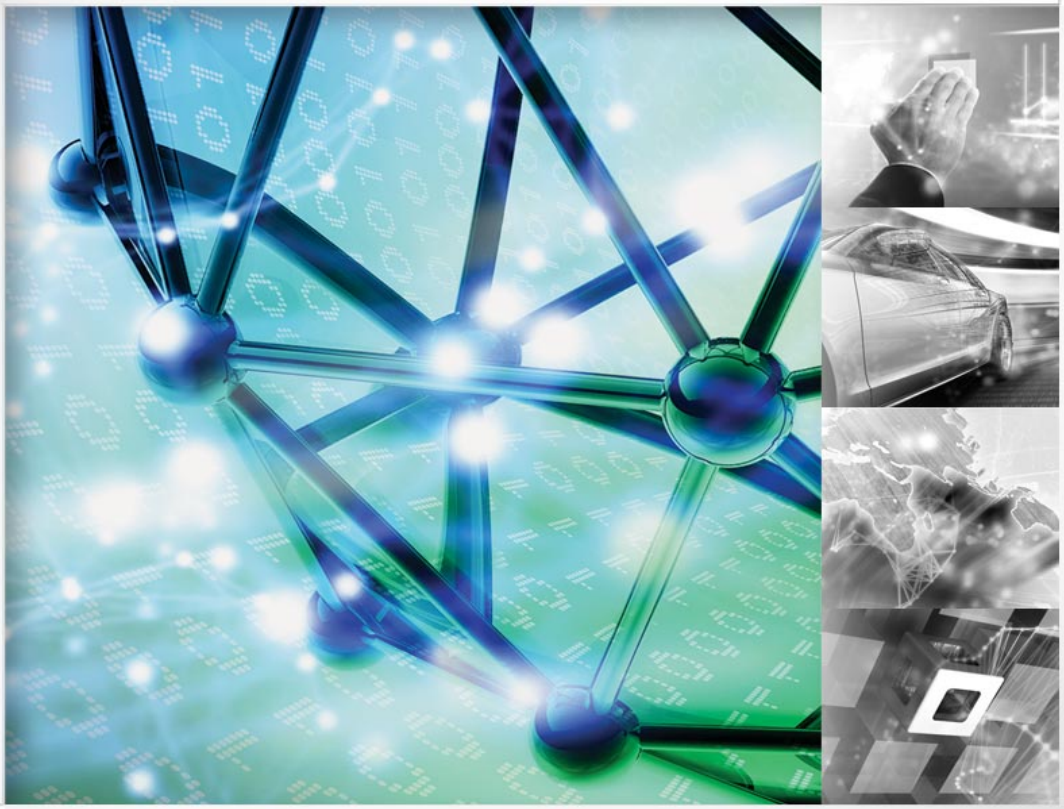

Caterpillar 1N TGF Dilemma

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September 2016

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Summary

SUCCESS TOGETHER

- 1Y3998 Liners introduced in 2004
- Analysis from 2014 analysis shows very strong statistical evidence that 1Y3998 Liners mild on 1N TGF
  - Industry correction (+0.419954) on LN(Y+1) scale introduced
- Correction factor worked fairly well through April 2015
- Since May 2015 there is evidence that correction factor does not work for most labs due to an unknown issue
  - RO 809 has moved **MILD** of target
  - RO 811 has moved **SEVERE** of target
    - RO 811 results also more variable
      - Perhaps due to Lab/Reproducibility
  - However, Lab A looks fine so far
- This is a MAJOR issue with no satisfactory solution
  - RO 809 and RO 811 have diverged in TGF severity & precision
  - Several options are offered

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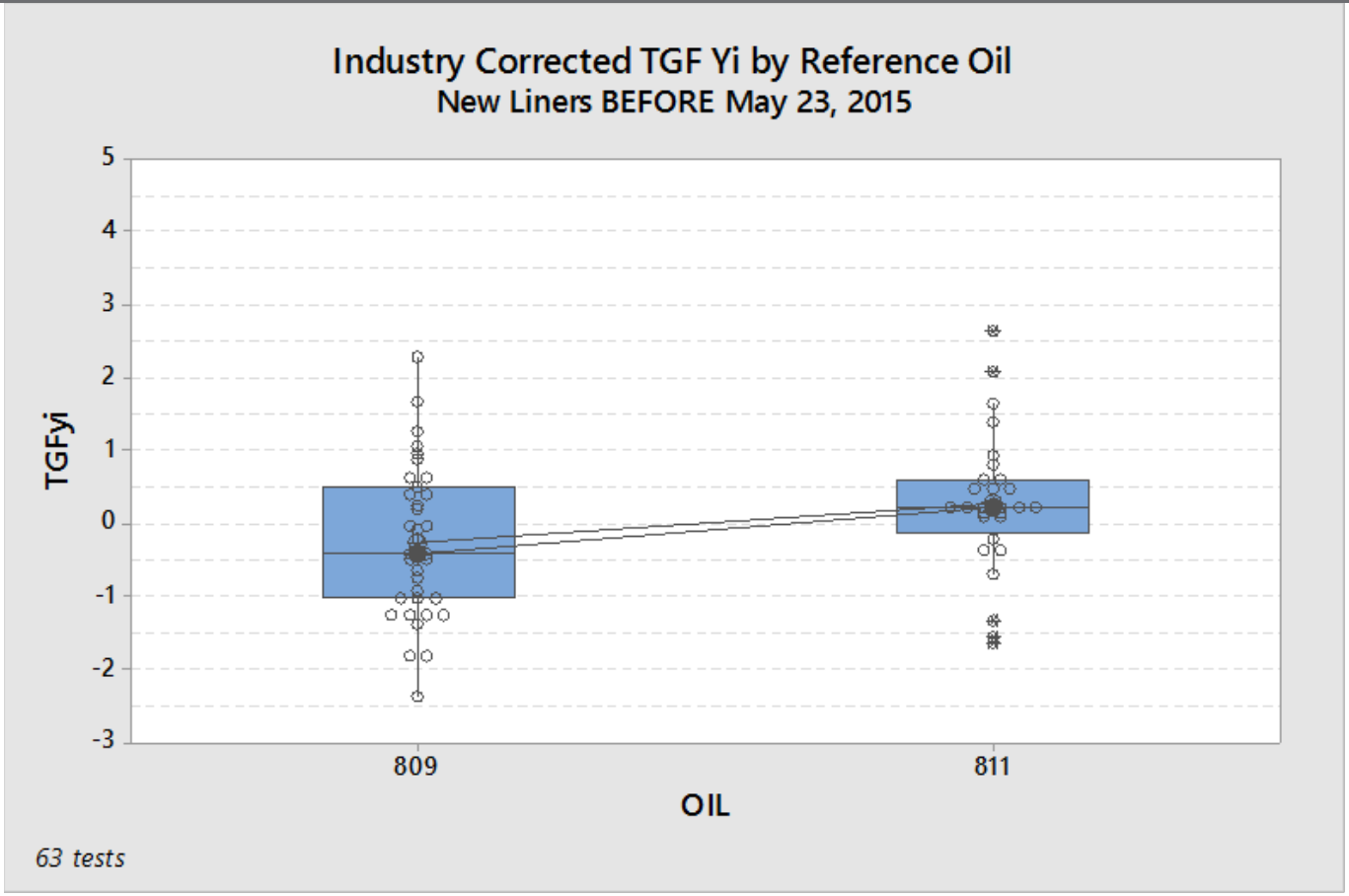
TGF Yi on 1Y3998 Liners Through April 2015



- Correction factor adequate through April 2015
  - 809 slightly mild
  - 811 on target to slightly severe

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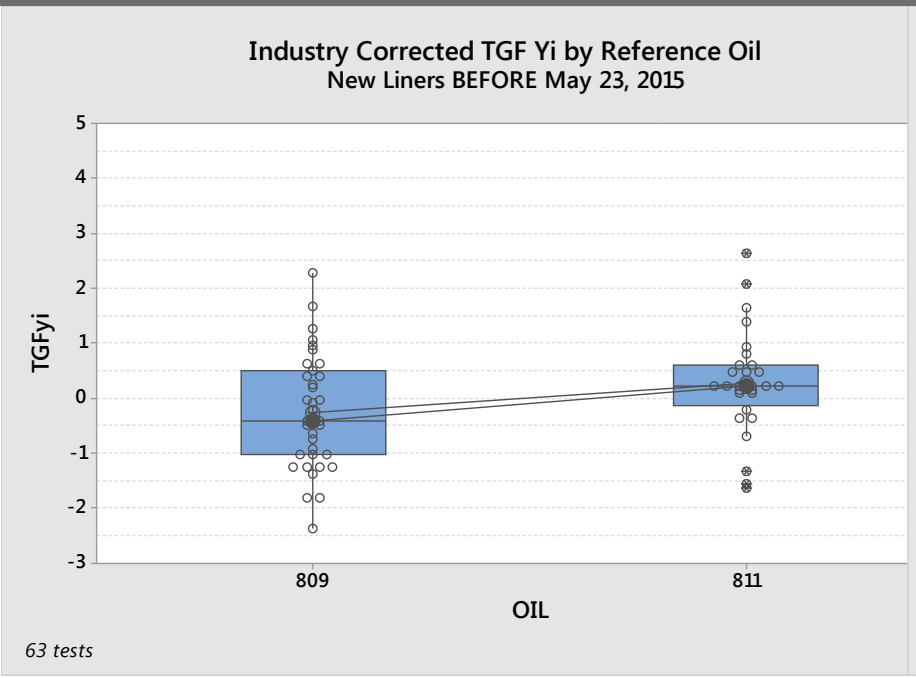
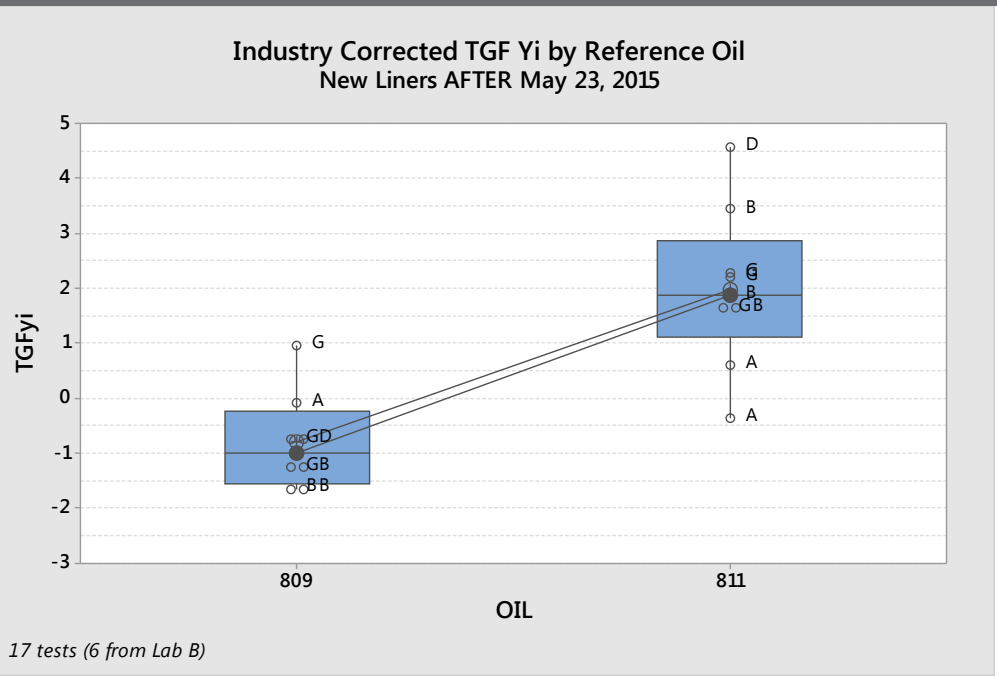
Evidence of Issue

SUCCESS TOGETHER



63 tests



17 tests (6 from Lab B)

- Since May 23, 2015
  - 809 has moved mild of target
  - 811 has moved very severe of target and exhibits greater variability
  - Correction factor under correcting for 809 and over correcting for 811

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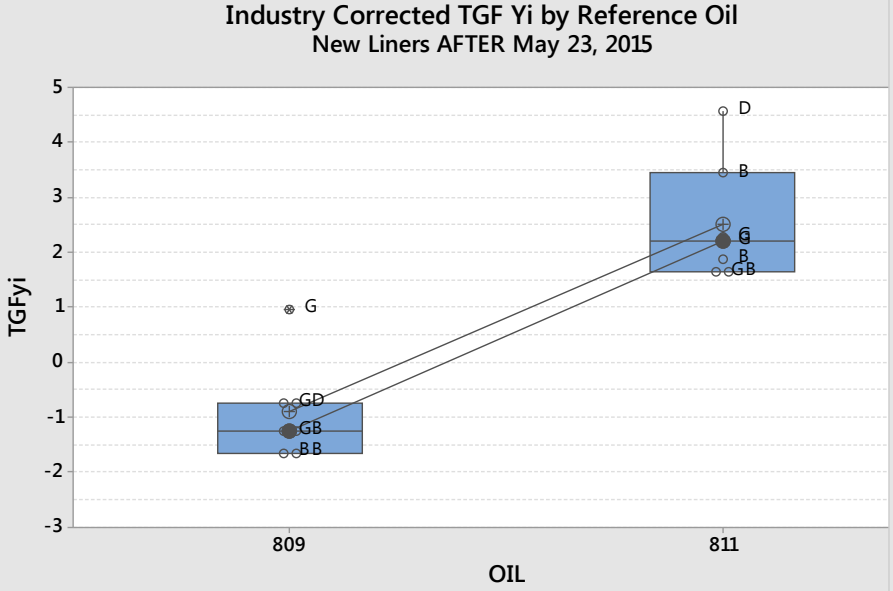
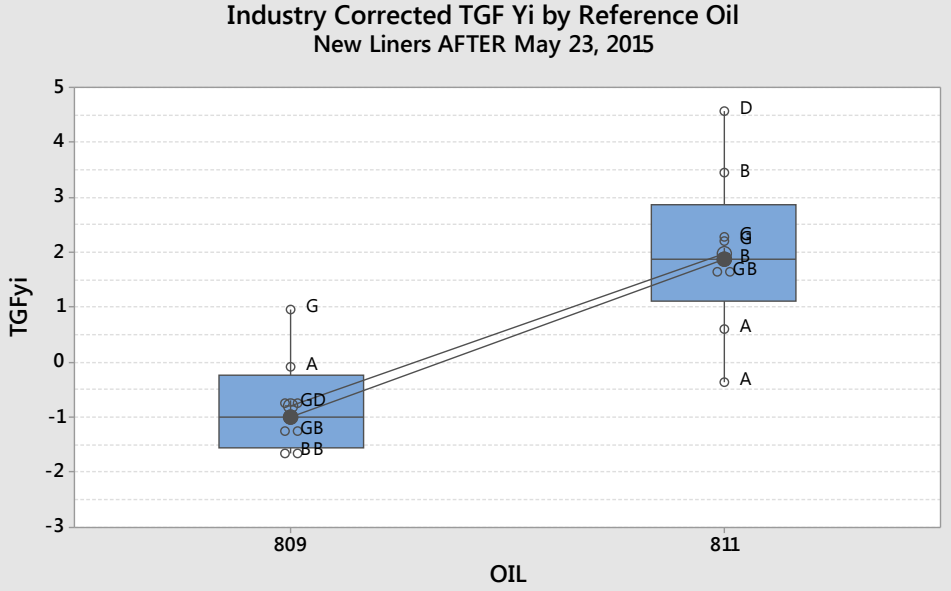
Evidence of Issue: What About Lab A



14 tests (Lab A Removed)



17 tests (6 from Lab B)

- 3 tests on Lab A right around target
  - Lab A does not appear to be affected
  - Situation now appears worse for Labs B, D and G

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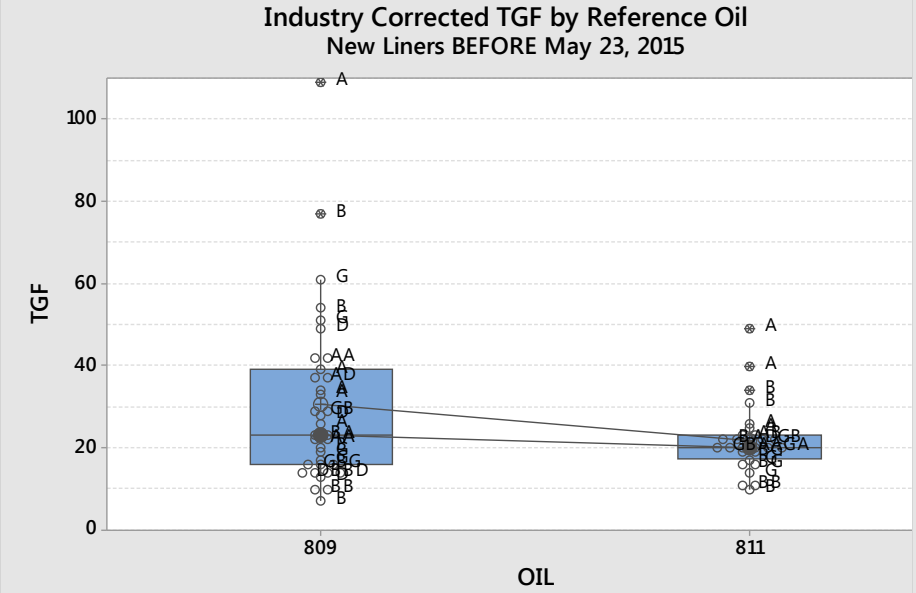
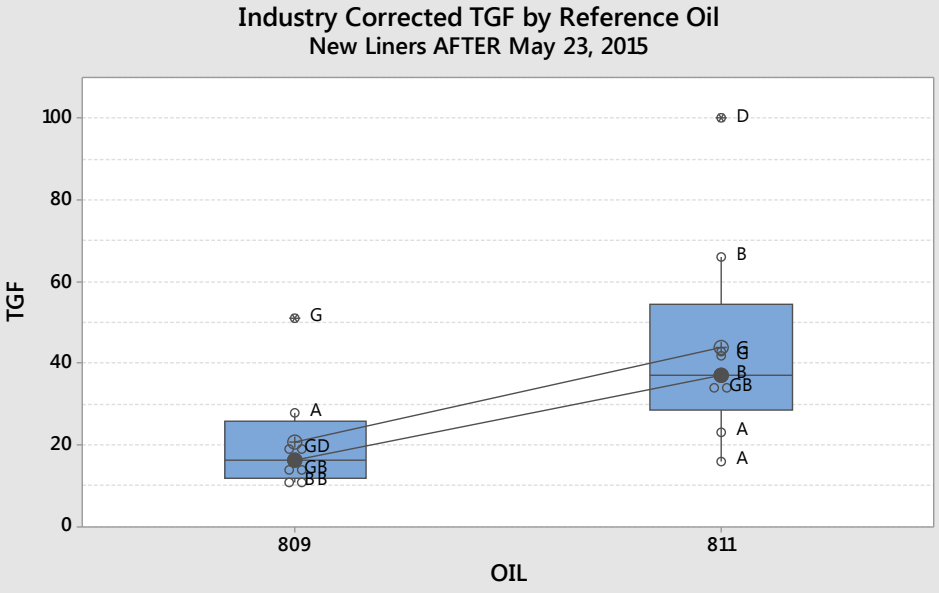
Evidence of Issue



63 tests



17 tests (6 from Lab B)

- Problem so bad that RO 809 and RO 811 have diverged in TGF severity!
  - Historically, 809 with higher TGF than 811
  - Now 811 way higher than 809
    - This is not due to the correction factor, but another issue

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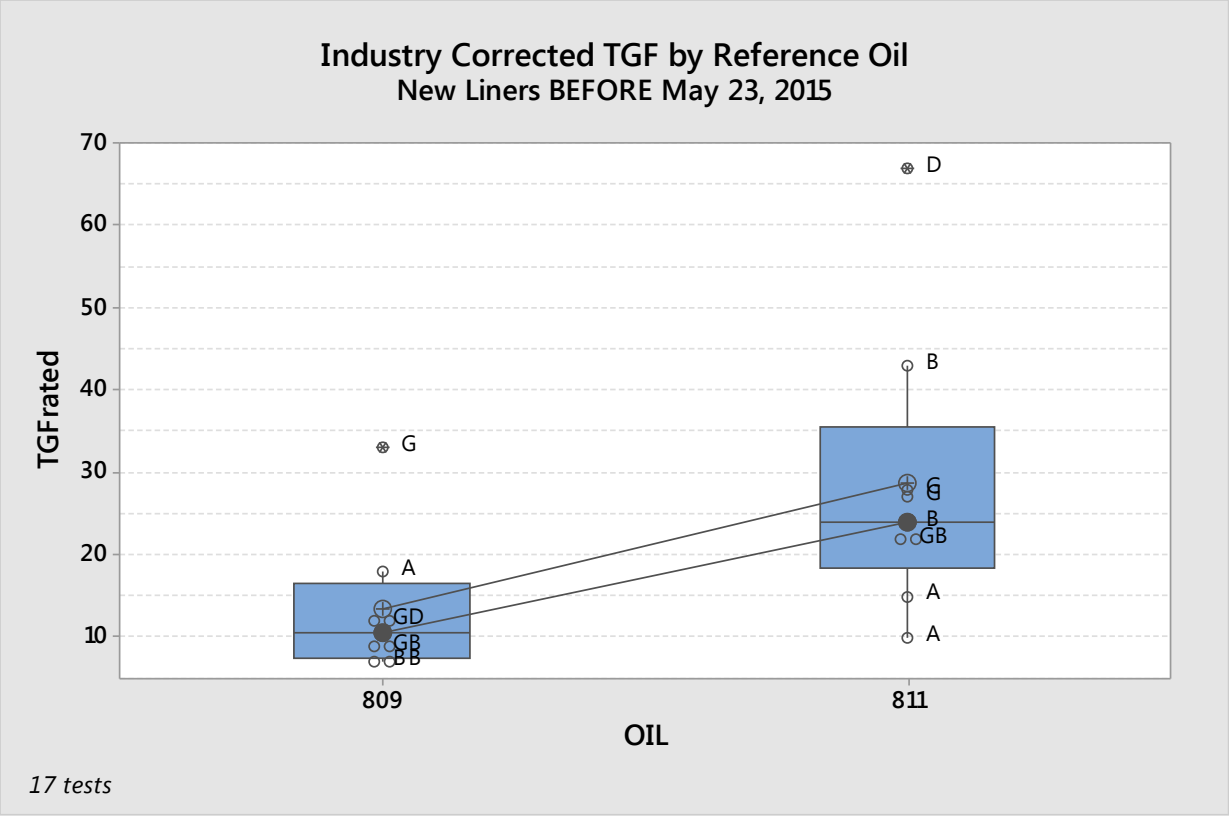
Evidence of Issue



- What if we dropped the Industry correction factor?
  - RO 811 would be closer to target, but **still** slightly severe
  - RO 809 would be extremely mild of target
  - Lab A mild on both oils, BUT consistent

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The Problem

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- So what? Is this really a problem? ABSOLUTELY
- Reference oils are moving in opposite severity directions AND one of the Labs (A) is different from the others (B, D, G)
  - This is the worst of the worst kind of problem
- We based a correction factor on Liners
  - Either not Liners or a new variable has emerged
    - However, Lab A appears unaffected
- Not all oils behave the same
  - Labs B, D and G will have difficulty referencing especially when 809 and 811 are alternately assigned
  - How are the candidates affected?

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Possible Solutions

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- No solutions that are satisfactory
  - Due to reference oil divergence and Lab differences
- Do nothing
  - Possible reference testing nightmare for Labs B, D, G
  - Conservative approach for candidates
  - Lab A would likely be OK
- Remove the correction factor
  - Reference testing nightmare remains for B, D, G
  - Lab A would likely be very mild of target
  - Most candidates will get better than expected results
- 2 alternative proposals

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Proposal 1

SUCCESS TOGETHER

- Temporarily suspend the use of RO 811 in TGF charts
  - This would cut the volume of our TGF chart data in half, but not affect the other parameters
  - Severity adjustments would be based solely on RO 809
    - This would be conservative for candidates since 809 is mild of target
- Continue using Industry Correction Factor

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Proposal 2

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- TGF Precision Ri only calculated based upon back to back runs on the same reference oil
  - When 809 is run, look to the previous 809 run to calculate Ri and when 811 is run, do the same
  - Update Ri and Qi calculations back from May 2015 to present time and update charts
  - This will prevent false precision alarms due to reference oils diverging in severity, BUT hold labs accountable for repeatable results on a reference oil
- Temporarily increase the K value for TGF stand severity to 2.5 (from 2.1)
  - This is not much, but may provide some relief from the change in severity without changing targets or target history
- Continue using Industry Correction Factor

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Follow Up Suggestions for Either Proposal

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- Look into possible causes
- Perform a round of testing of 809-1 and 811-2 in each test lab
  - Why?
    - Confirm the hypothesized issue with additional data
    - If not confirmed drop any adopted proposals
    - If confirmed, either continue with adopted proposal or consider suspended testing
- Voluntary call for candidate test results and/or candidate test result predictions using Liner 1Y3998
  - Would like to compare results from before the Industry Correction Factor was applied to recent results
  - Check to see if Correction Factor working
- Note that we are not happy with proposals, but it is an improvement over doing nothing

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Another Suggestion

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- A suggestion was made to update the TGF standard deviation of RO 811 to widen the calibration window
- While test results on RO 811 are certainly more variable, this is mostly due to lab differences
  - Within lab variability remains the same
- Current: 811-2 s=0.361554
- Since May 23, 2015: 811-2 within Lab s=0.264776
  - Since May 23, 2015: 811-2 between Lab s=0.567

TOP GROOVE FILL
Unit of Measure: LN(TGF+1)
CRITICAL PARAMETER

Reference Oil	Mean	Standard Deviation
809-1	3.410591	0.563970
811-1	3.077855	0.362927
811-2	2.961267	0.361554

Variance Components, using Adjusted SS

Source	Variance	% of Total	StDev
LTMSLAB	0.251174	78.18%	0.501173
Error	0.0701061	21.82%	0.264776
Total	0.321280		0.566816

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Lubrizol Candidate Data

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- Use model based upon 348 candidate results completed between January 31, 1994 and December 24, 2011
  - Calculate Yi based upon model; boxplot Yi by time
    - 258 results pre 1Y3998
    - 90 results 3/14/04-12/24/11
    - 107 results 12/24/11-5/1/15 (not part of modeling dataset)
    - 40 results since Industry Correction Factor
      - Results not part of modeling dataset
- Appears that Industry Correction factor appropriate
- Boxplots show that Industry Correction factor needed for 'Most' LZ candidates
  - Although there are now more severe results supporting the theory that the factor does not work for all oils
  - There also appears to be more variability

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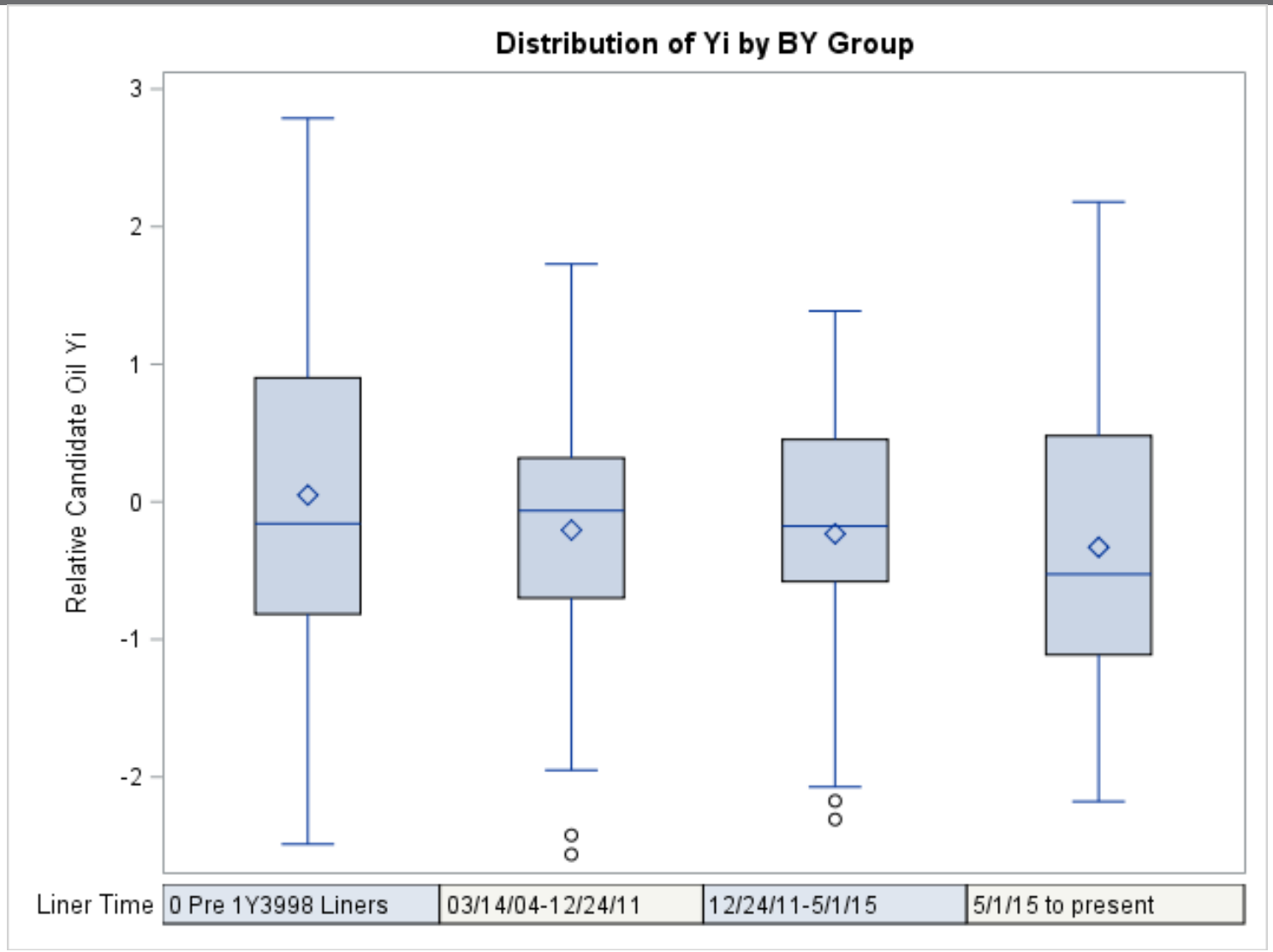
LZ Candidate TGF Yi by Liner Time Period



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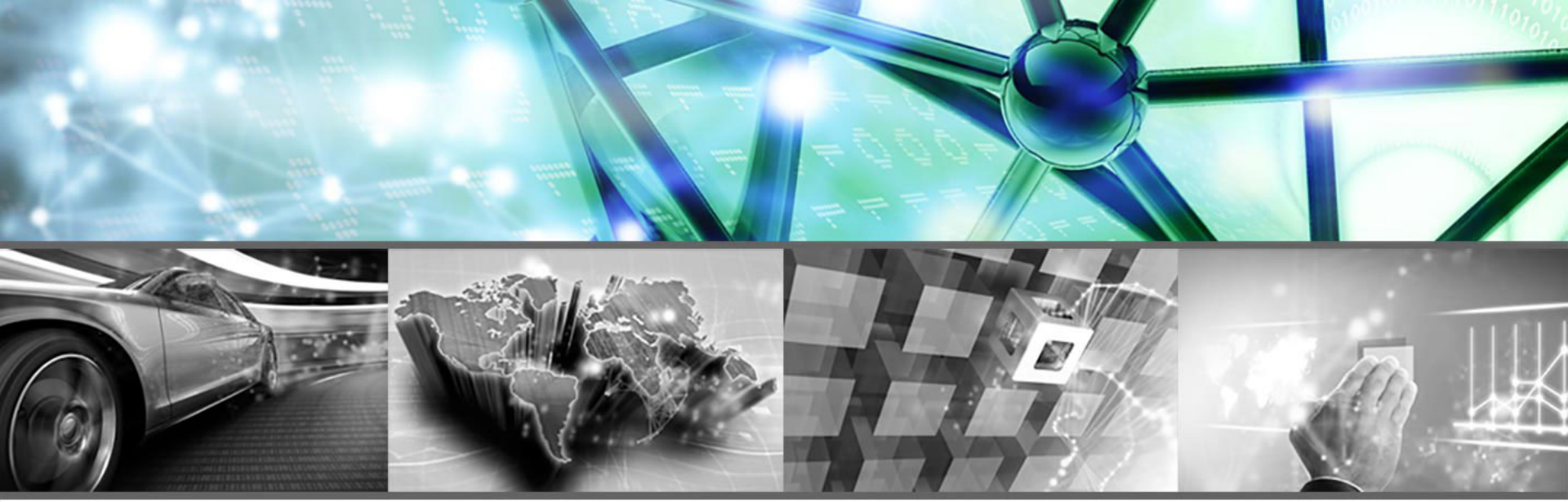

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Working together, achieving great things

When your company and ours combine energies, great things can happen. You bring ideas, challenges and opportunities. We'll bring powerful additive and market expertise, unmatched testing capabilities, integrated global supply and an independent approach to help you differentiate and succeed.

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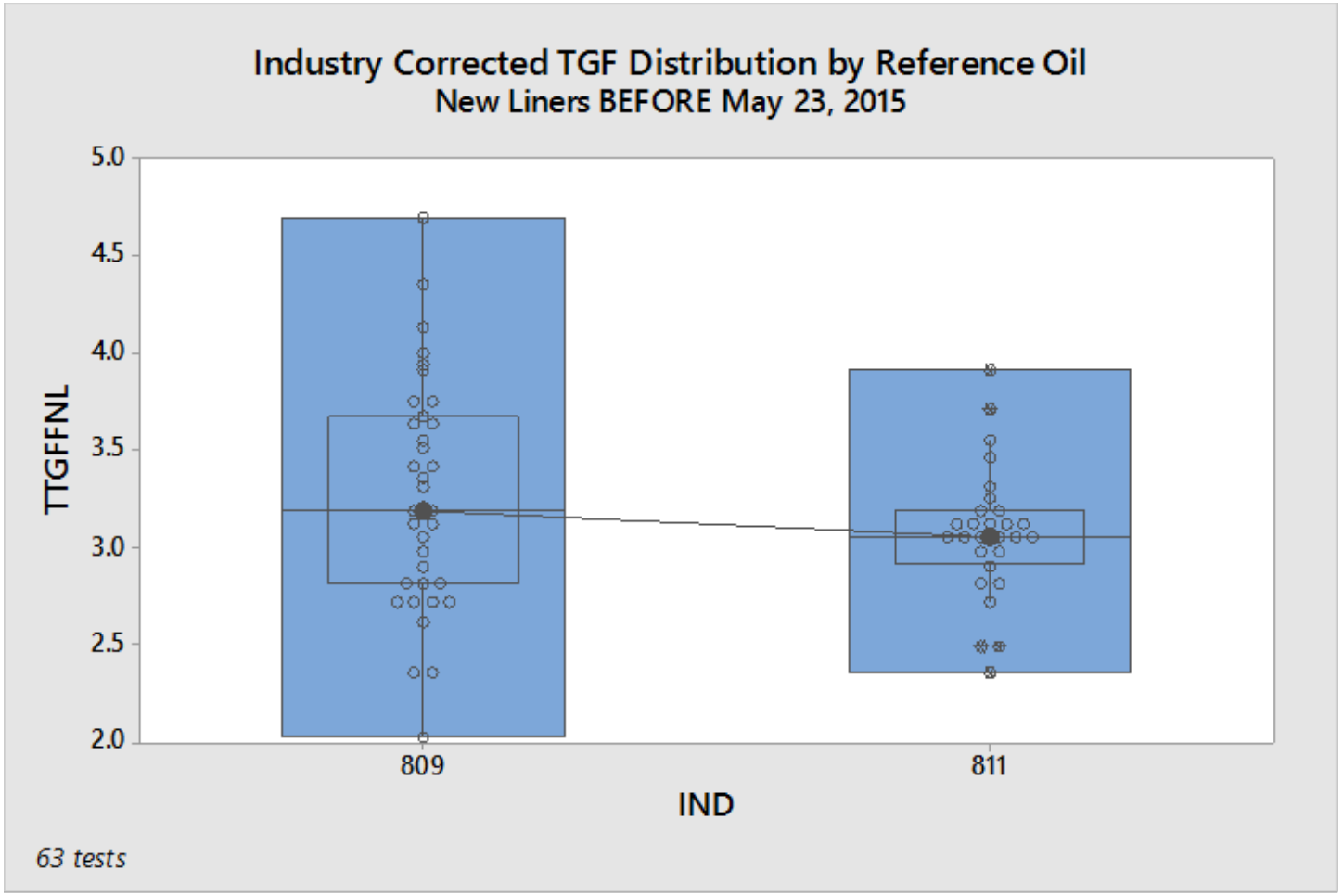

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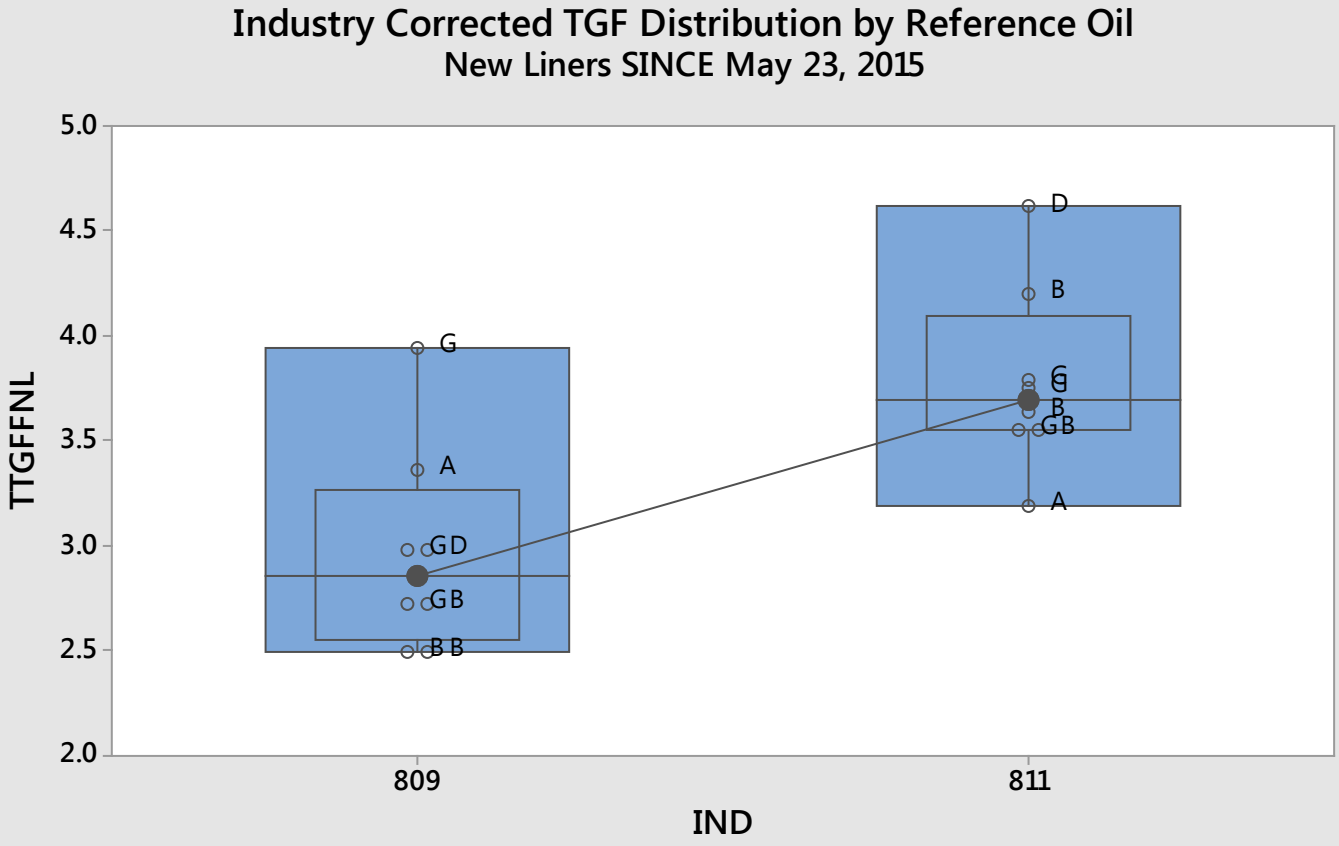

16 tests of which 6 are from Lab B

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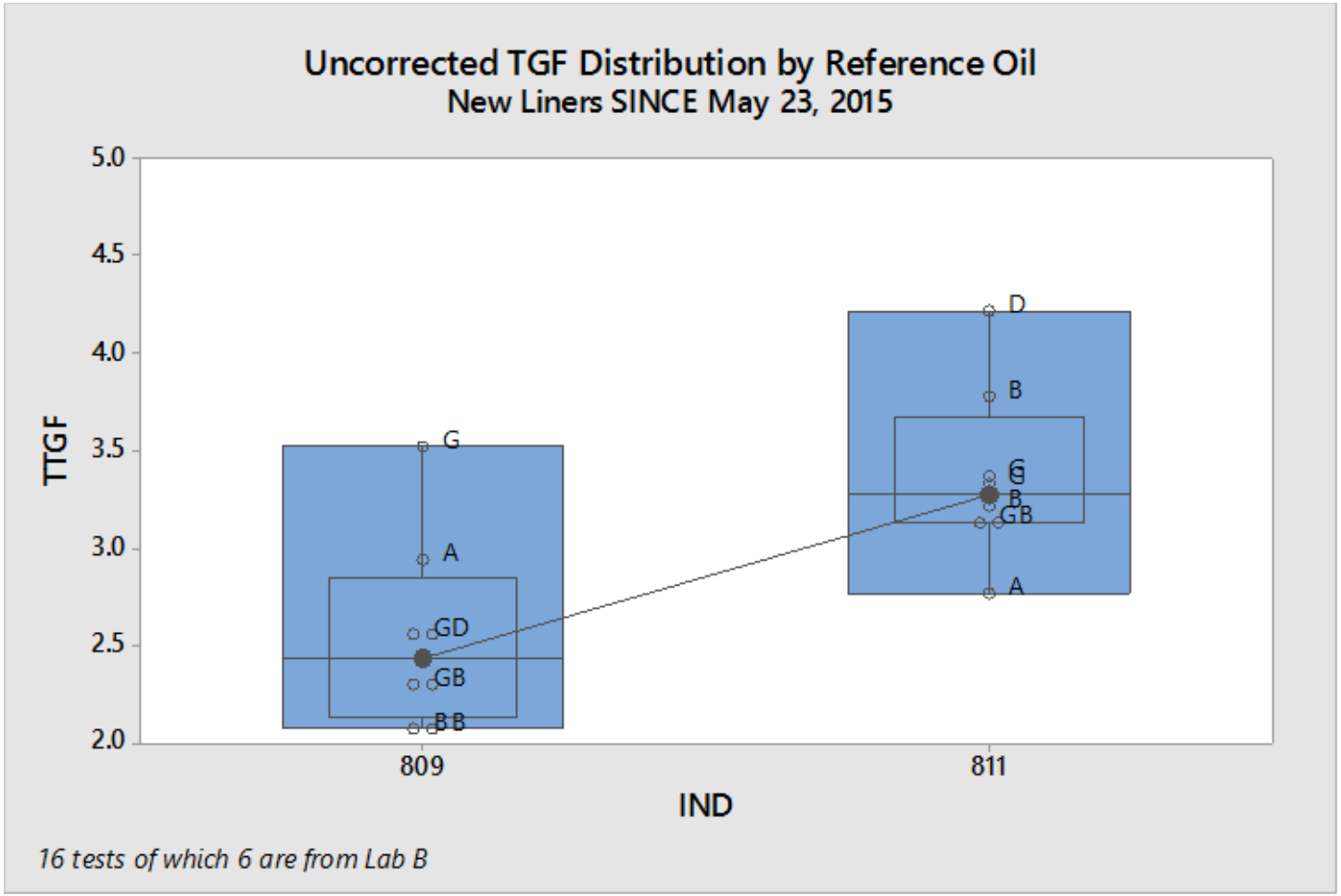

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