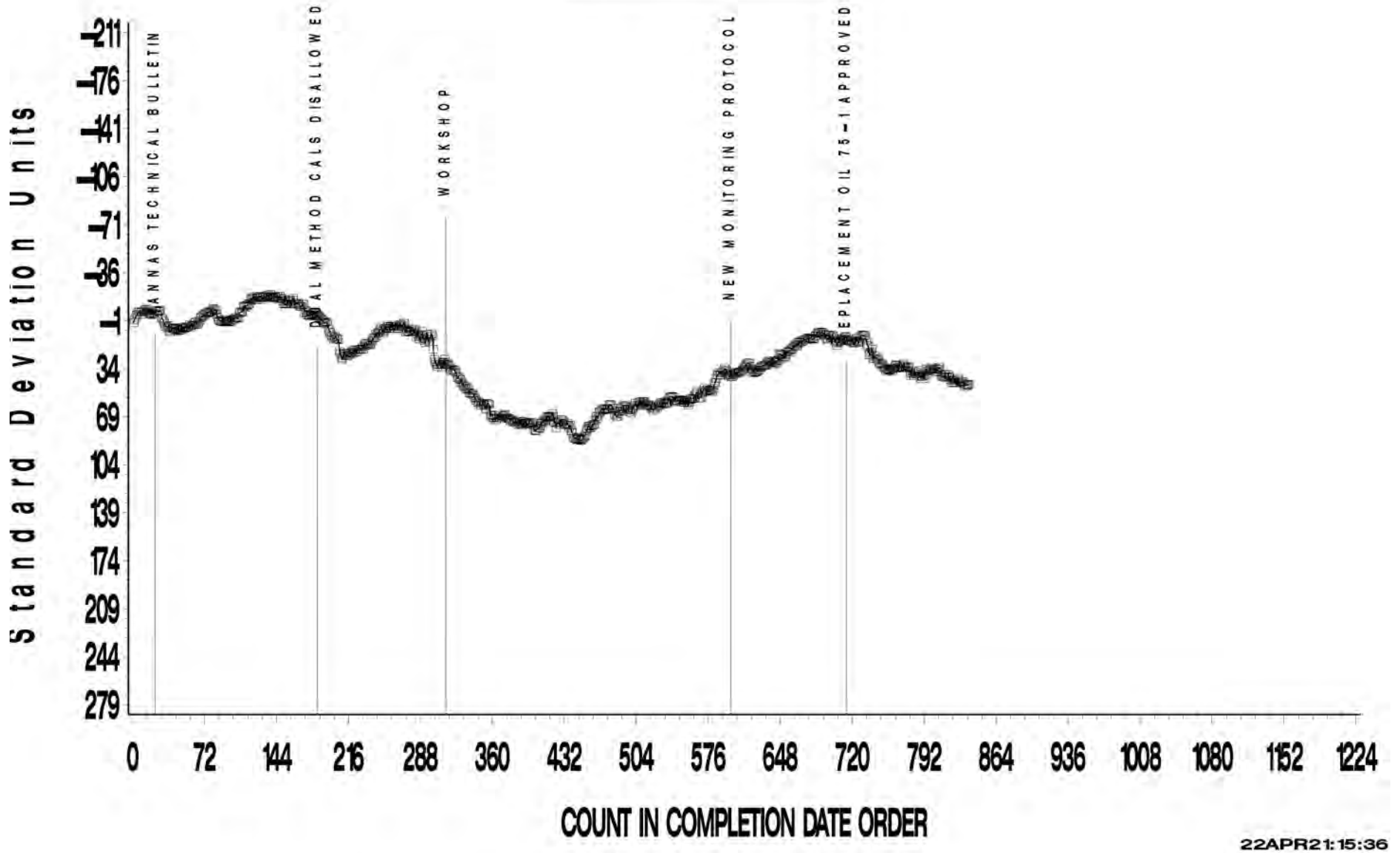
TOTAL DEPOSITS MG

CUSUM Severity Analysis



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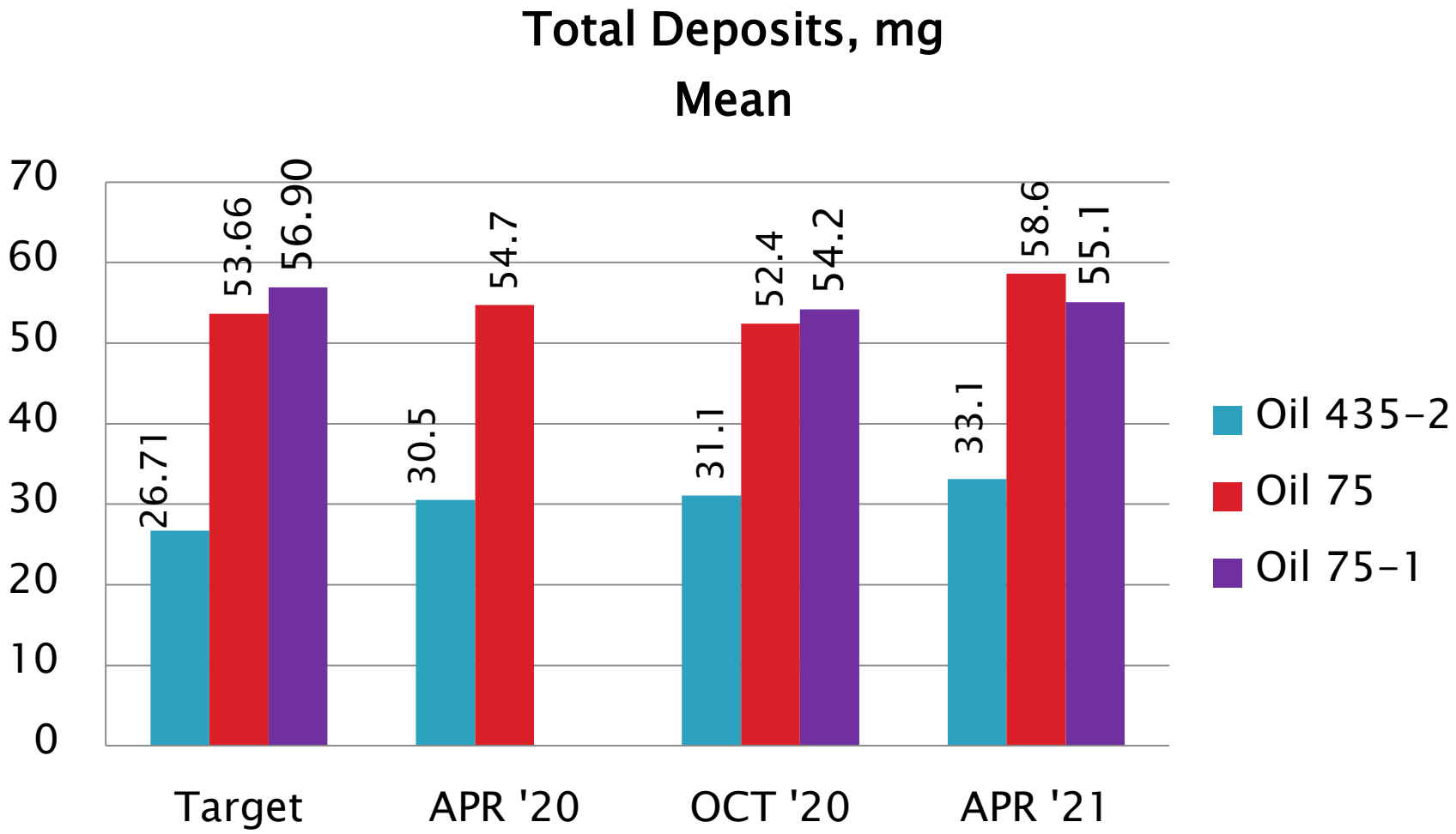
D6335 Performance by Oil



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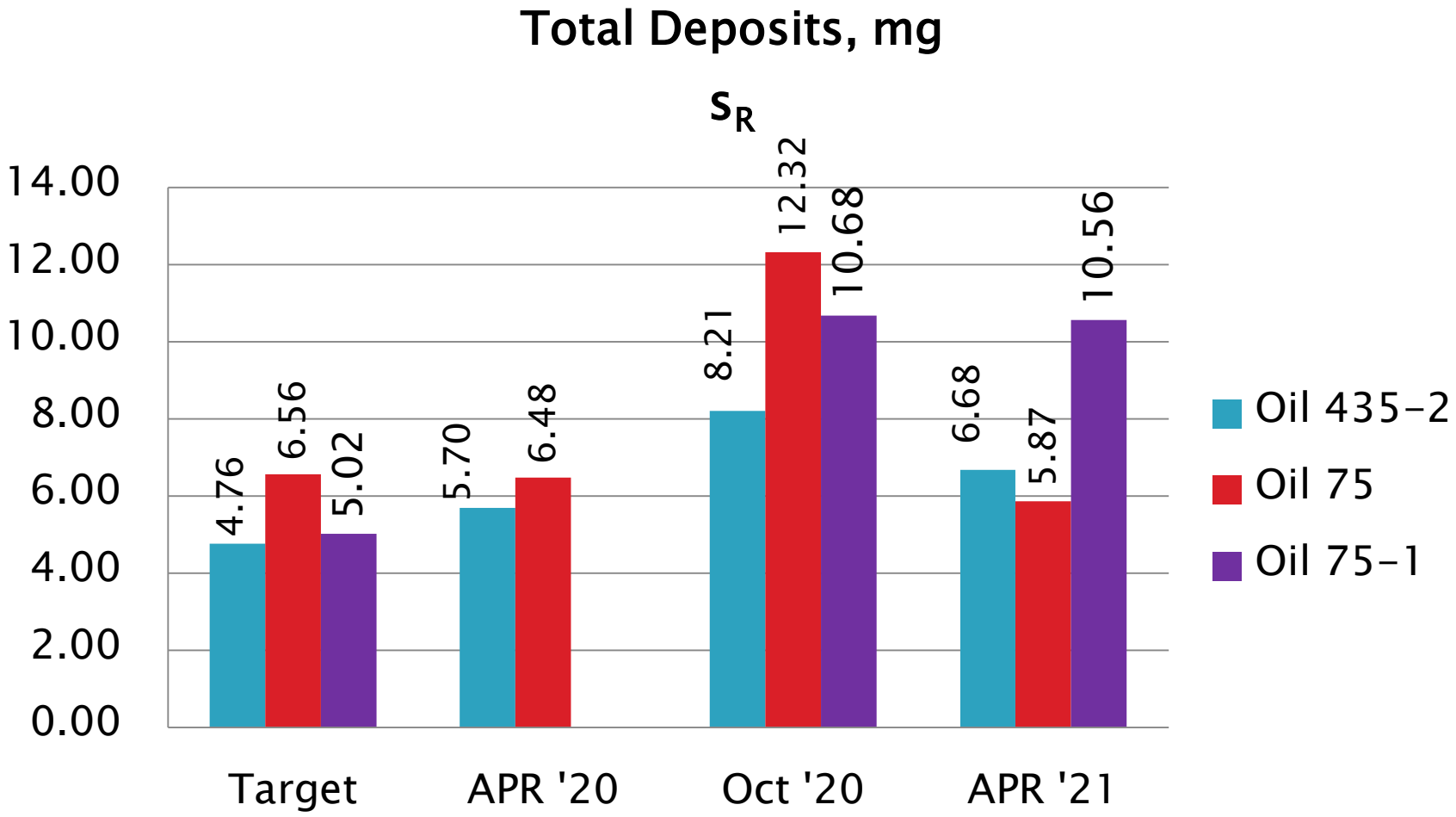
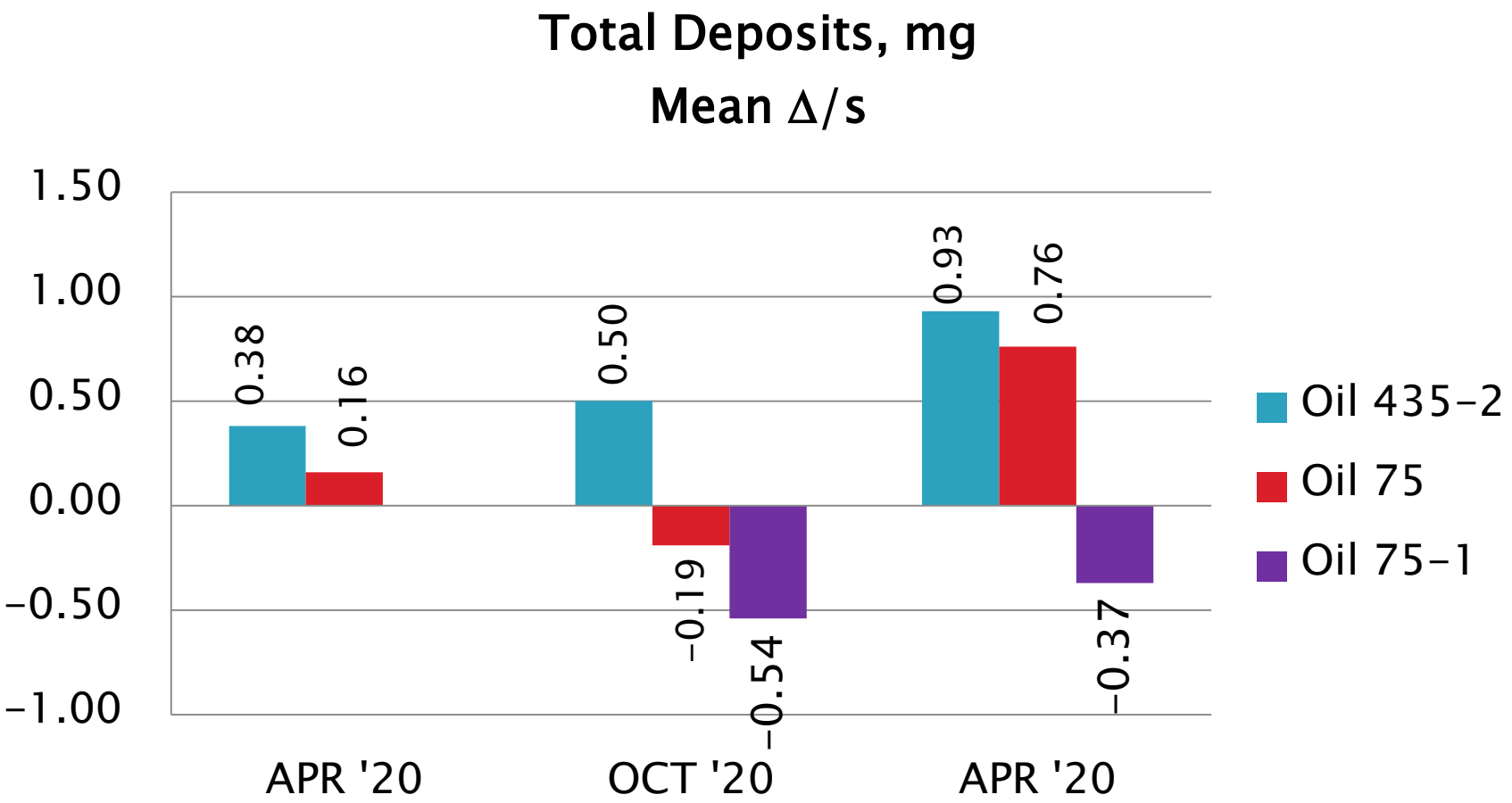
D6335 Performance by Oil



D6335 Performance by Oil



Return to Executive Summary

D7097: Deposits by MHT TEOST

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	92
Failed Calibration Test	OC	9
Operationally Invalidated by Lab	LC, XC	2
Operationally Invalidated After Initially Reported as Valid	RC	0
Instrument Shakedown Run	AN	2
Total		**105**

Number of Labs Reporting Data: 9
Fail Rate of Operationally Valid Tests: 9%

D7097: Deposits by MHT TEOST

Statistically Unacceptable Tests (OC)	No. Of Tests
Total Deposits Mild	0
Total Deposits Severe	9

- Two operationally invalid calibration test reported this period:
  - Sample leak and O-ring seal failure (XC)
- Two instrument shakedown runs on new rig prior to calibration
- There were no MTEOS technical updates issued this report period.
- Calibration requirement updates are issued as LTMS document updates.

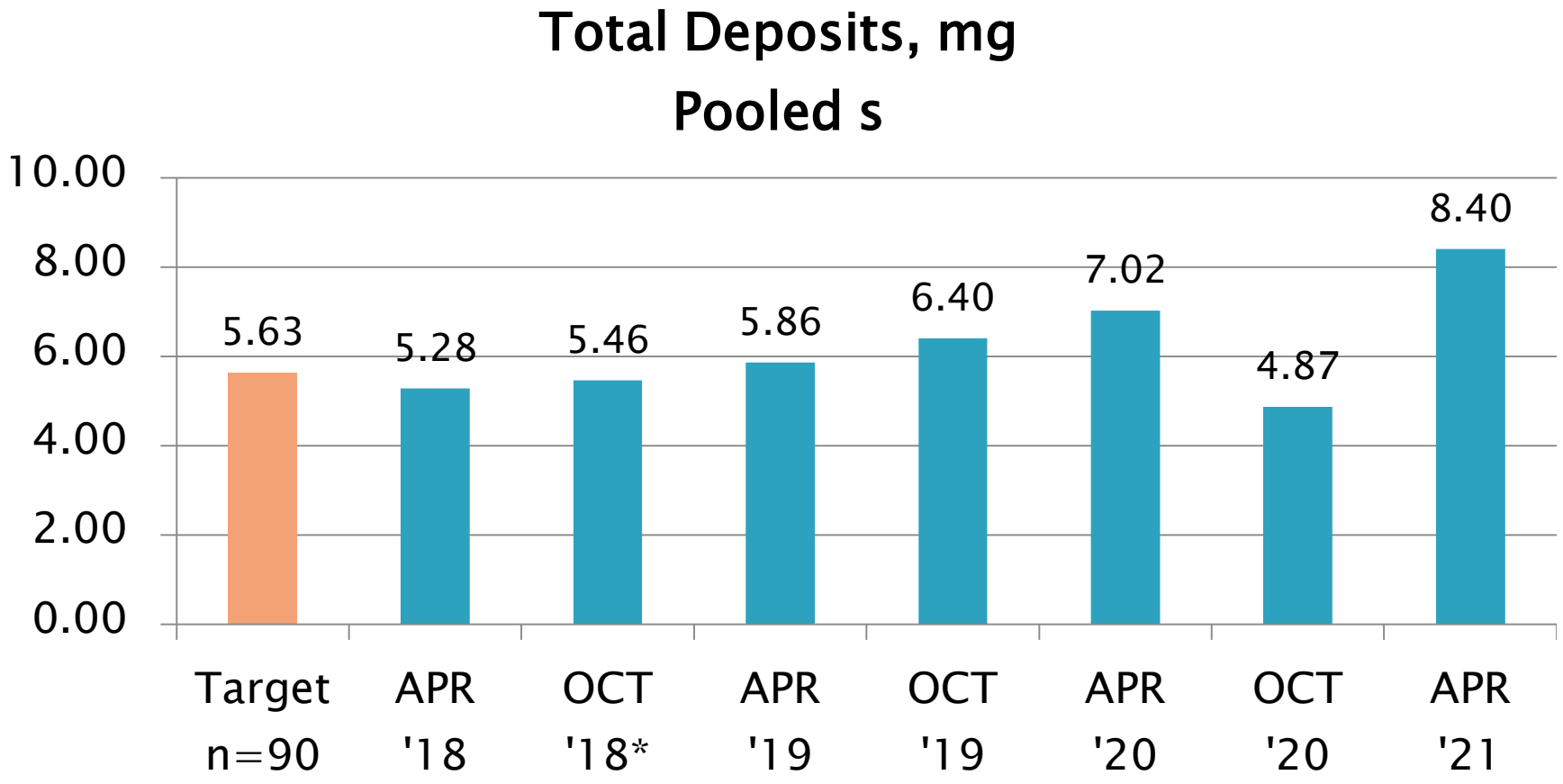
D7097: Deposits by MHT TEOST

Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Current Targets 7/31/2006	90	87	5.63	-----
10/1/17 through 3/31/18	88	86	5.28	0.33
4/1/18 through 9/30/18[1] 4/1/18 through 9/30/18[1]	95 94	93 92	6.69 5.46	0.29 0.20
10/1/18 through 3/31/19	97	95	5.86	-0.14
4/1/19 through 9/30/19	109	107	6.40	-0.30
10/1/19 through 3/31/20	103	101	7.02	-0.02
4/1/20 through 9/30/20	72	70	4.87	-0.22
10/1/20 through 3/31/21	101	99	8.40	0.17

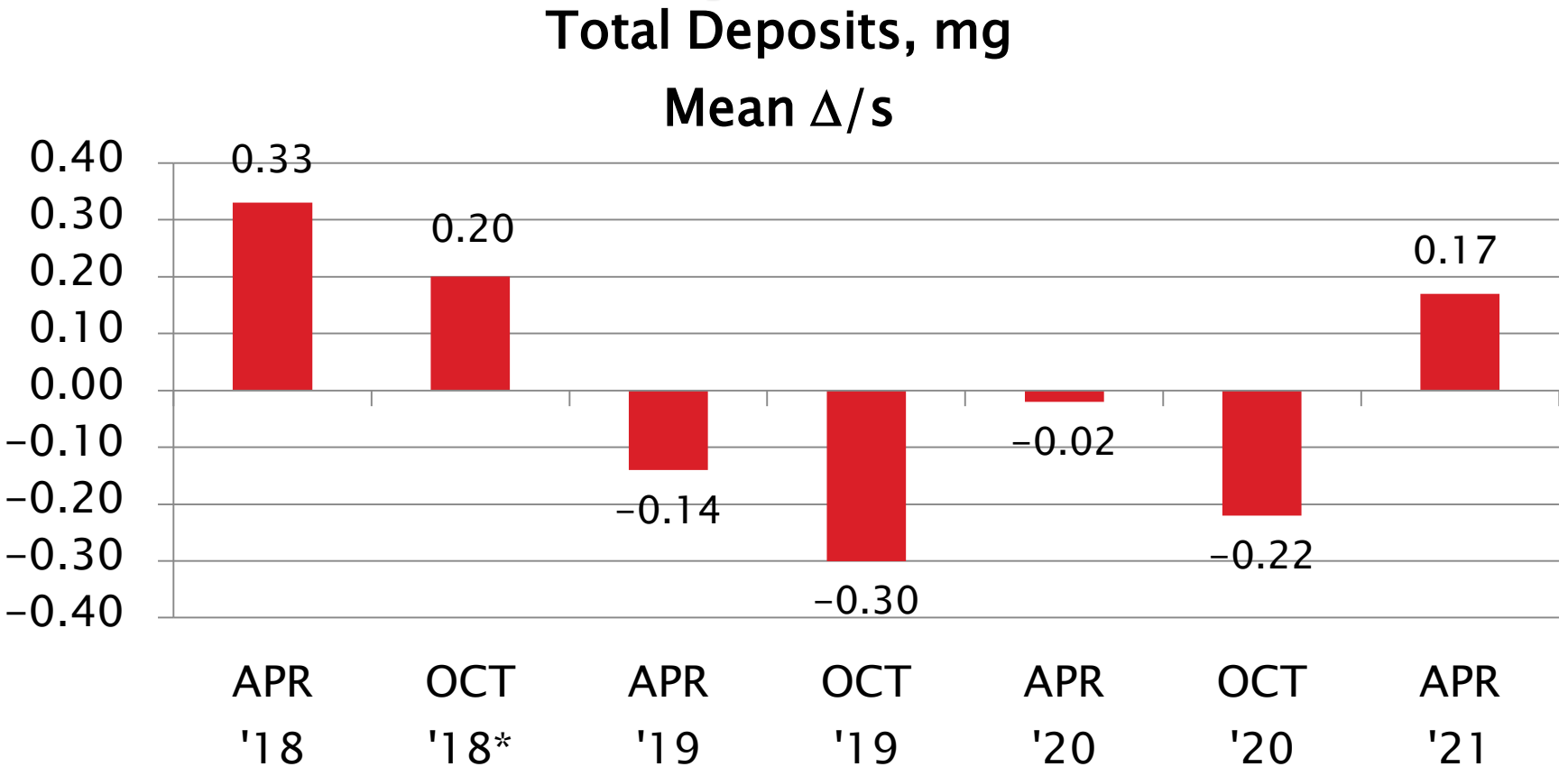
[1]One severe OC test from instrument G5 included and excluded (8.9 s)

D7097 Precision Estimates



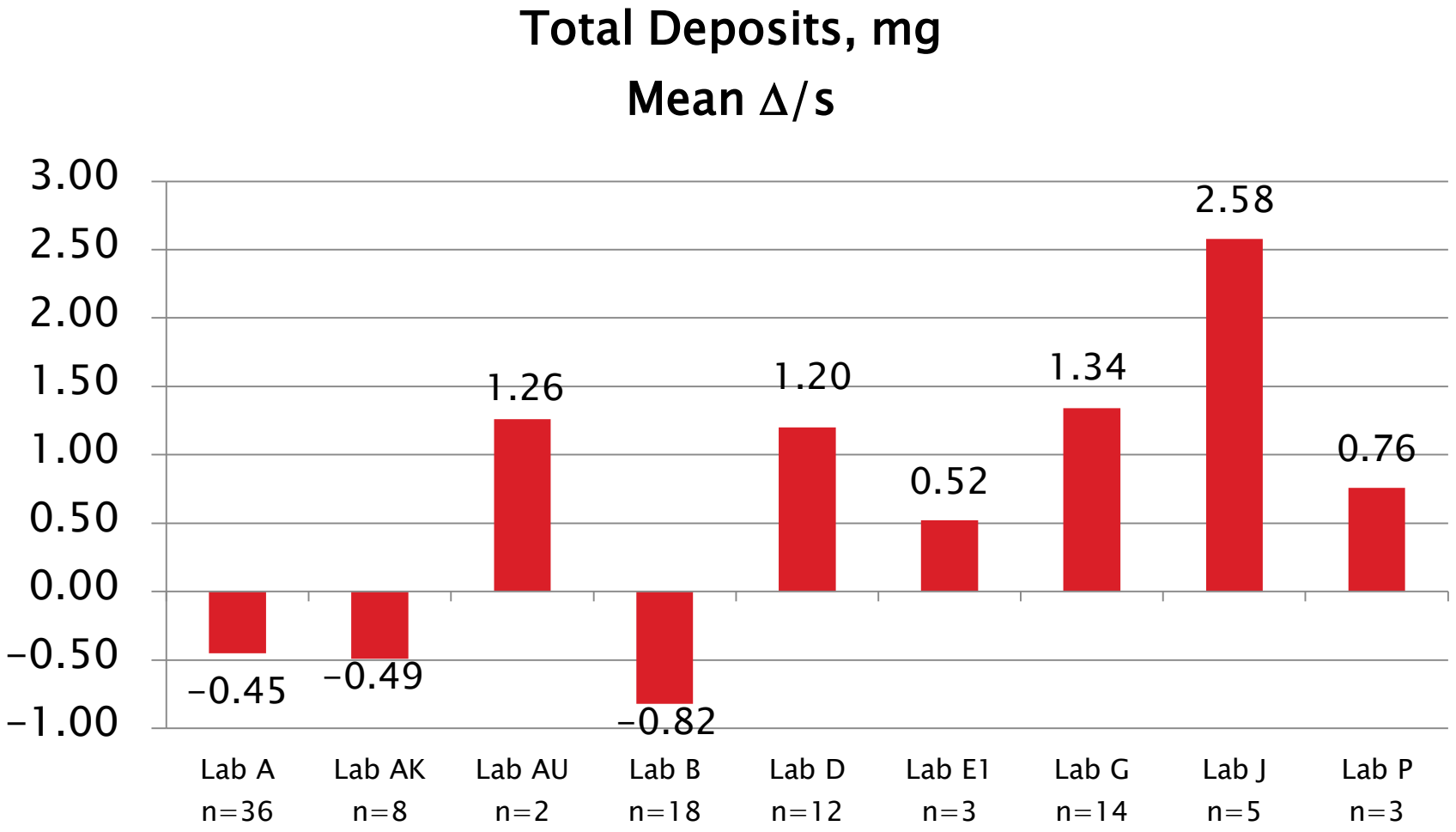
*One severe OC test from instrument G5 excluded (8.9 s)

D7097 Severity Estimates



*One severe OC test from instrument G5 excluded (8.9 s)

D7097 Lab Severity Estimates



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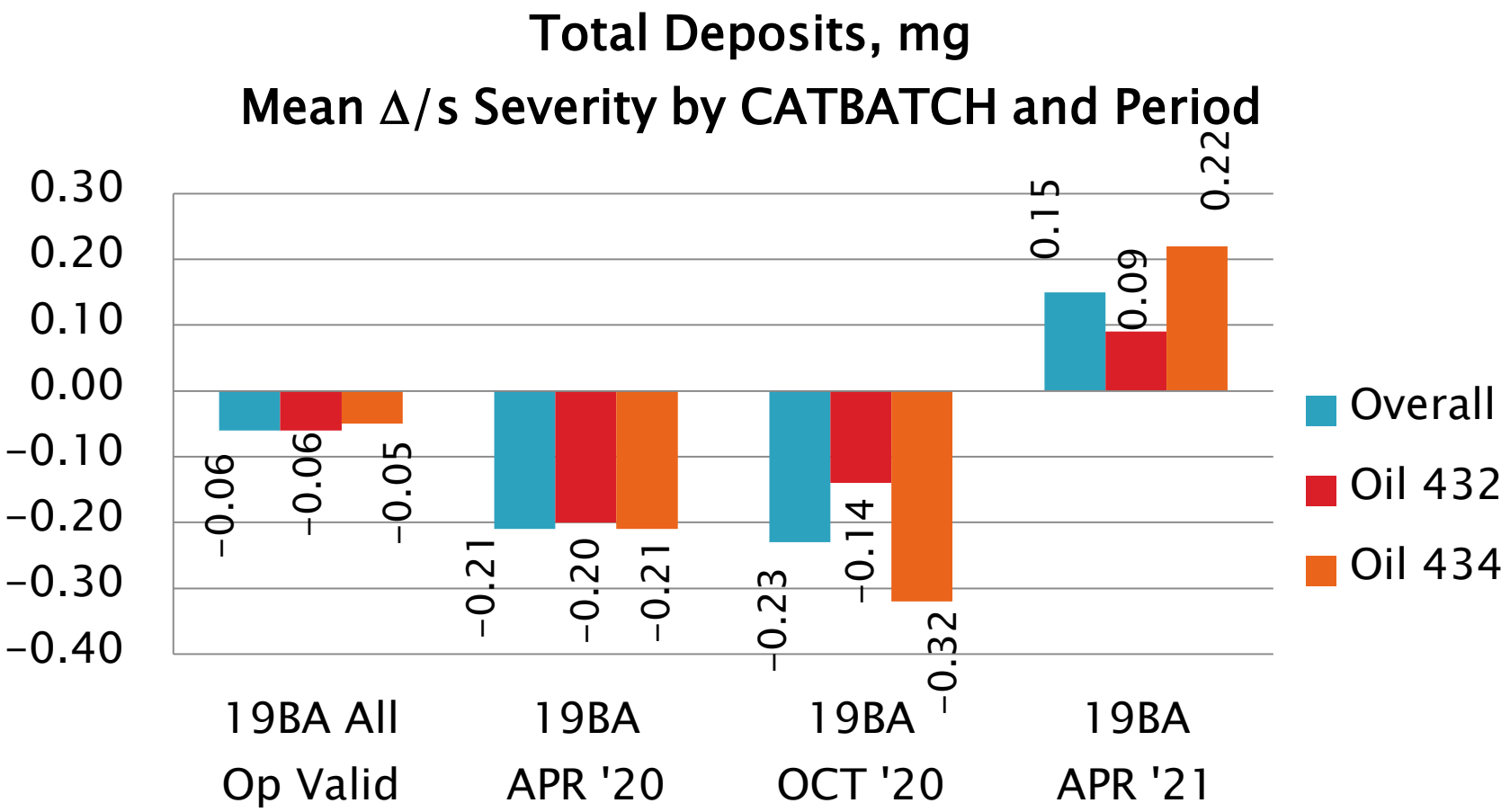
D7097: Deposits by MHT TEOST



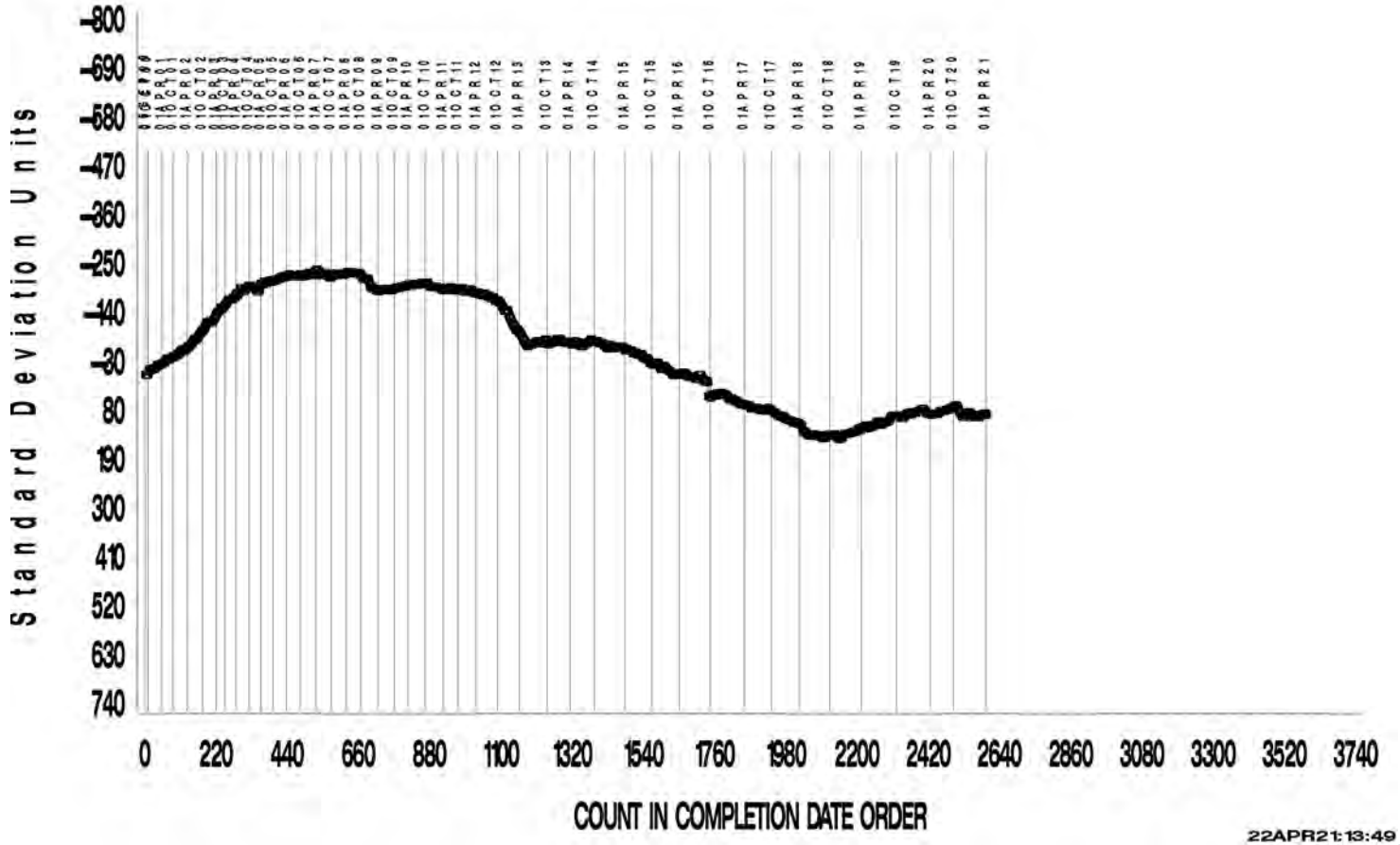
D7097: Deposits by MHT TEOST

- Precision (Pooled s) is significantly less precise than prior report periods
  - Less precise than target precision
- Performance (Mean Δ/s) is 0.17 s severe
- All operationally valid tests this period report using Rod Batch M
- All operationally valid calibration tests this period report using Catalyst Batch 18AB (n=3) or 19BA (n=101)
  - Lab P continues to report using prior catalyst batch 18AB
- Overall severity on catalyst batch 19BA (n=217) appears to be on-target, and on target for both reference oils.

MHT—4 TEOST INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

CUSUM Severity Analysis



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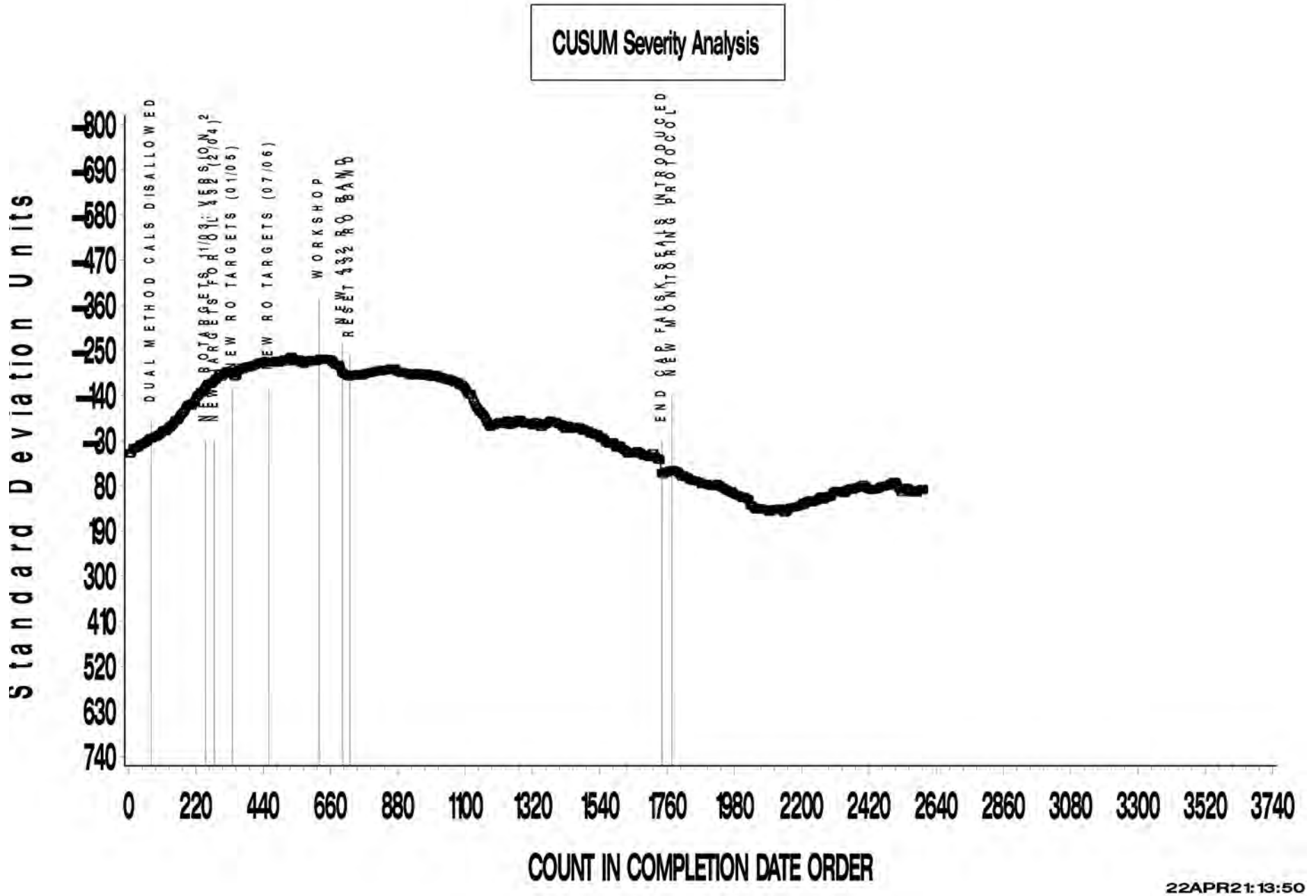
MHT —4 TEOST INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG



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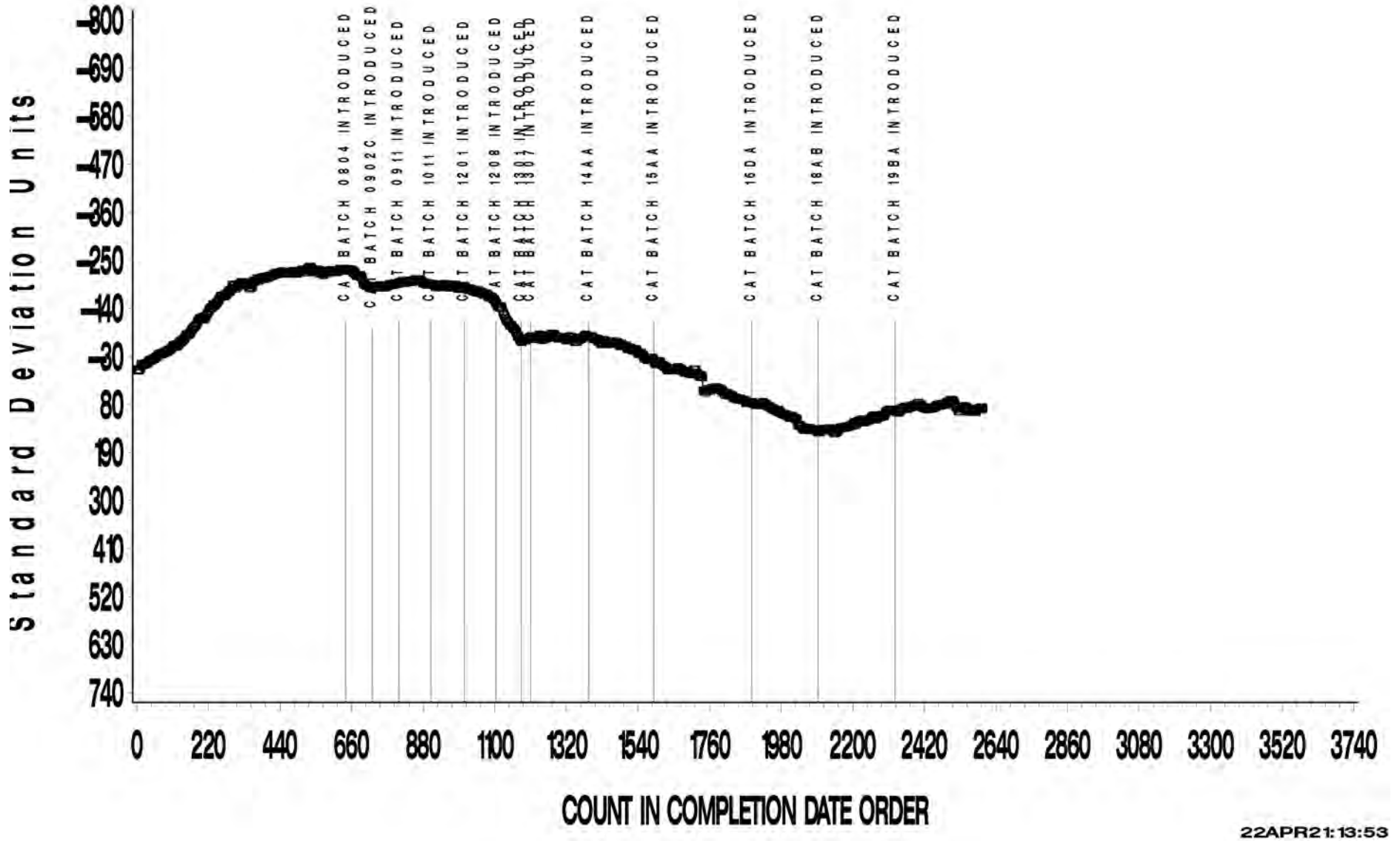
MHT –4 TEOST INDUSTRY OPERATIONALLY VALID DATA

TOTAL DEPOSITS MG

CUSUM Severity Analysis



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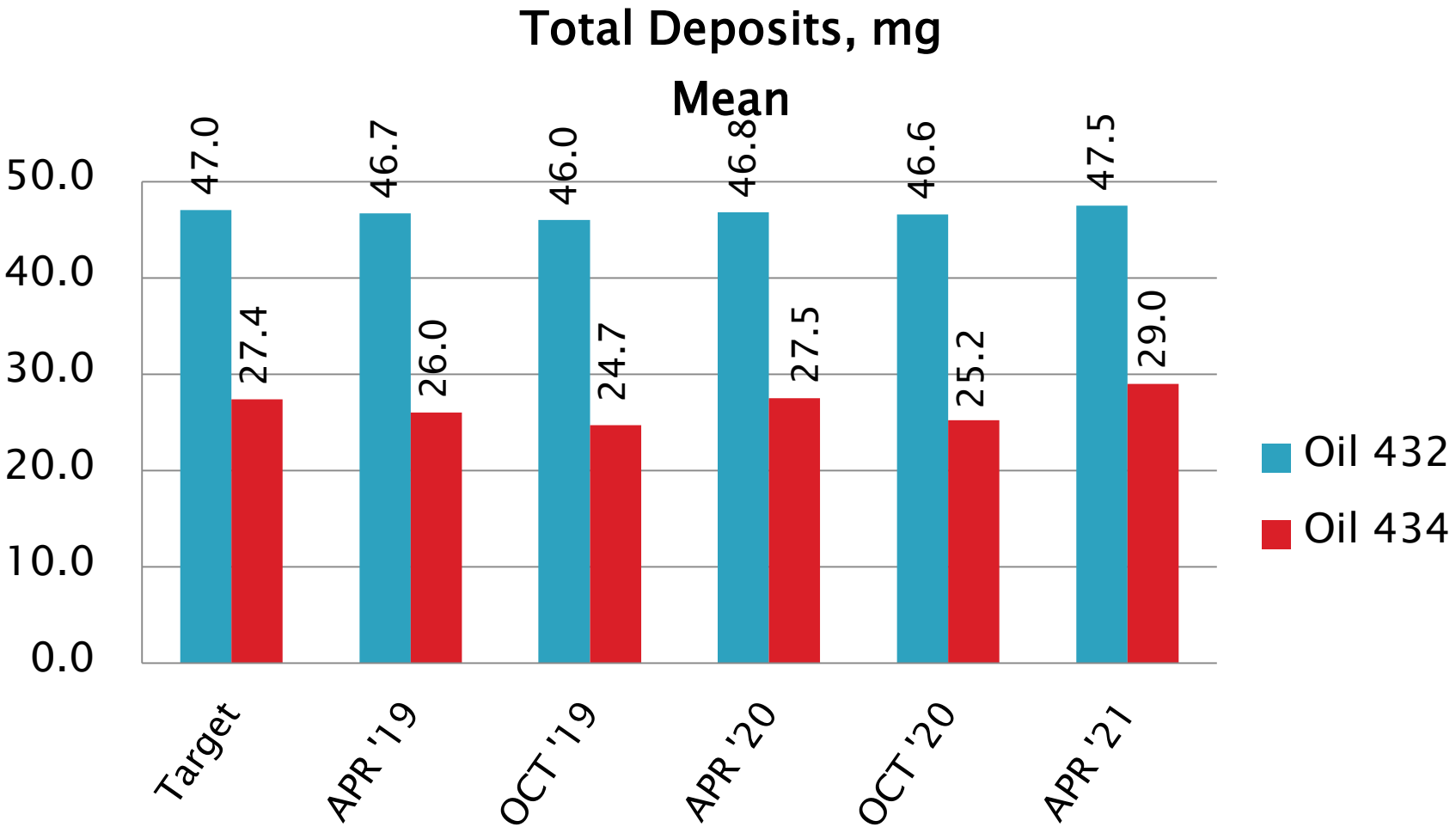
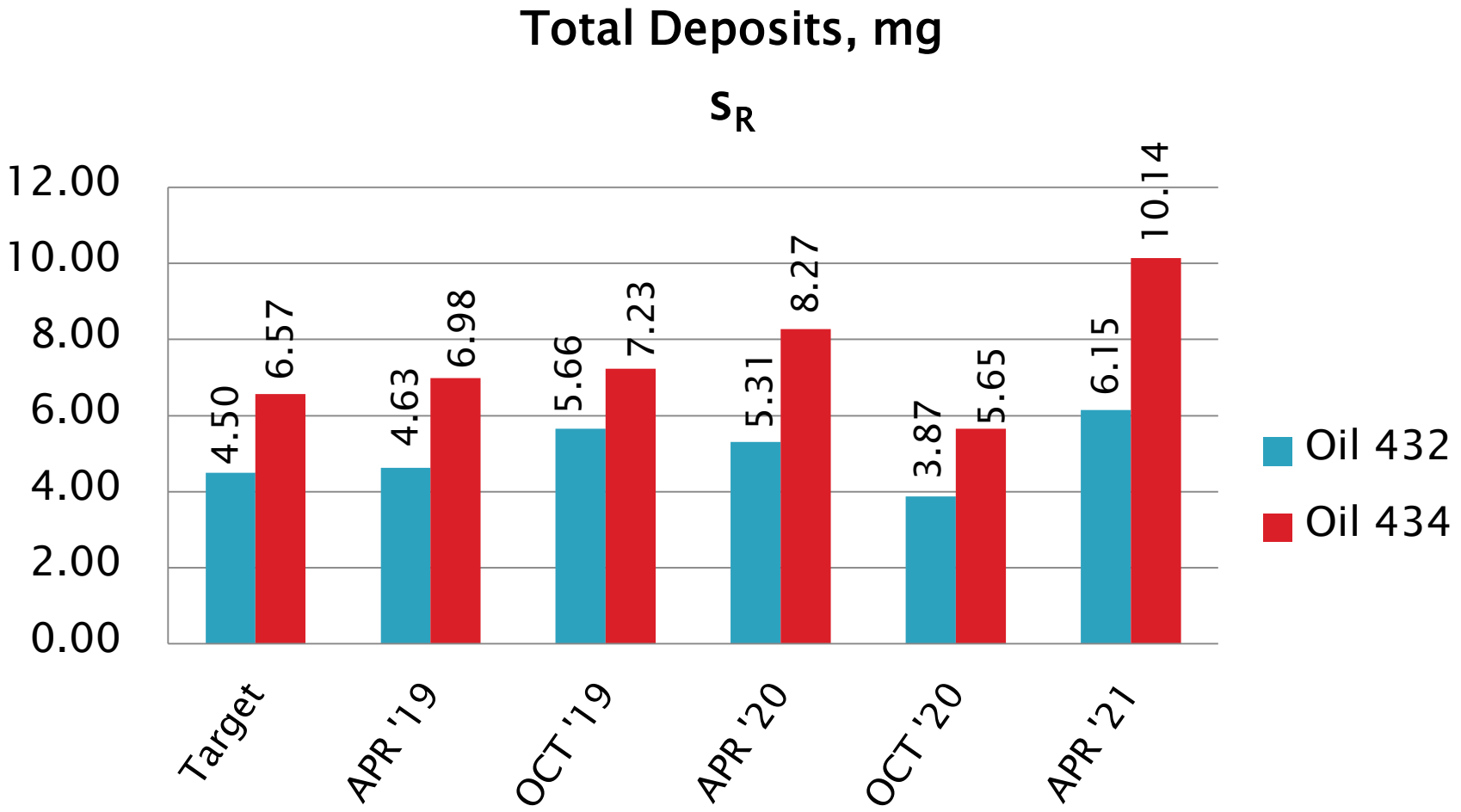
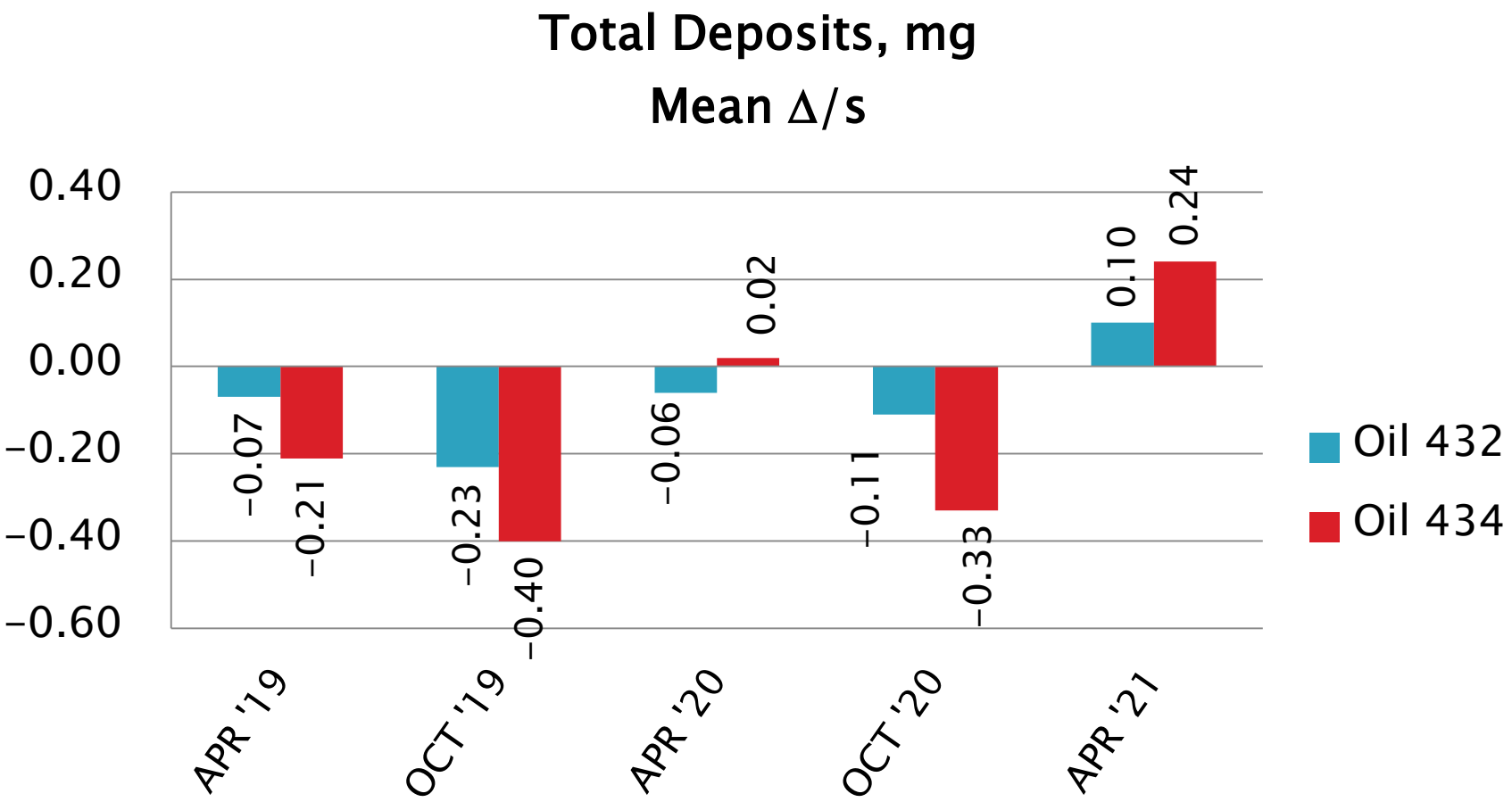
D7097 Performance by Oil



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	12
Acceptable Discrimination Test	AS	5
Failed Statistically	OC	0
Operationally Invalidated by Lab	LC, XC	0
Total		**17**

Number of Labs Reporting Data: 7
Fail Rate of Operationally Valid Calibration Tests: 0%

D6082: High Temperature Foam

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

- All severe oil discrimination runs (on TMC oil 66) reported this period demonstrated acceptable discrimination.
  - Discrimination runs are not evaluated for overall period precision or severity due to poor test precision above 100 ml foam tendency.
- No invalid runs this period.
- There were no TMC technical updates issued this period for D6082.
- D6082 Calibration requirement updates are issued as LTMS document updates.

D6082: High Temperature Foam

Period Precision and Severity Estimates

Foam Tendency, ml	n	df	Pooled s	Mean Δ/s
Targets updated 20201001[1]	18	17	9	-----
4/1/17 through 9/30/17	12	11	10	0.17
10/1/17 through 3/31/18[2] 10/1/17 through 3/31/18[2]	14 13	13 12	17 11	-0.02 -0.19
4/1/18 through 9/30/18	14	13	9	-0.07
10/1/18 through 3/31/19	14	13	12	-0.07
4/1/19 through 9/30/19	14	12	12	-0.18
10/1/19 through 3/31/20	15	13	10	-0.23
4/1/20 through 9/30/20	13	11	8	-0.85
10/1/20 through 3/31/21	12	10	7	-0.48

[1]Target precision updated to current reference oil FOAMB18

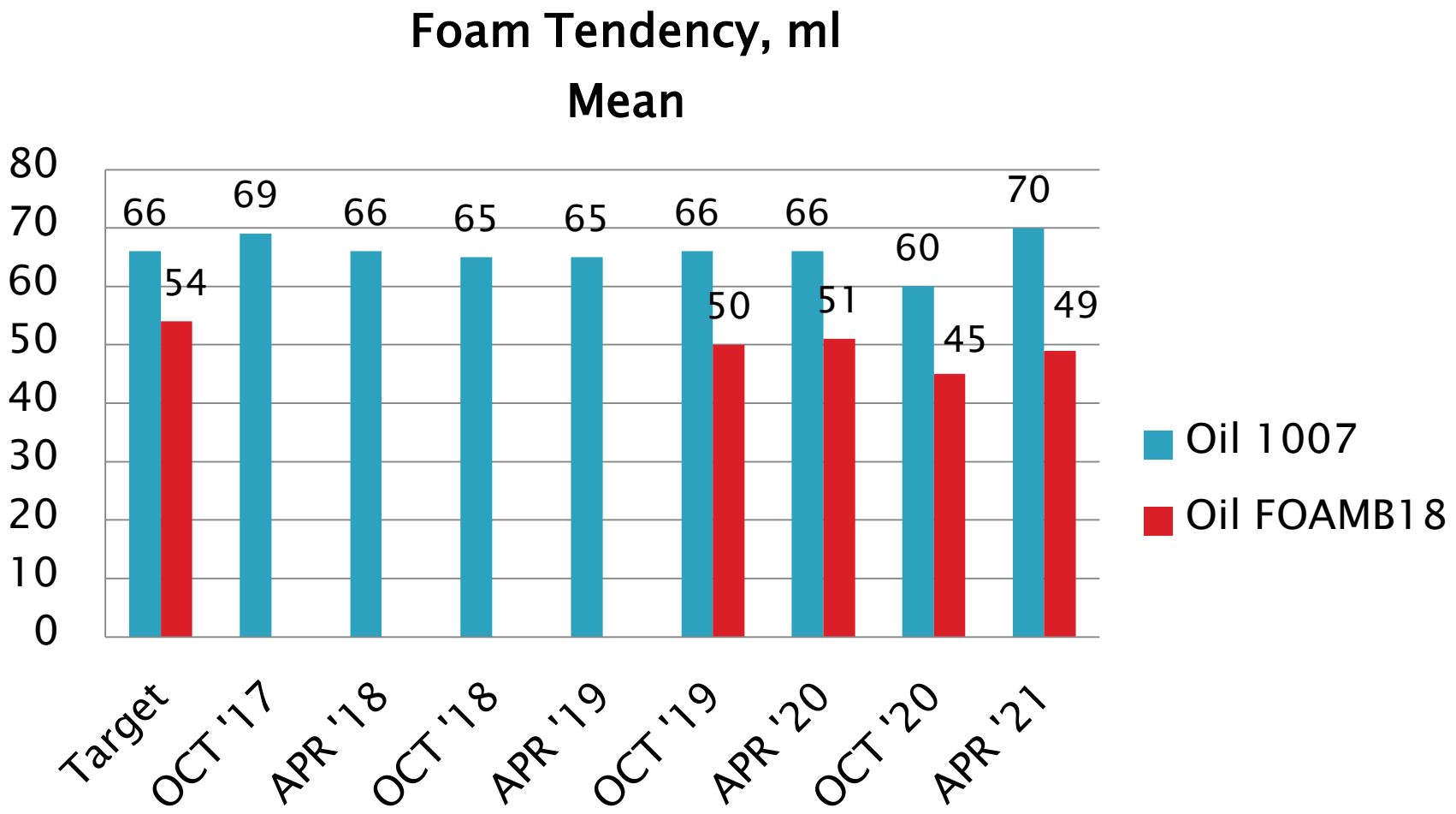
[2]Single OC result Yi=2.3 s severe included and excluded

D6082: High Temperature Foam

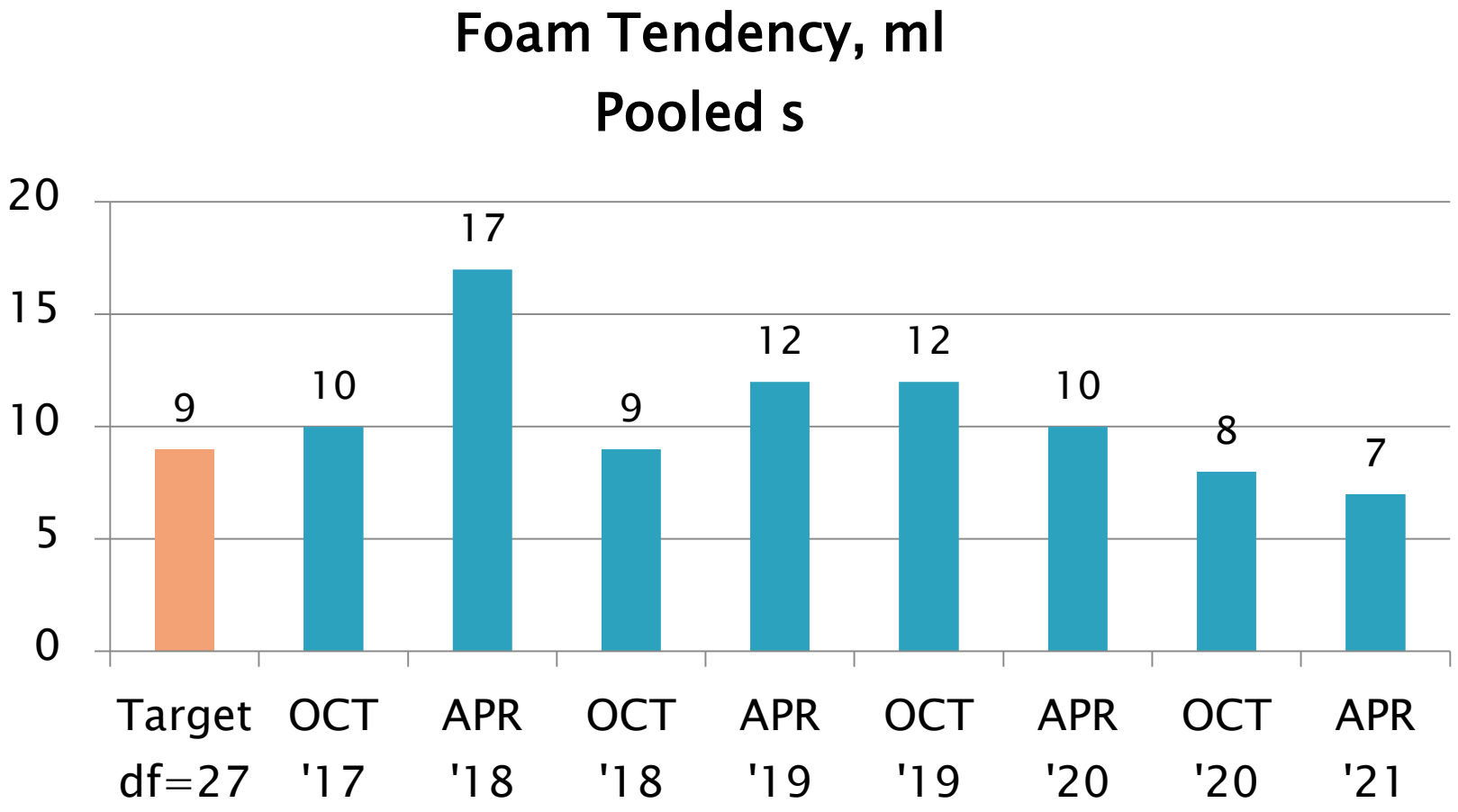
Period Precision and Severity Estimates

Foam Stability @ 1 min, ml	n	Mean	s
Current Targets	18	0.00	0.00
4/1/17 through 9/30/17	12	No non-zero occurrences	
10/1/17 through 3/31/18	14	No non-zero occurrences	
4/1/18 through 9/30/18	14	No non-zero occurrences	
10/1/18 through 3/31/19	14	No non-zero occurrences	
4/1/19 through 9/30/19	14	No non-zero occurrences	
10/1/19 through 3/31/20	15	No non-zero occurrences	
4/1/20 through 9/30/20	13	No non-zero occurrences	
10/1/20 through 3/31/21	12	No non-zero occurrences	

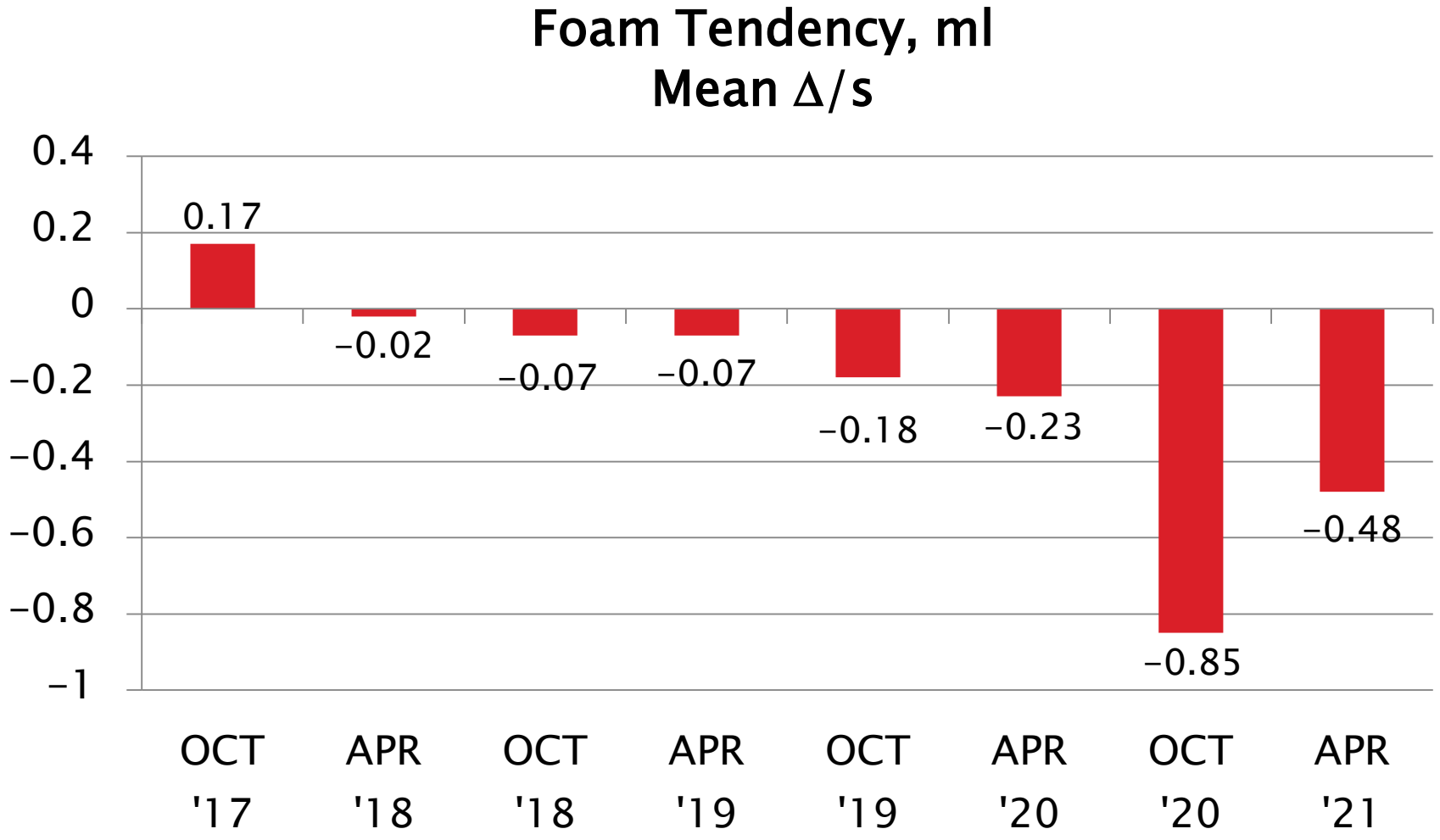
D6082 Performance by Oil



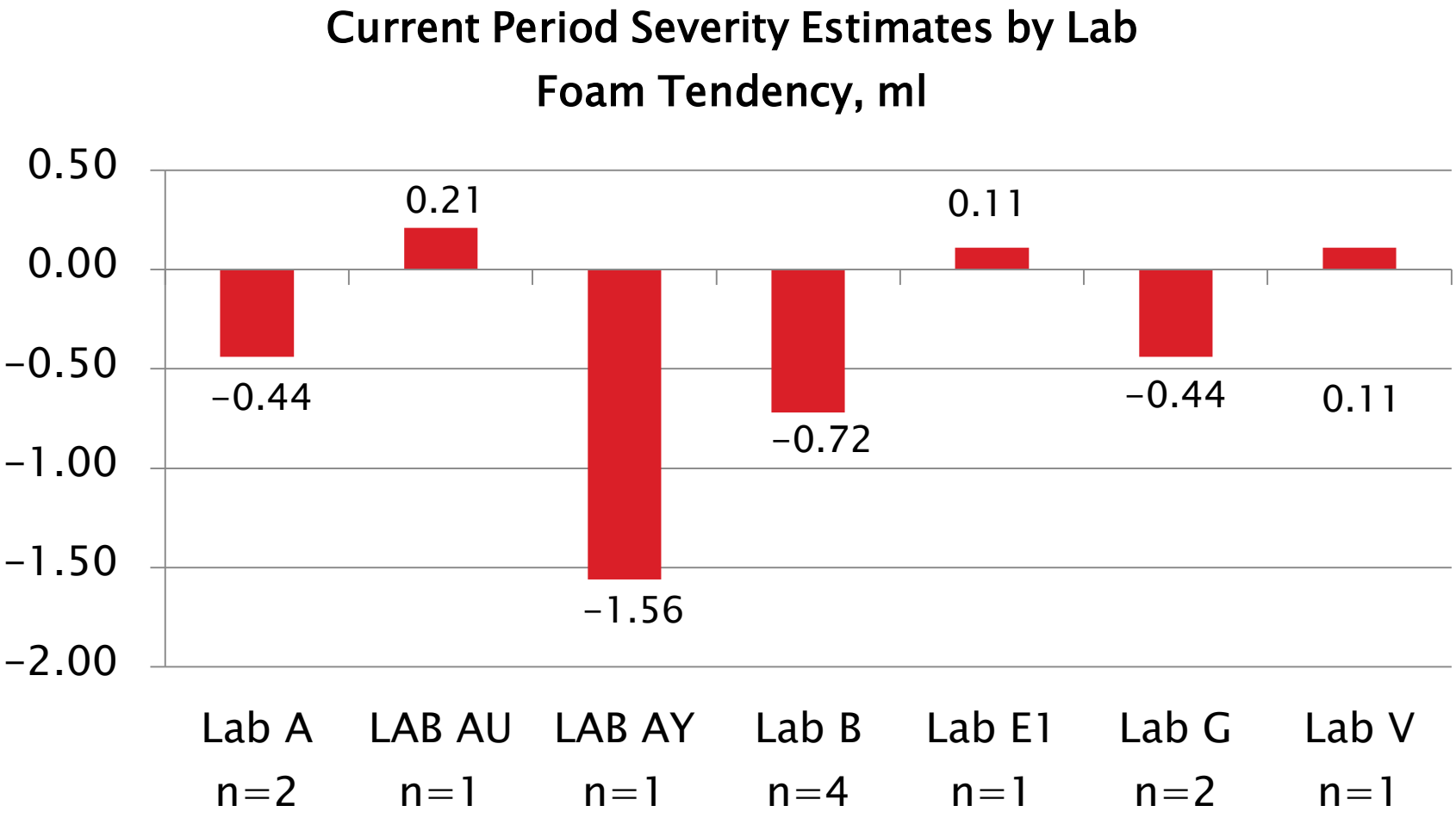
D6082: High Temperature Foam



D6082: High Temperature Foam



D6082: High Temperature Foam



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D6082: High Temperature Foam

- Foam Tendency Precision (Pooled s) is more precise than the prior report period
  - More precise than updated target precision
  - Target precision updated this period to current reference oil FOAMB18 only (oil 1007 removed from target precision calculation, replaced by oil FOAMB18)
    - Only one test this period was oil 1007; oil is nearly used up
- Performance (Mean Δ/s) is -0.48 s mild
  - Replacement reference oil FOAMB18 performing at -0.55 s mild (n=11)
  - Fourth consecutive period of mild performance on FOAMB18.
    - Target performance, set on 18 runs in a RR, may need revisited.
- No non-zero occurrences of Foam Stability
- All five severe oil discrimination runs (on TMC oil 66) demonstrated acceptable discrimination.

D6082 HIGH TEMPERATURE FOAM INDUSTRY OPERATIONALLY VALID DATA
IND in ('1007', 'FOAMB18')
FOAM TENDENCY

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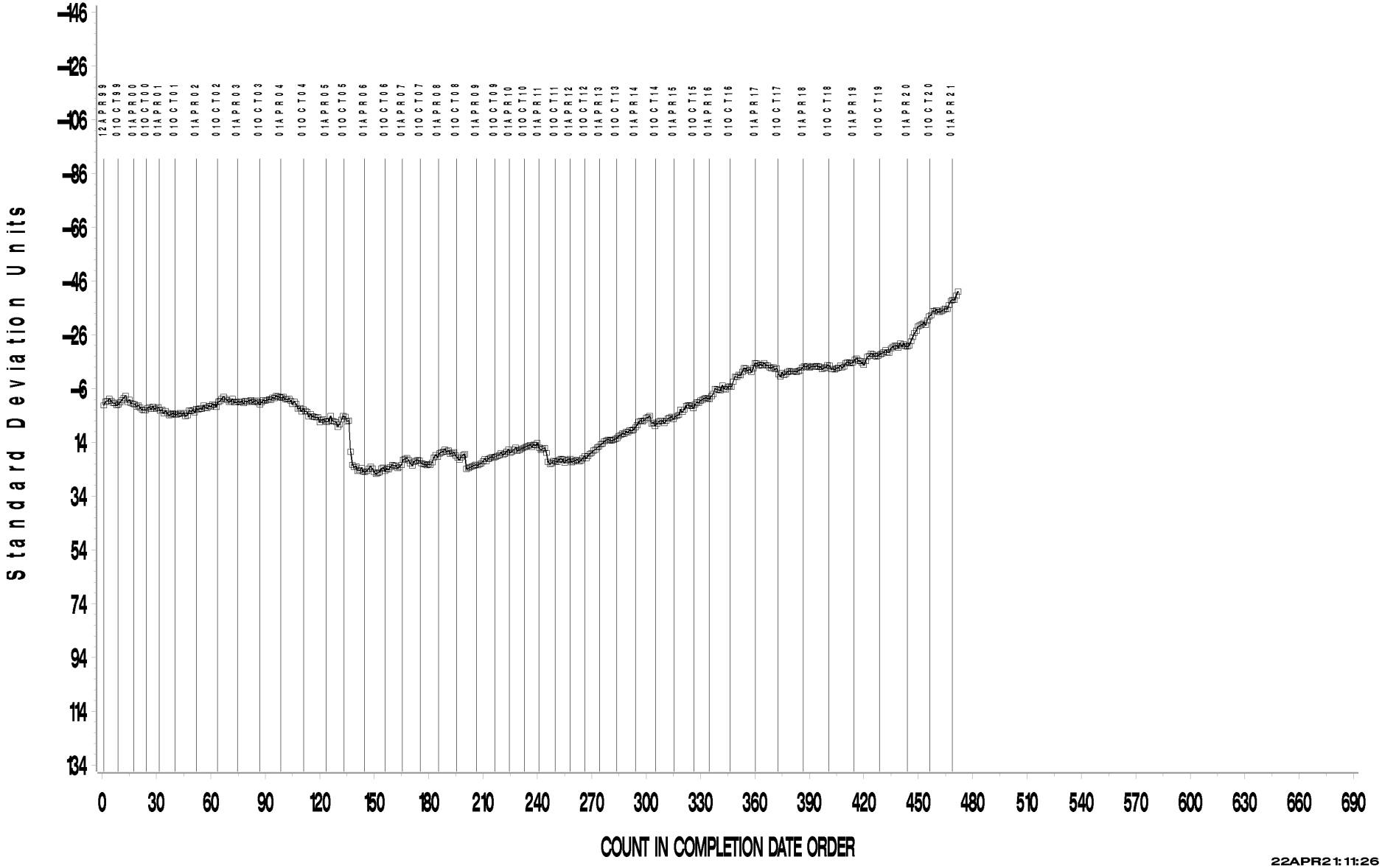
CUSUM Severity Analysis

Return to Executive Summary



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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	1
Total		**9**

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

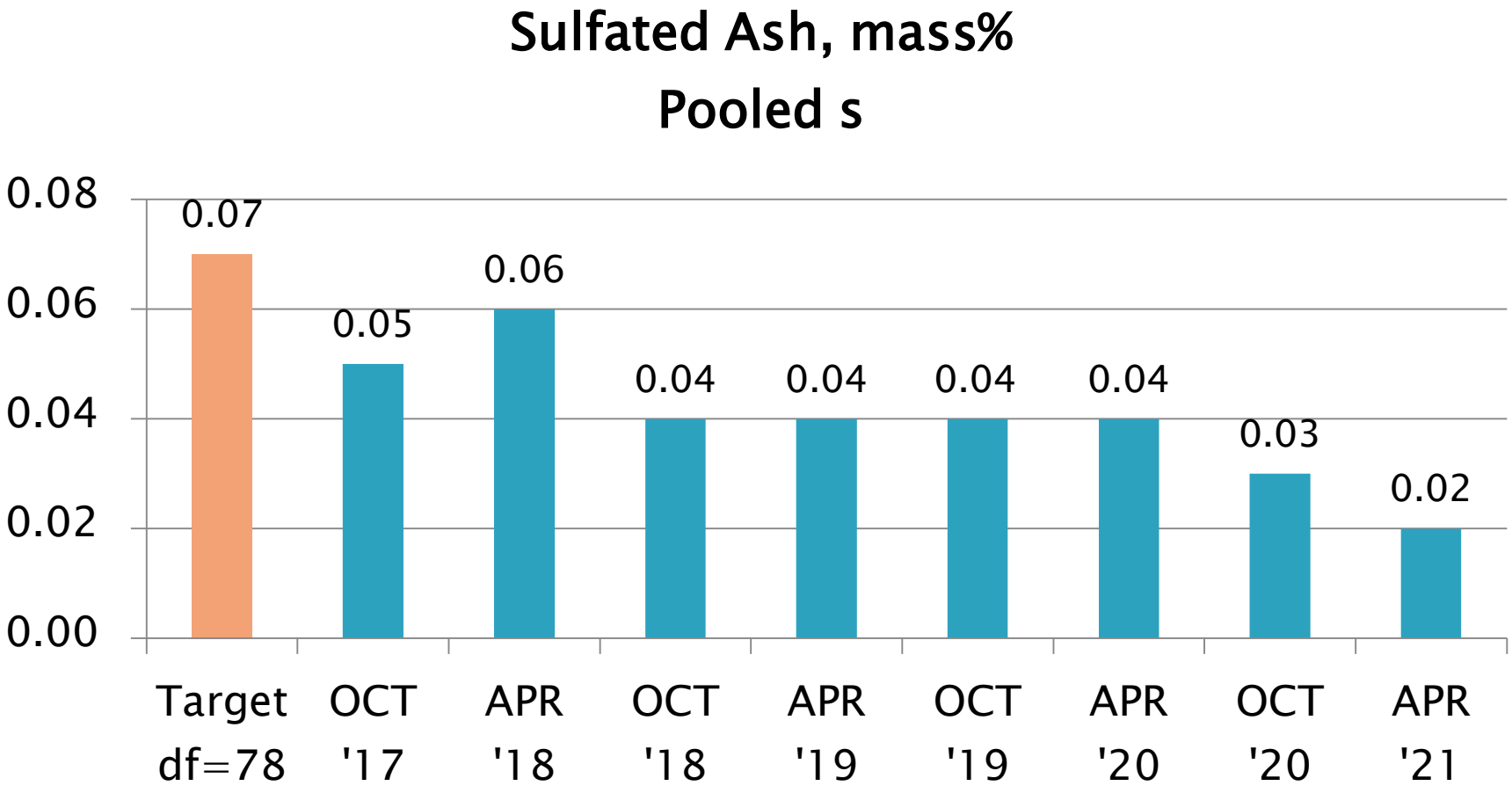
- No statistically invalid tests this period
- One operationally invalid tests reported this period:
  - Unstable EOT ash weight
- No D874 TMC technical updates were issued this period

D874: Sulfated Ash

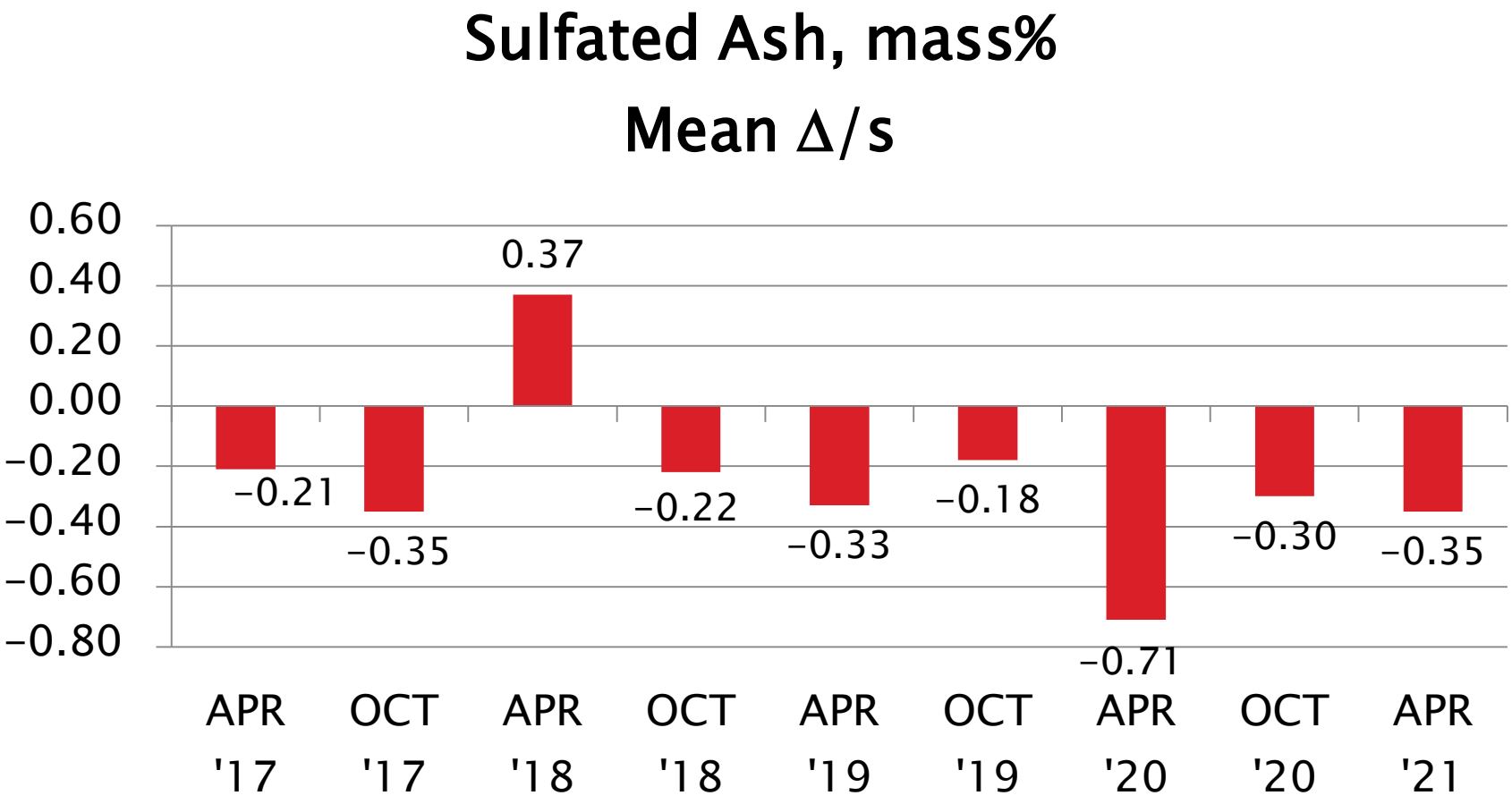
Period Precision and Severity Estimates

Total Deposits, mg	n	df	Pooled s	Mean Δ/s
Current Targets	81	78	0.07	-----
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
4/1/18 through 9/30/18	8	5	0.04	-0.22
10/1/18 through 3/31/19	8	5	0.04	-0.33
4/1/19 through 9/30/19	8	5	0.04	-0.18
10/1/19 through 3/31/20	7	4	0.04	-0.71
4/1/20 through 9/30/20	8	5	0.03	-0.30
10/1/20 through 3/31/21	8	5	0.02	-0.35

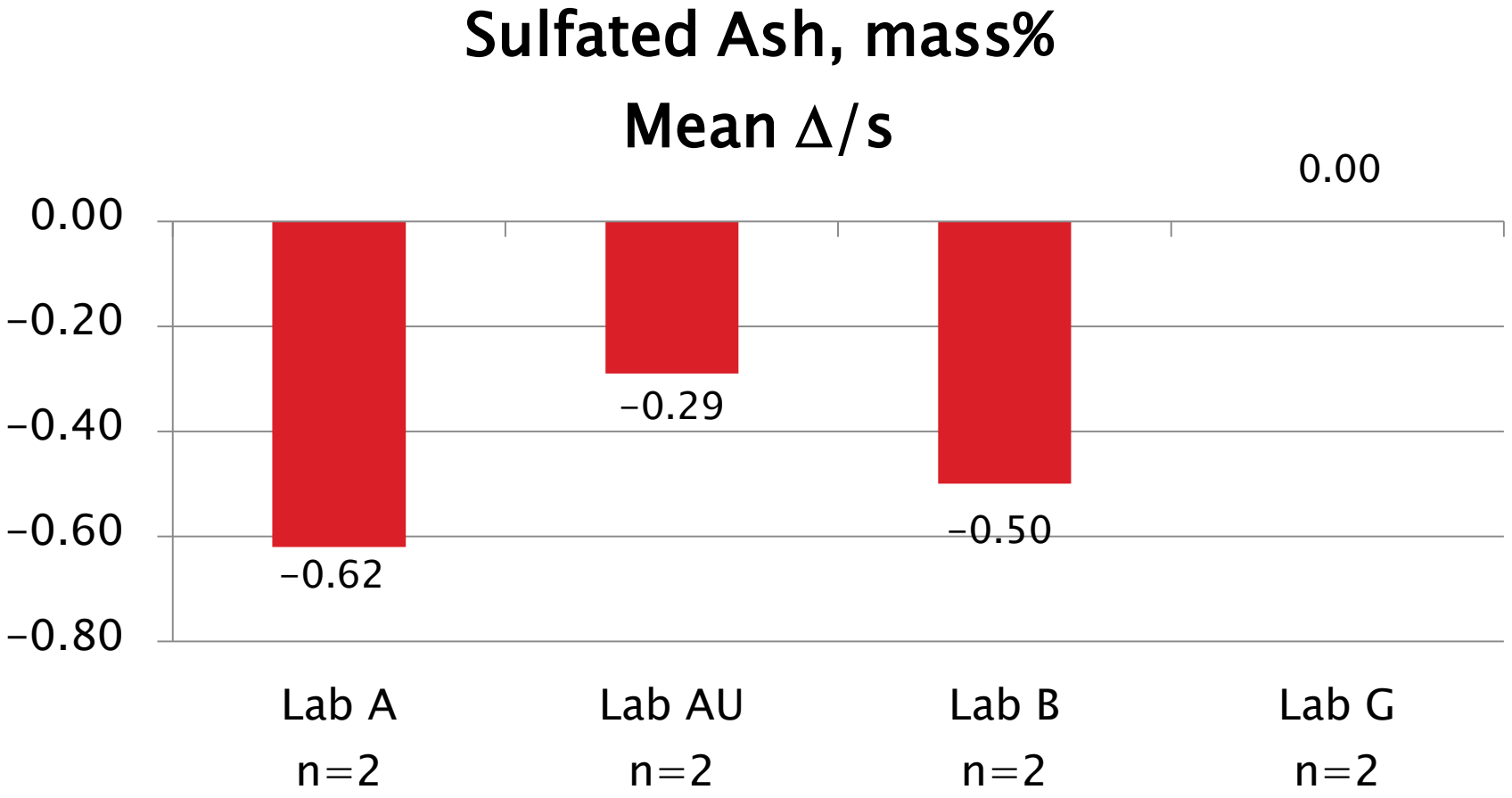
D874: Sulfated Ash



D874: Sulfated Ash



D874: Sulfated Ash



Test Monitoring Center
http://astmtmc.cmu.edu
A Program of ASTM International

D874: Sulfated Ash

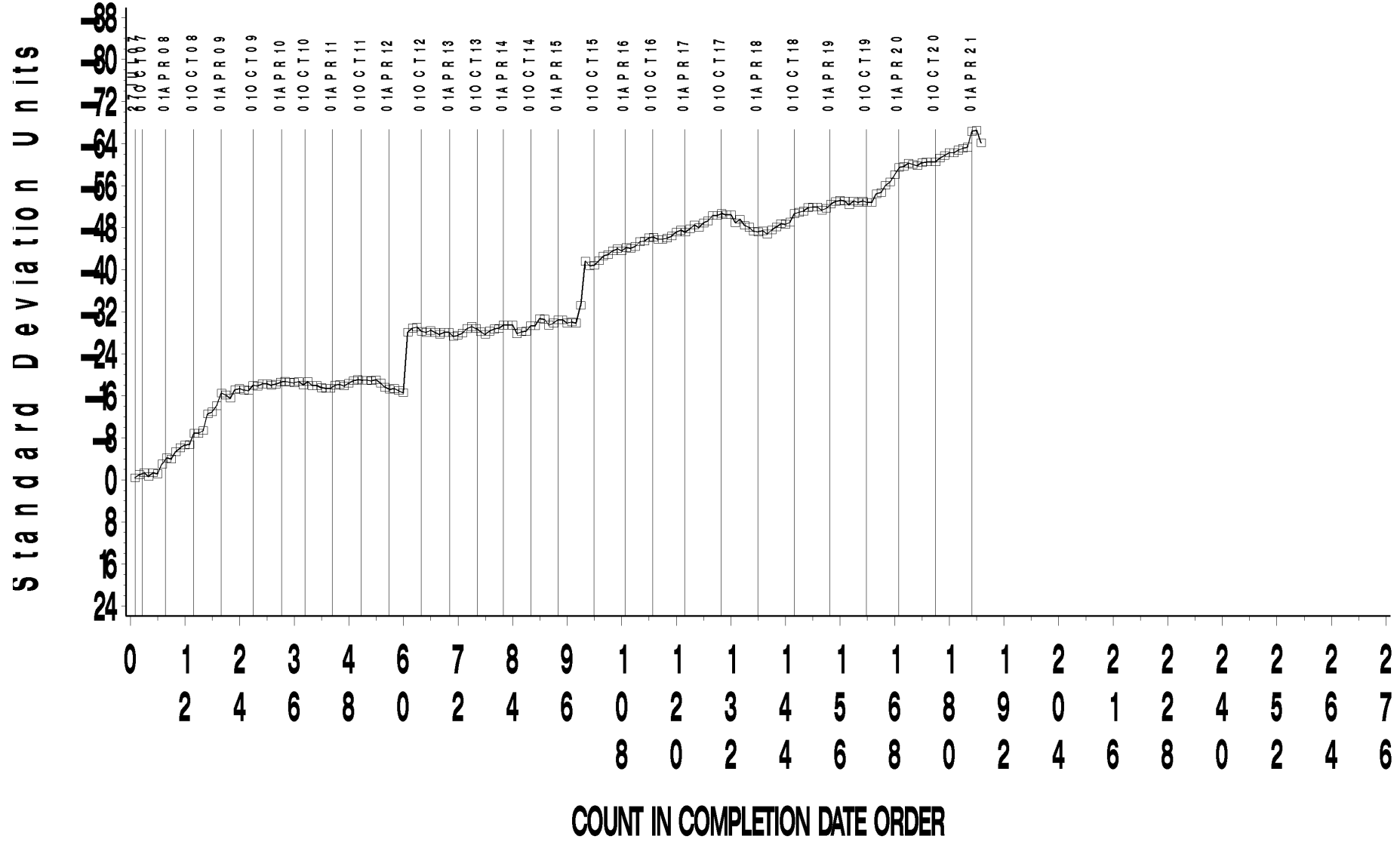
- Precision (Pooled s) is more precise than prior periods
  - More precise than target precision
- Performance (Mean Δ/s) is -0.35 s mild

D874 INDUSTRY OPERATIONALLY VALID DATA

TEST SAMPLE PERCENT SULFATED ASH

A Program of ASTM International

CUSUM Severity Analysis



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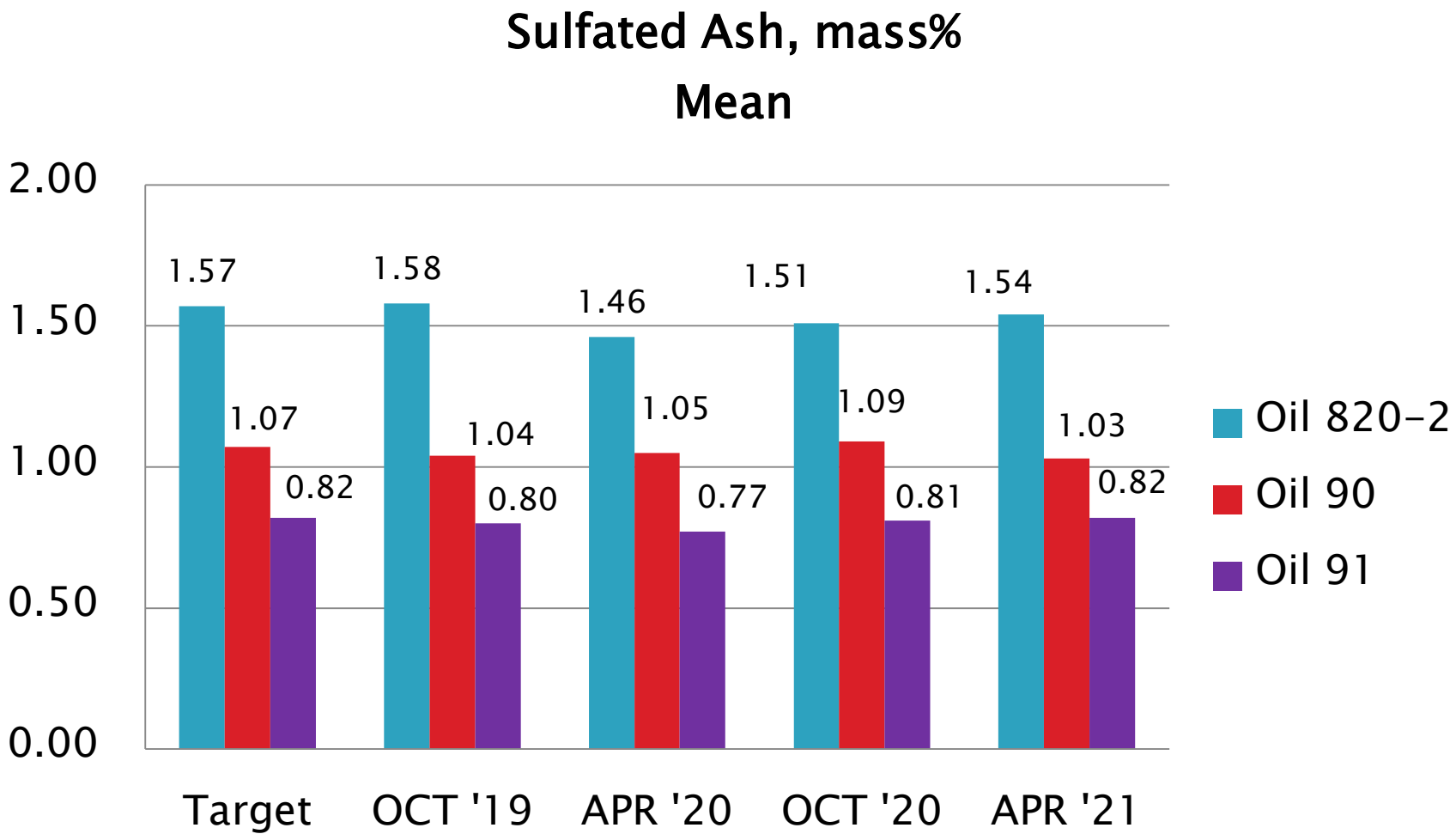
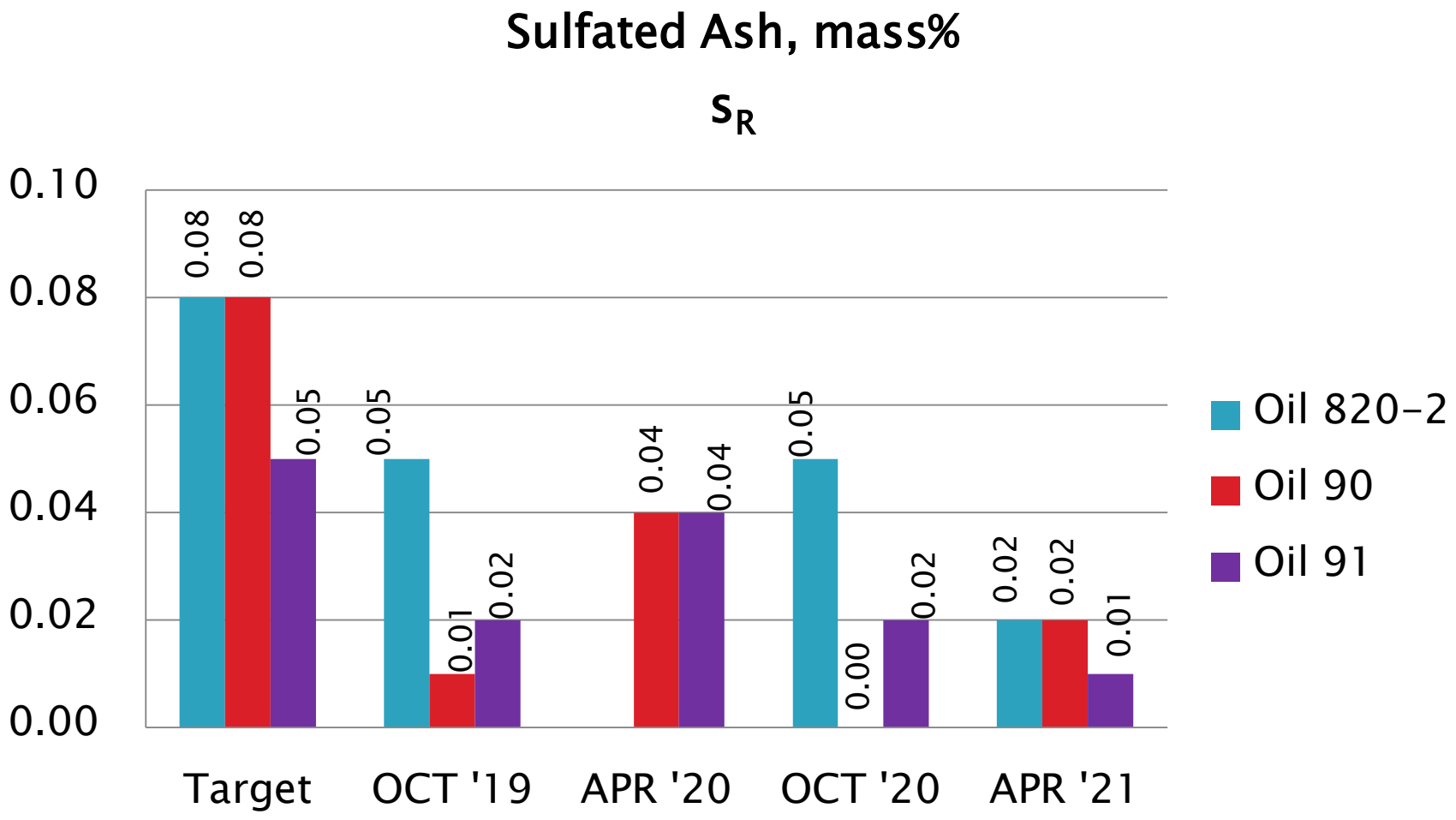
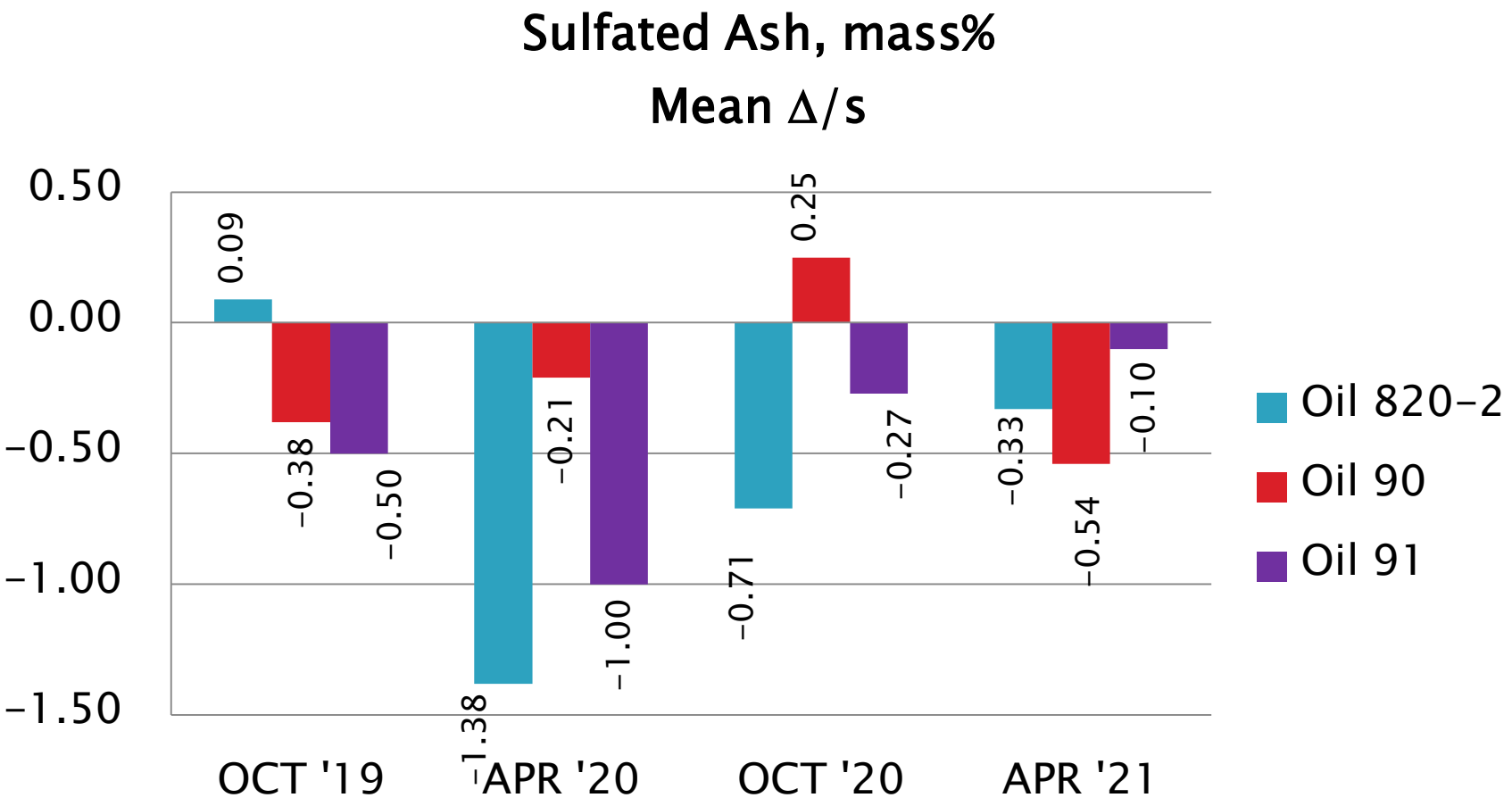
D874: Sulfated Ash



D874: Sulfated Ash



D874: Sulfated Ash



Return to Executive Summary

D7528: Oxidation by ROBO

Test Status	Validity Code	No. Tests
Acceptable Calibration Test	AC	90
Failed Calibration Test	OC	23
Operationally Invalidated by Lab	LC, XC	22
Operationally Invalidated After Initially Reported as Valid	RC	1
Held out of statistics (new rigs, failed to calibrate)	MC	2
Industry Information Run (436 RR)	AG	15
Total		**153**

Number of Labs Reporting Data: 8
Fail Rate of Operationally Valid Tests: 20%

D7528: Oxidation by ROBO

Statistically Unacceptable Tests (OC)	No. Of Tests
Natural Log (MRV Viscosity) Mild	10
Natural Log (MRV Viscosity) Severe	13

- There was one ROBO technical update issued this period:
  - Memo 20-58, January 15, 2021, Subject Updated Reference Oil Targets

- Subsequent ROBO Calibration requirement updates are issued as LTMS document updates

D7528: Oxidation by ROBO

Operationally Invalid Calibration Tests

- 5 tests NO_2 flow off-spec (LC, XC)
- 7 tests vacuum leak or vacuum failure (LC, XC)
- 2 tests power failure (XC)
- 1 test exhibited unexpected yield stress (RC)
- 1 test excess EOT volatiles (XC)
- 2 tests stirrer failure (LC)
- 3 tests condenser leak (LC)
- 1 test cracked reactor vessel (LC)
- 1 test wrong CCS temperature

Other Tests

- 2 tests held out of statistics (MC), failed to demonstrate passing calibrations on new rigs
- 15 industry information tests (AG) on proposed new oil 436

D7528: Oxidation by ROBO

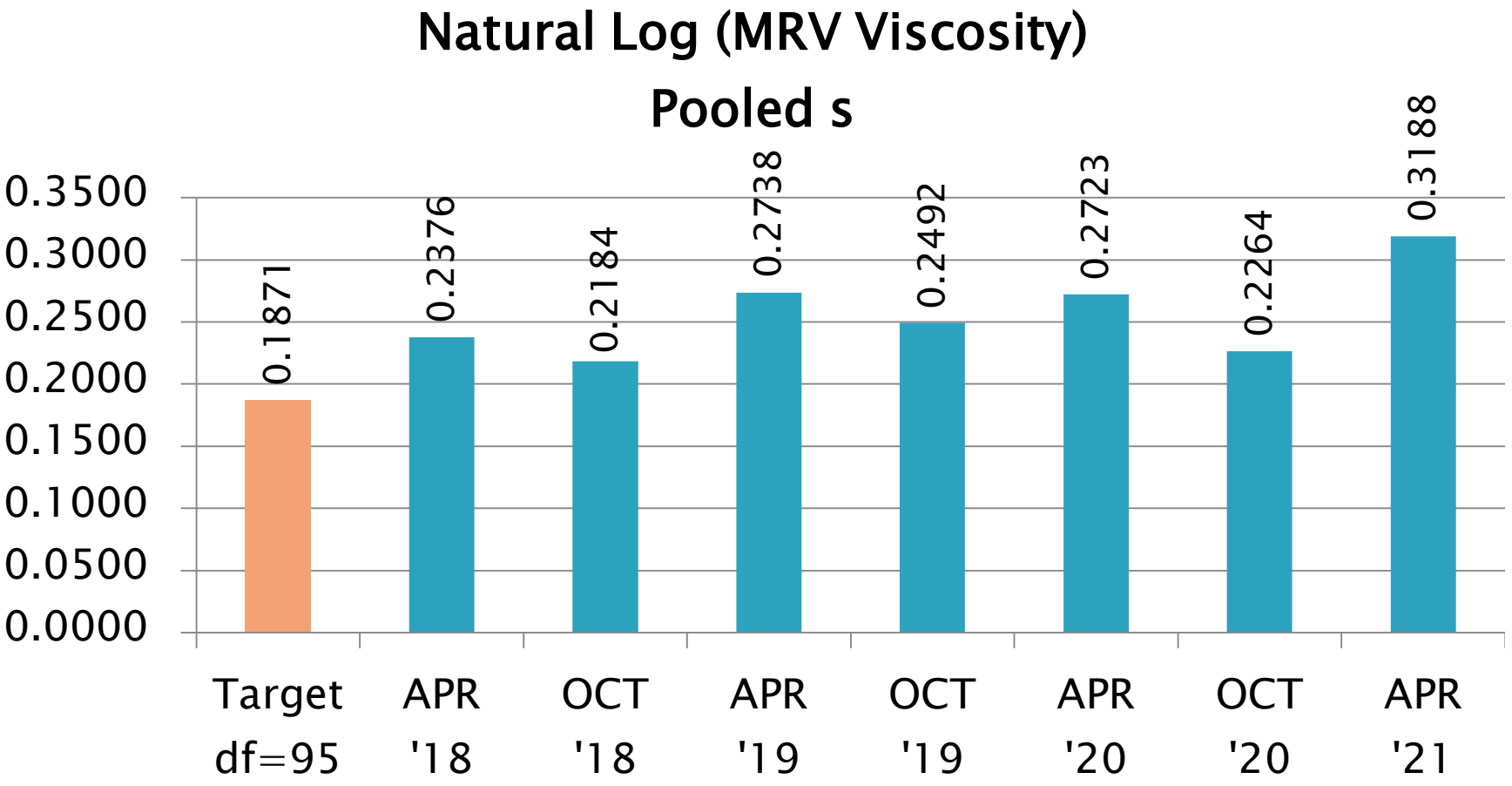
Period Precision and Severity Estimates

Natural Log (MRV Viscosity)	n	df	Pooled s	Mean Δ/s
Targets Updated 20201001[1]	99	95	0.1871	-----
10/1/17 through 3/31/18[2]	90	86	0.2376	-0.91
10/1/17 through 3/31/18[2]	83	79	0.2076	-0.74
4/1/18 through 9/30/18	126	122	0.2184	-0.49
10/1/18 through 3/31/19	100	96	0.2738	0.04
4/1/19 through 9/30/19	95	91	0.2492	-0.32
10/1/19 through 3/31/20	158	153	0.2723	-0.10
4/1/20 through 9/30/20	119	113	0.2264	-0.76
10/1/20 through 3/31/21	113	108	0.3188	-0.11

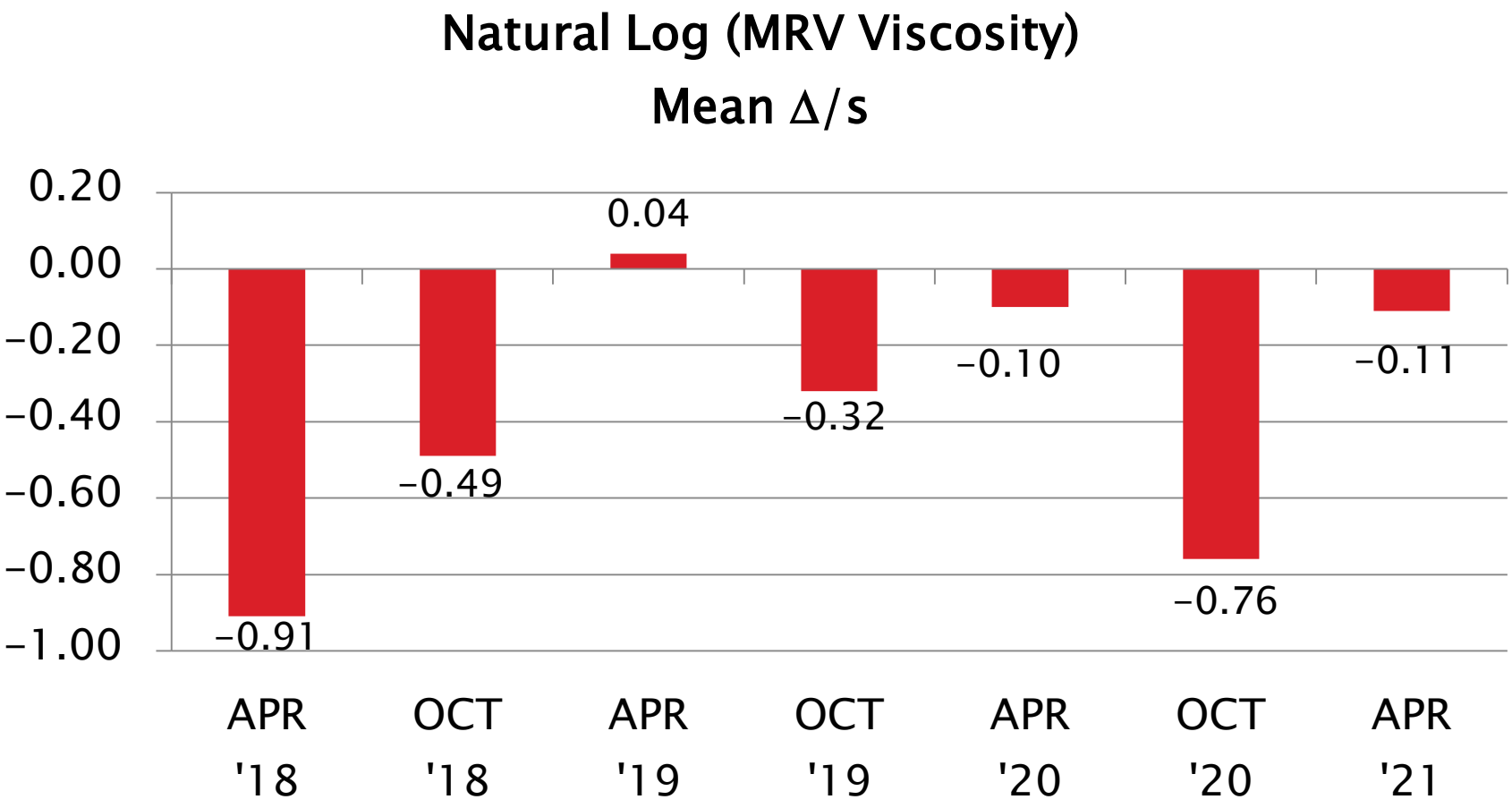
[1]Updated targets to include period primary oils 434-2, 434-3, 435-1 and 438-2

[2]Period statistics with seven suspect results from two rigs included and excluded

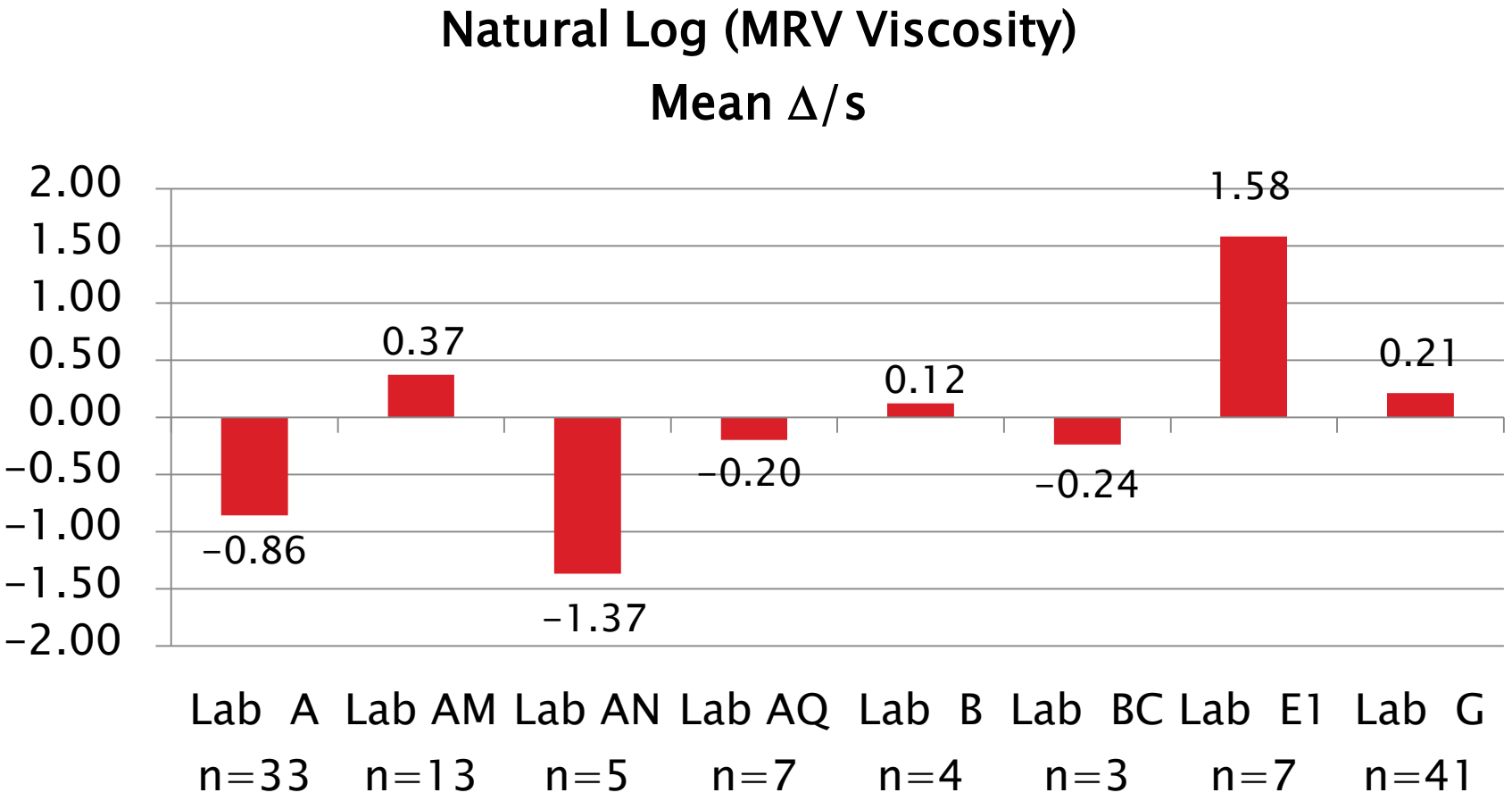
D7528: Oxidation by ROBO



D7528: Oxidation by ROBO



D7528: Oxidation by ROBO



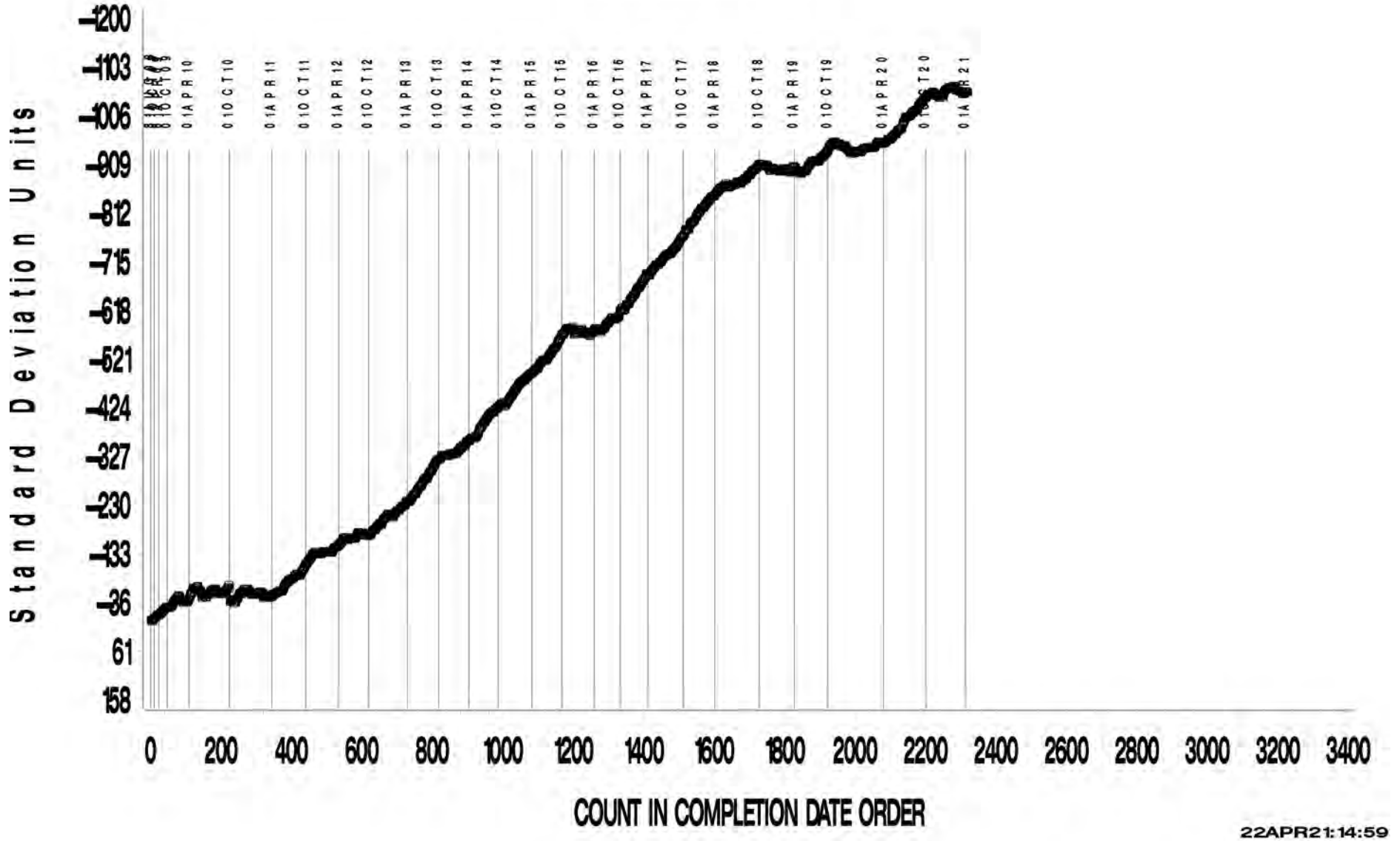
D7528: Oxidation by ROBO

- Precision (Pooled s) is less precise than last period
  - Less precise than all periods since at least April 2018
  - Continues to be less precise than target
  - Target precision updated to include primary period reference oils 434-2, 434-3, 435-1 and 438-2
- Performance (Mean Δ/s) is -0.11 s mild for this report period
- CUSUM severity plot shows variable performance the past three report period

ROBO TEST INDUSTRY OPERATIONALLY VALID DATA

AGED OIL MRV APPARENT VISCOSITY

CUSUM Severity Analysis



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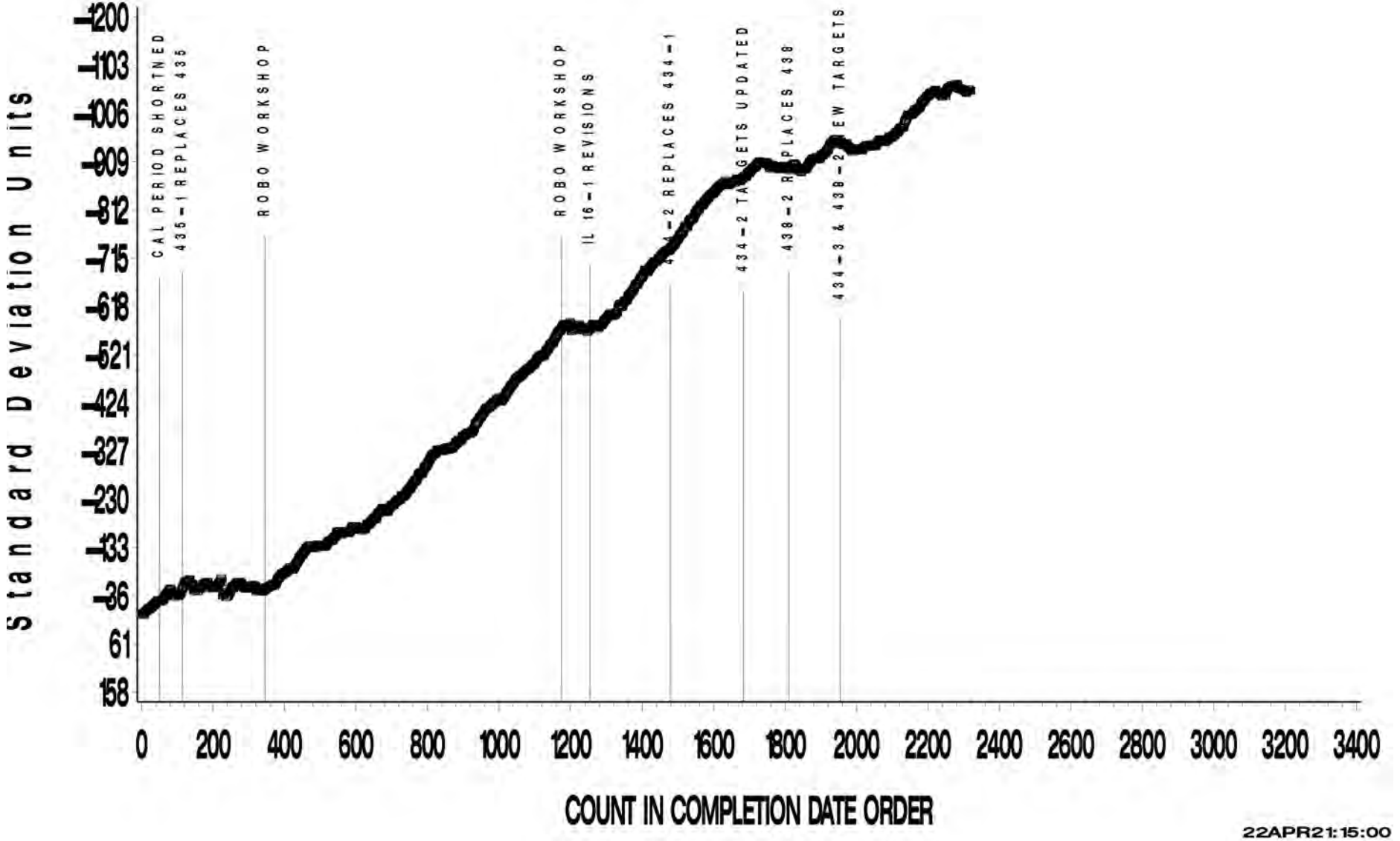
ROBO TEST INDUSTRY OPERATIONALLY VALID DATA

AGED OIL MRV APPARENT VISCOSITY

CUSUM Severity Analysis



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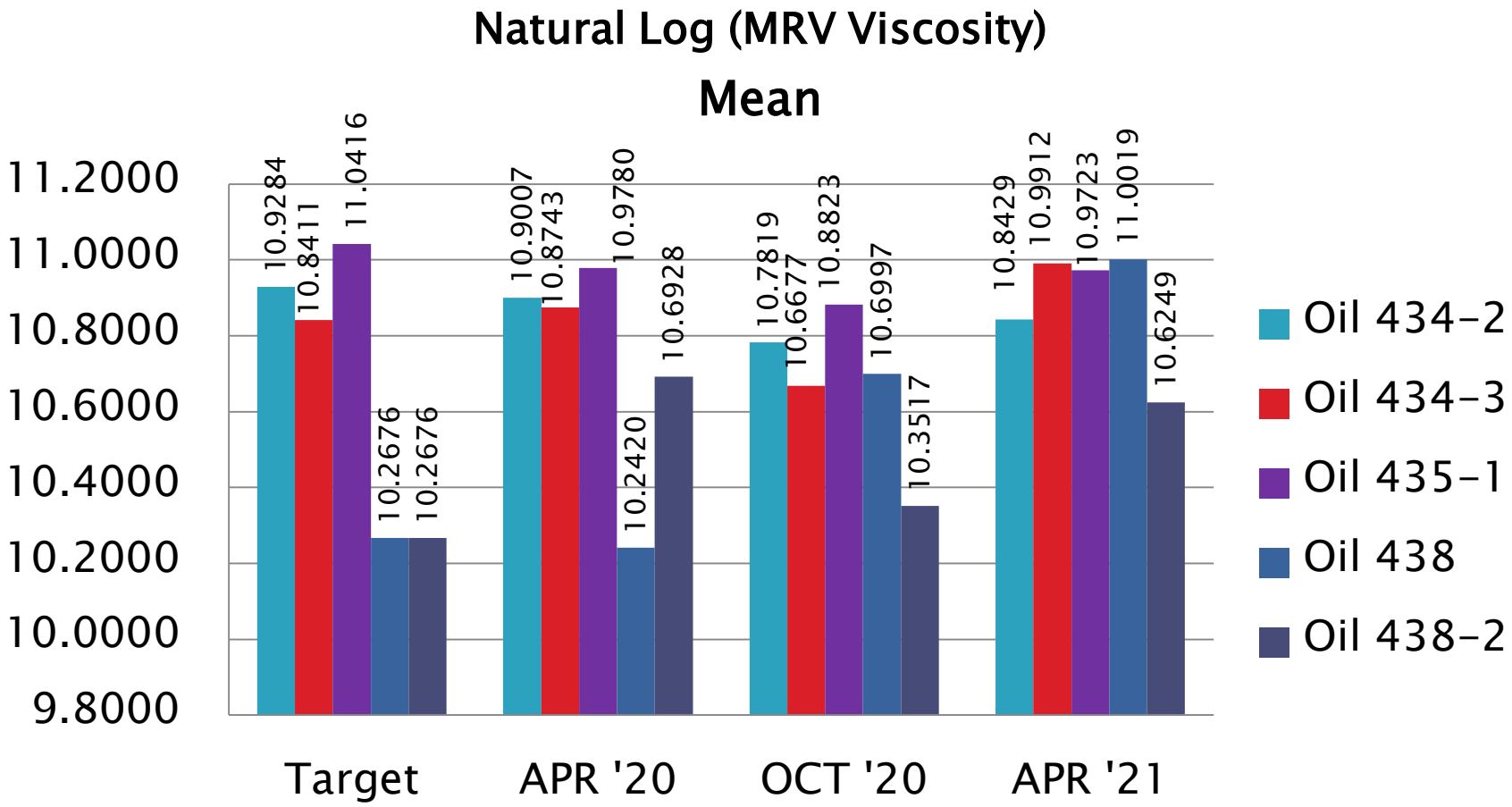
D7528: Oxidation by ROBO



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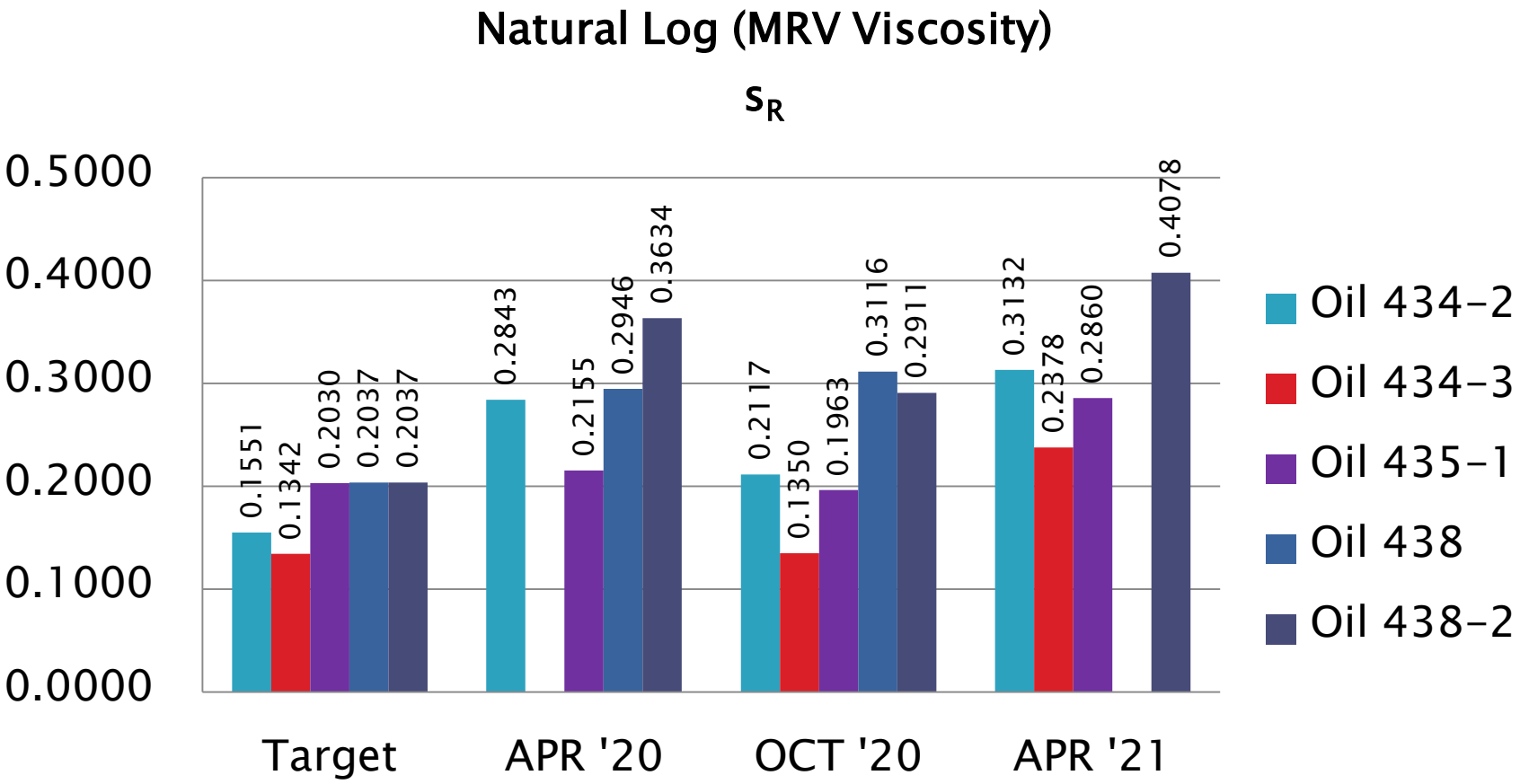

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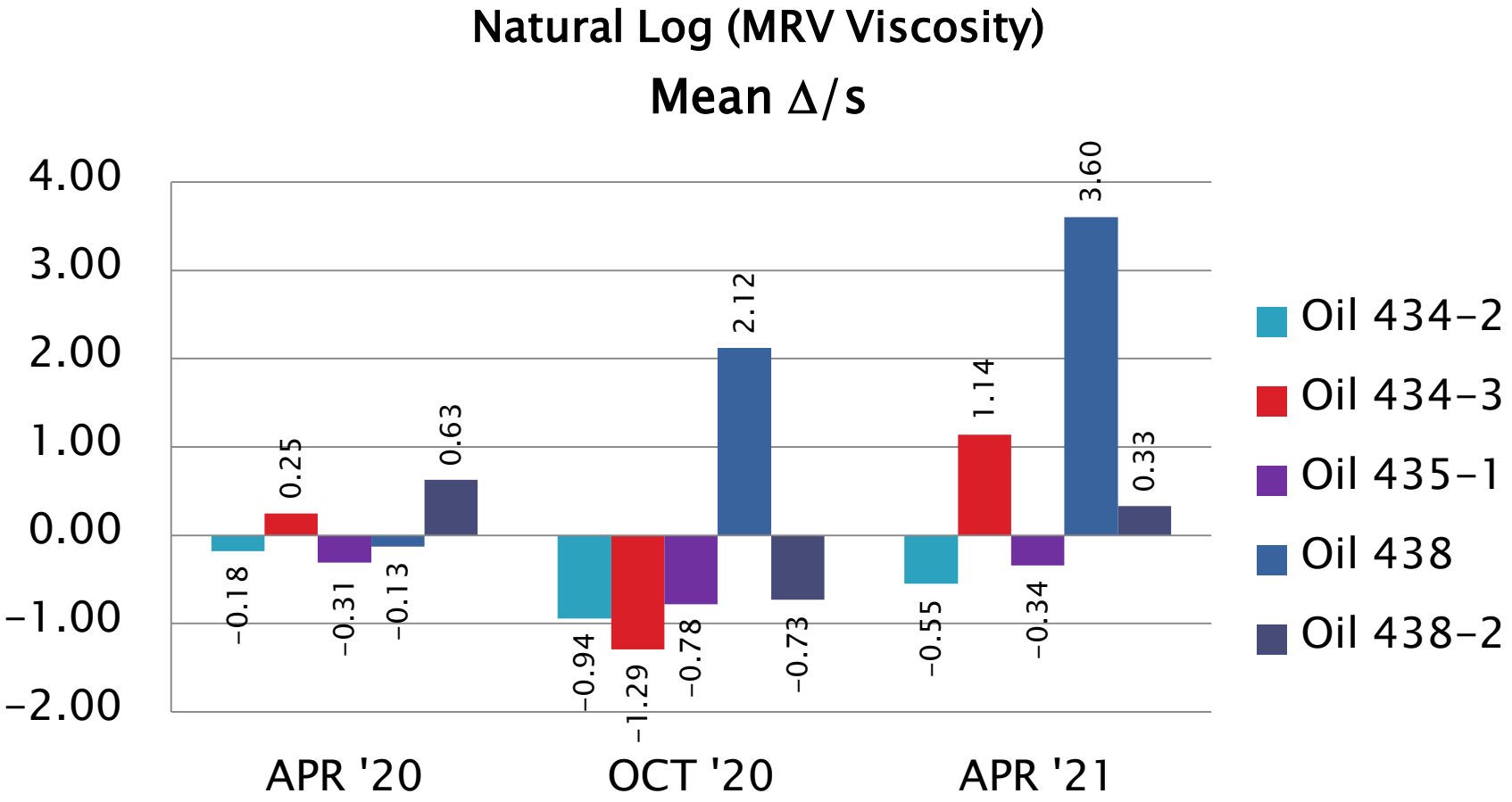

Return to Executive Summary

Reference Oil Inventory

- As of 3/31/2021

Reference Oil Inventory

D5800

Oil	Year Rec'd By TMC[A]	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
VOLC12	2013	D5800	28.9	1.4
VOLD12	2013	D5800	27.3	1.3
VOLE12	2013	D5800	25.0	1.4
VOLD18	2018	D5800QC	851	116

[A] The integrity of TMC reference oils is confirmed annually by analytical QC testing of chemical and physical properties.

Reference Oil Inventory

D6417, GI

Oil	Year Rec'd By TMC[A]	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
52	1995	D6417	59.4	0.01
55	1995	D6417	66.0	0.01
58	1998	D6417, D6417QC, GI	113.9	1.3
GIA17	2017	GI	8.5	1.3
1009	2002	GI	36.8	0.9

[A] The integrity of TMC reference oils is confirmed annually by analytical QC testing of chemical and physical properties.

Reference Oil Inventory

TEOST, MTEOS & ROBO

Oil	Year Rec'd By TMC[A]	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
432	1998	MTEOS	102.9	0.5
75-1	2016	TEOST	5.5	1.5
435-2[B]	2010	TEOST	39.8	0.6
434-3[B]	2017	ROBO/MTEOS	34.8	9.8
435-1	2008	ROBO	358	24.3
436[B]	2014	ROBO	47.9	7.1
438-2[B]	2017	ROBO	37.5	0.0

[A]The integrity of TMC reference oils is confirmed annually by analytical QC testing of chemical and physical properties.

[B] Multi-test oil; estimated aliquot reserved for bench testing.

Reference Oil Inventory

D6082 & D874

Oil	Year Rec'd By TMC[A]	Tests	TMC Inventory, gallons	Gallons Shipped last 12 months
FOAMB18	2018	D6082	88.7	1.7
66	2002	D6082	75.4	0.7
820-2	2001	D874	8.8	0.1
90	2005	D874/D874QC	14.9	1.1
91	2006	D874	3.5	0.1

[A] The integrity of TMC reference oils is confirmed annually by analytical QC testing of chemical and physical properties.

Additional Information

Additional Information

- Available on the TMC's Website:
  - Lubricant Test Monitoring System (LTMS) Document
  - 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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