PPIM 2025
PIPELINE PIGGING & INTEGRITY MANAGEMENT

283. Validating Crack Detection In-Line Inspections with API 1163

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Validating Crack-Detection In-Line Inspections with API 1163

- This paper discusses using the third edition of API 1163 to validate crack-detection ILIs
  - Crack-detection ILIs are not easily analyzed using the third edition of API 1163 because the uncertainty of field-measured depths is similar to the uncertainty associated with the ILI-reported depths
- The paper introduces a method of estimating the actual ILI tolerances (i.e., the difference between the ILI-reported depth and the true depth) from ILI and field NDE depths only (i.e., without “truth” data)

Background

- API 1163 Level 2 validations evaluate performance against the combined field plus ILI tolerance:

$$\sigma_{combined} = \sqrt{\sigma_{ILI}^2 + \sigma_{Field}^2}$$

  where σ represents a standard deviation

- When the field tolerance is small compared to the ILI tolerance, the combined tolerance is dominated by the ILI tolerance alone
  - The PRCI guidance document suggests a Level 2 validation is valid if the field tolerance is less than about one-third of the ILI tolerance

Incorporating Field Measurement Tolerances

- Level 2 validations accounts for measurement tolerances that are small relative to the ILI tolerances
  - For cracks, the field tolerance is similar to the ILI tolerance
  - Field tolerances for cracks are often quoted as being ±0.5 to 1.5 mm, while ILI tolerances are typically ±1.0 mm (±1.0 mm shown at right)
  - So, field tolerances for cracks are greater than recommended for Level 2 validations

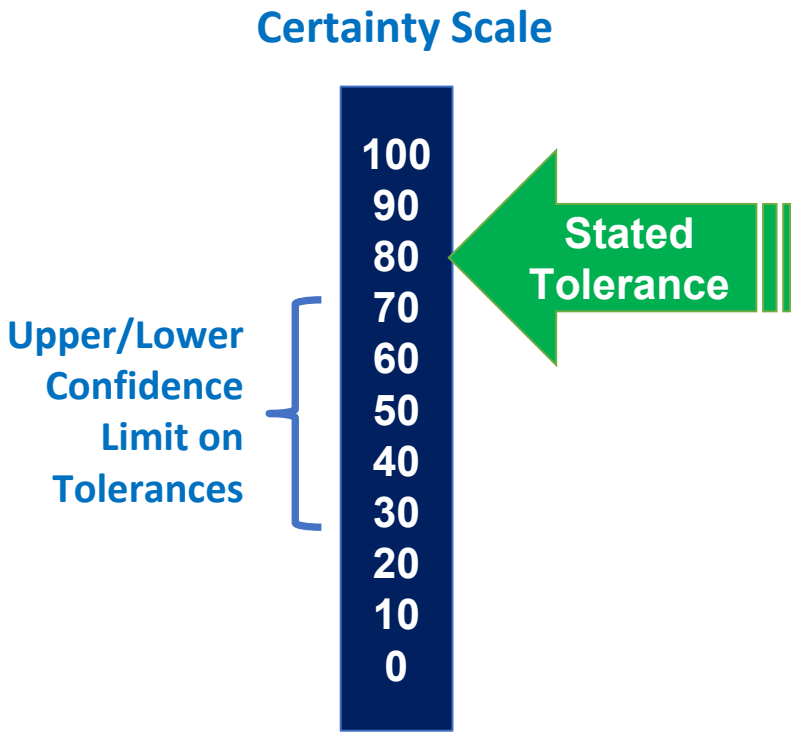
Wall Thickness (inches)	Tolerance (%WT)
0.188	21%
0.250	16%
0.313	13%
0.375	10%
0.438	9%
0.500	8%

Level 2 Validation Outcomes

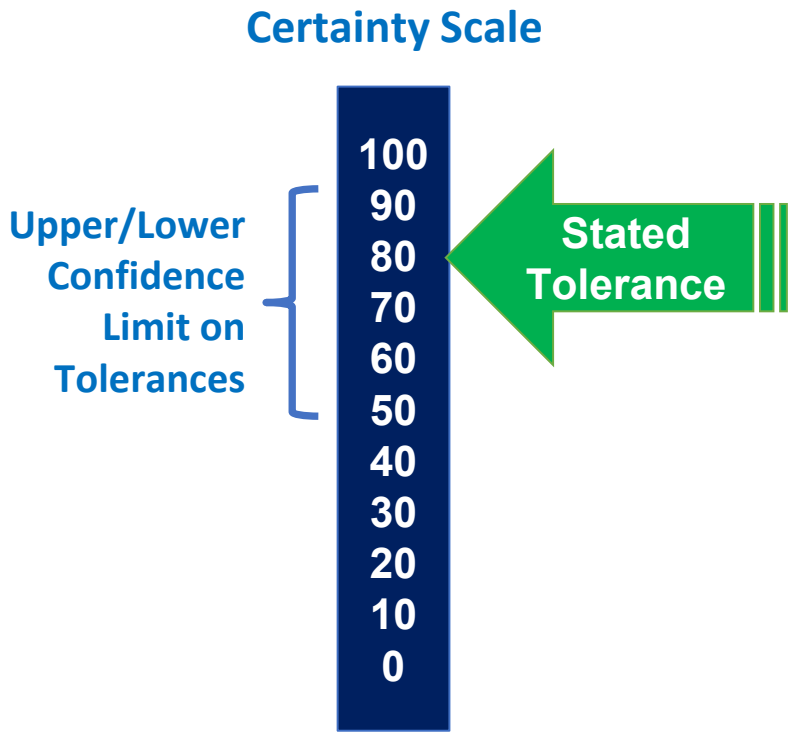
- In Level 2 validations, assessments are assigned one of three “Outcomes” that determine whether the ILI is rejected (Outcome 1), further evaluated (Outcome 2), or exceeded (Outcome 3)
- These outcomes depend on where an estimated range of actual certainties falls relative to the performance specification given by the ILI service provider

Outcomes 1, 2, and 3

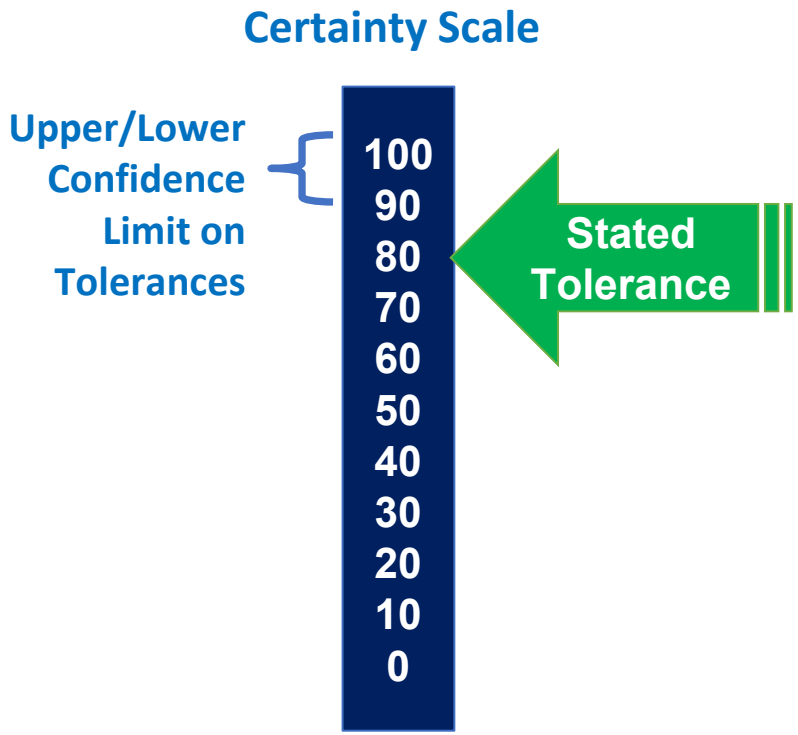
Outcome 1 (Reject)



Outcome 2 (Evaluate)



Outcome 3 (Exceed)

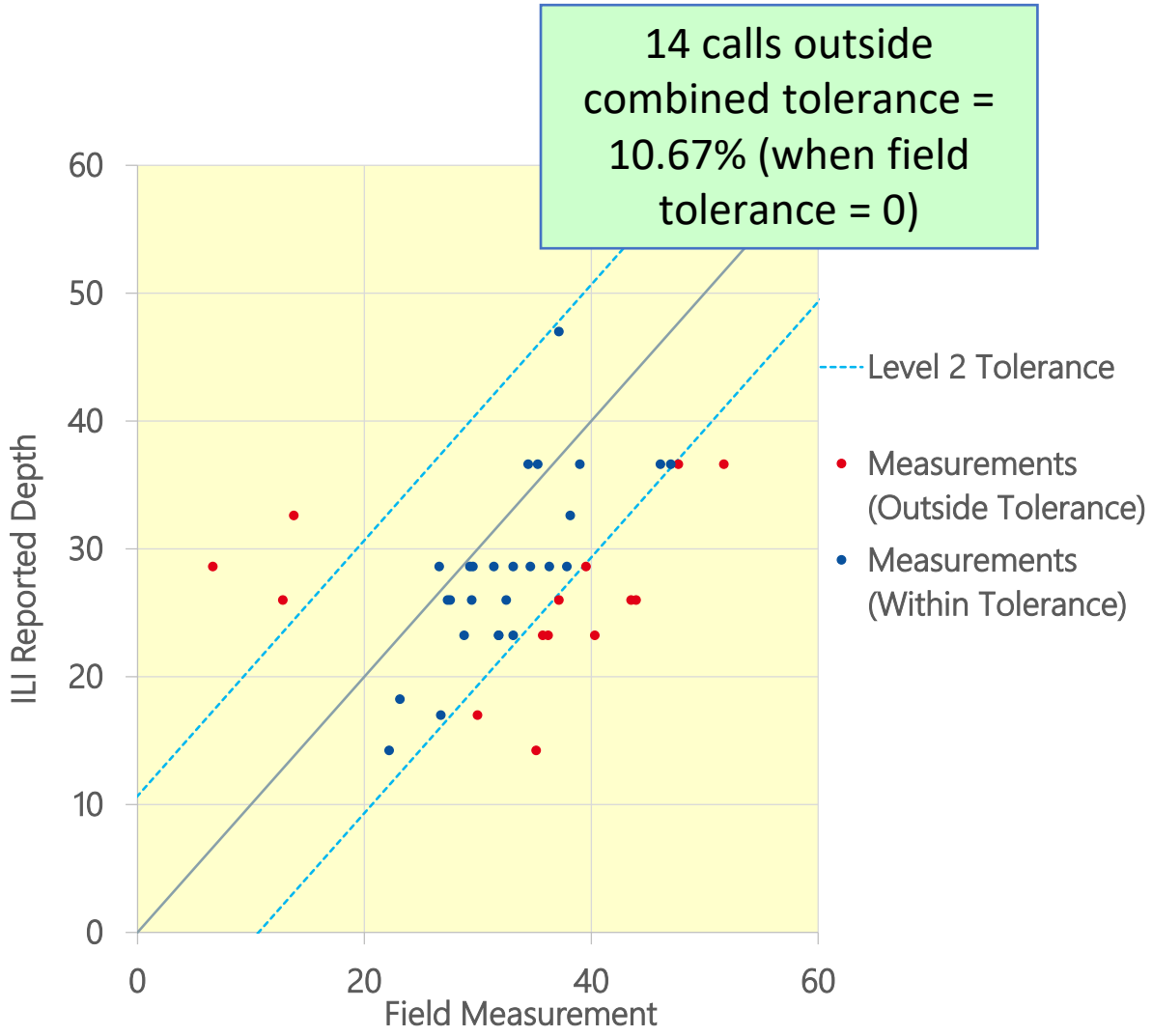


Case Study

- API 1163 3rd edition and the PRCI guidance document and spreadsheet were used to evaluate a crack detection ILI
  - 40 crack-like anomalies were reported by the ILI, which had an assumed tolerance of ±1 mm with 80% certainty
    - The tolerance corresponds to ± 10.67% WT for the wall thickness of 0.375 inches
  - ILI-reported depths range from 13% WT to 47% WT, while field-measured depths are from 7% WT to 52% WT.

Case Study Unity Plot

- 26 of the 40 ILI-reported anomalies were within the ILI tolerance of the field measurements – there were no false positives – for a success rate of 65% versus the ILI certainty specification of 80%



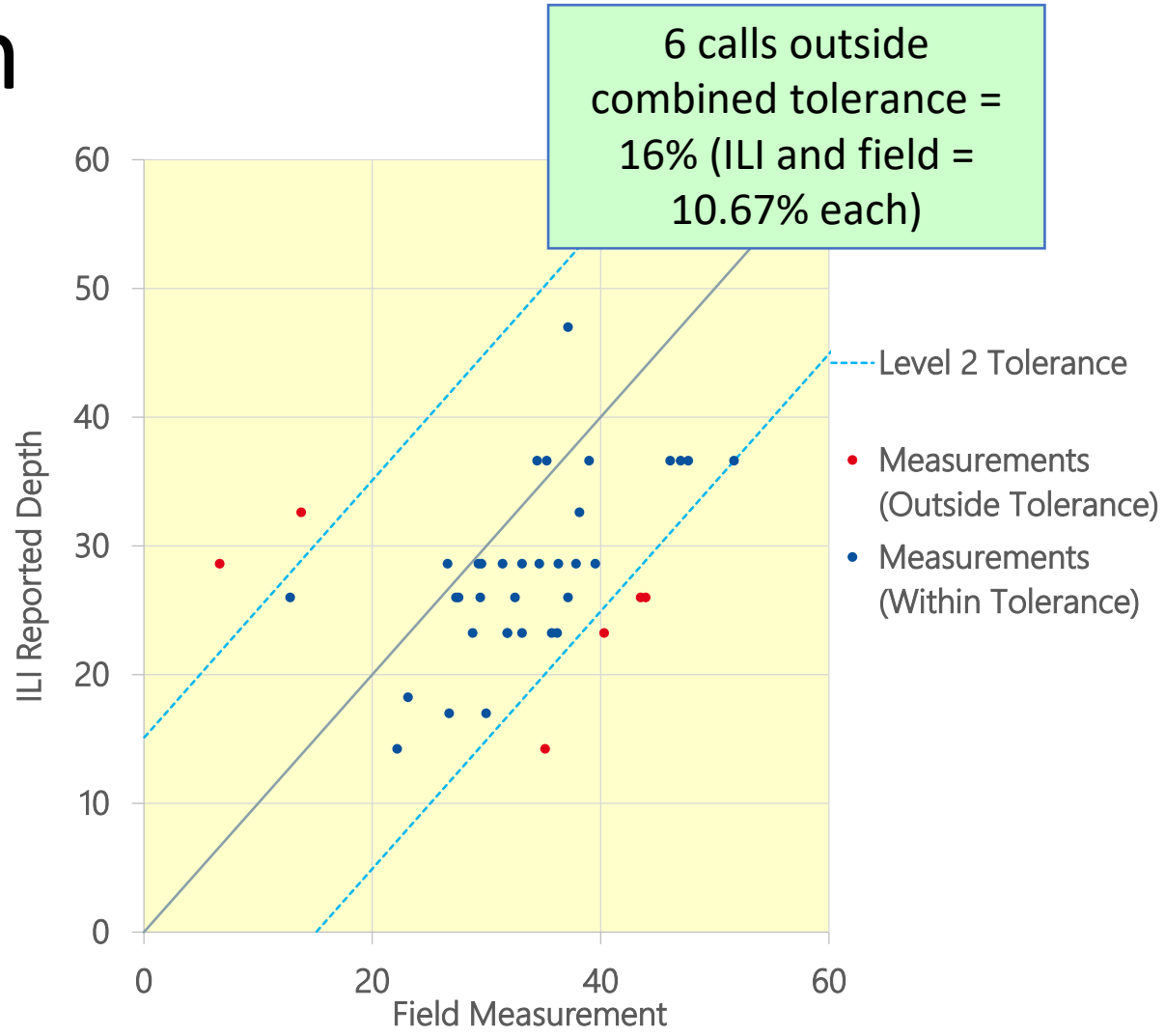
Level 2 Validation Results – Field Tolerance = 0%

- Results shown correspond to a field depth tolerance of 0 – i.e., the field depths are assumed to be accurate
- In this case, the Level 2 validation leads to Outcome 1, in which the ILI is rejected because there is statistical evidence the ILI did not meet its stated performance specification

Level 2 Sizing Results:	
Min. Combined Tolerance	10.67
Max. Combined Tolerance	10.67
Certainty Z-Value	1.28
Confidence Z-Value	1.64
X	26
n	40
$\tilde{n}$	42.71
$\tilde{p}$	0.64
$\hat{p}$, lower	51.97%
$\hat{p}$	65.00%
$\hat{p}$, upper	**76.13%**
Equivalent Tolerance at 80% Certainty (Assuming no Bias)	**Equivalent Tolerance is Only Relevant for Outcome 2**
Level 2 Endpoint Criteria Met	**Endpoint Criteria is Only Relevant for Outcome 2**
Result	**Measurement Spec. Rejected**
	76.13% < 80%
	Outcome 1

Level 2 Validation Results – Field Tolerance = ±1 mm

- Results shown correspond to a field depth tolerance of ±1.0 mm – i.e., the field and ILI tolerances are the same
- In this case, the Level 2 tolerance lines move apart, representing the larger combined tolerance
  - Fewer points are outside spec, which increases the likelihood the validation will pass



Level 2 Validation Results – Field Tolerance = ±1 mm

- Now, the Level 2 validation produces (Outcome 2), and because both endpoint criteria are met, the validation concludes the ILI is acceptable
  - That is, it is appropriate to use the ILI tolerance in integrity decision-making

Level 2 Sizing Results:

Min. Combined Tolerance	15.09
Max. Combined Tolerance	15.09
Certainty Z-Value	1.28
Confidence Z-Value	1.64
X	34
n	40
ñ	42.71
p̃	0.83
p̂, lower	73.28%
p̂	85.00%
p̂, upper	**92.29%**

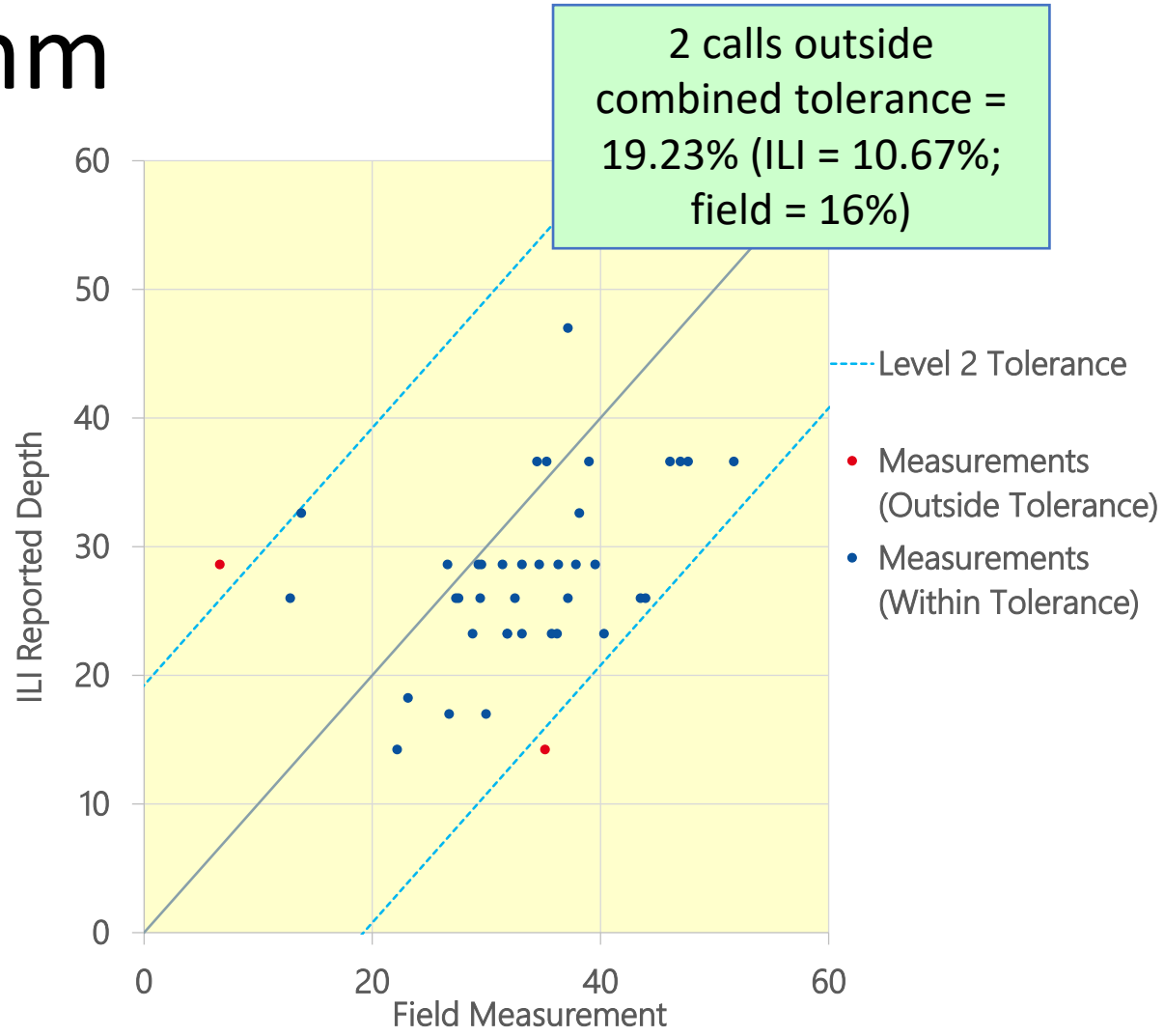
Equivalent Tolerance at 80% Certainty (Assuming no Bias)	**+/- 12.32%WT**

Level 2 Endpoint Criteria Met	**Yes**

Result	**Measurement Spec. NOT Rejected; Endpoint Criteria Met**
	73.28% <= 80% <=92.29%
	Outcome 2

Level 2 Validation Results – Field Tolerance = ±1.5 mm

- Results shown correspond to a field depth tolerance of ±1.5 mm – i.e., the field tolerance is worse than the ILI tolerance
- In this case, the Level 2 tolerance lines move further apart, reducing the number of points that are outside the tolerance



Level 2 Validation Results – Field Tolerance = ±1.5 mm

- Now, the Level 2 validation reaches (Outcome 3), which suggests the actual tolerance is better than the ILI tolerance!

Level 2 Sizing Results:

Min. Combined Tolerance	19.23
Max. Combined Tolerance	19.23
Certainty Z-Value	1.28
Confidence Z-Value	1.64
X	38
n	40
ñ	42.71
p̃	0.92
p̂, lower	85.38%
p̂	95.00%
p̂, upper	**98.92%**

Equivalent Tolerance at 80% Certainty (Assuming no Bias)	**Equivalent Tolerance is Only Relevant for Outcome 2**

Level 2 Endpoint Criteria Met	**Endpoint Criteria is Only Relevant for Outcome 2**

Result	Measurement Spec. Exceeded
	80% <= 85.38%
	Outcome 3

Level 2 Validation Summary

- Level 2 validation evaluates the field measurements against the *combined* field plus ILI tolerance
- Increasing the field tolerances to the stated ILI tolerance and above changes the Level 2 validation from Outcome 1 (reject ILI) to Outcome 2 (further evaluate ILI) and eventually to Outcome 3 (ILI tolerance exceeded)

Basic Statistical Considerations – Level 2 and 3 Validations

- In a crack validation, we want to evaluate the variance or tolerances associated with (ILI – truth) using ILI and field measurement data – i.e., without knowing the true crack depths

For validation, we want to calculate the variance
or tolerances associated with (ILI – truth),
which is not the same as the variance or tolerance of (ILI – field)

Basic Statistical Considerations – Variance of ILI minus Truth

- To estimate the variance of (ILI – truth), we can use the following relationship, which again assumes (ILI – truth) is independent of (field – truth)

$$Var(ILI - field) = Var(ILI - truth) + Var(field - truth)$$

We know Var(ILI-field)

We can estimate Var(ILI-truth)…

…if we know Var(field-truth)

Basic Statistical Considerations – Calculating Var(ILI-truth) when Var(field-truth) is unknown

- Ideally, we would measure and know Var(field – truth), but this is not always possible
- When we do not know Var(field – truth), we can still estimate the Var(ILI – truth) by assuming Var(field – truth) equals the Var(ILI – truth) times a scaling factor, A:

$$Var(field - truth) = \boldsymbol{A} * Var(ILI - truth)$$

using

$$Var(ILI - field) = Var(ILI - truth) + Var(field - truth)$$
$$= (1 + \boldsymbol{A}) * Var(ILI - truth)$$

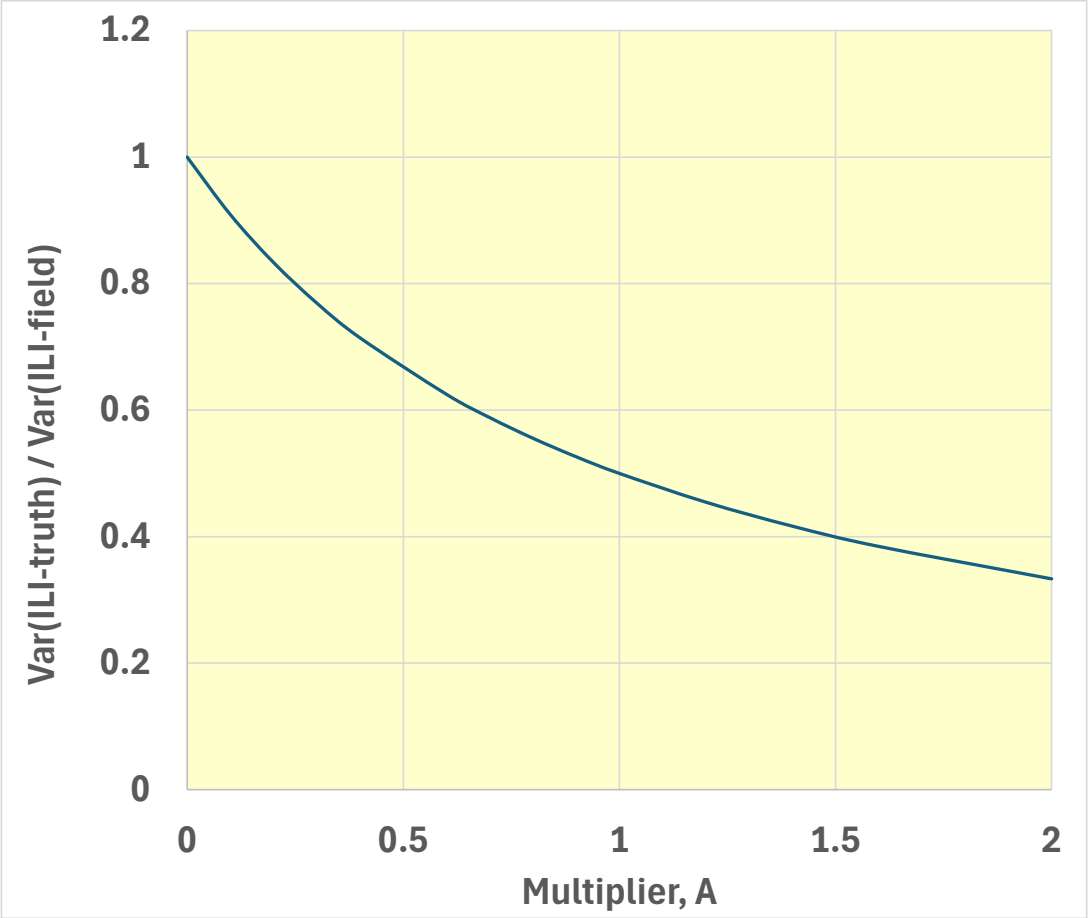
Basic Statistical Considerations – Calculating Var(ILI-truth) from Multiplier, A

- Estimating Var(ILI – truth) is straightforward when the multiplier, A, is known

$$Var(ILI - truth)$$

$$\div Var(ILI - field)$$

$$= 1/(1 + \boldsymbol{A})$$



Realistic Estimates of Multiplier, A

- Many ILI systems use angle beam ultrasonics to estimate the crack depth - this is the same technology employed in most field NDE depth measurements
  - Typical field depth measurement accuracies are in the range of ±0.5 to ±1.0 or ±1.5 mm
  - Typical ILI depth measurement accuracies are in the range of ±1.0 mm
- So, assuming “A” is in the range of 0.5 to 1.5 is reasonable

Dependency between ILI and Field

- The information on the previous slides is valid if the ILI and field measurements are independent, which they may not be…
- If the errors are not independent, the relationship changes to:

$$\text{Var(ILI-Field)} = \text{Var(ILI-truth)} + \text{Var(Field-truth)} - 2 * r * SD(\text{ILI-truth}) * SD(\text{Field-truth})$$

- Where *r* is the correlation coefficient between (ILI – truth) and (field – truth) and *SD* indicates the standard deviation

Example Case when Var(ILI-Truth) = Var(Field-Truth)

- We want to solve

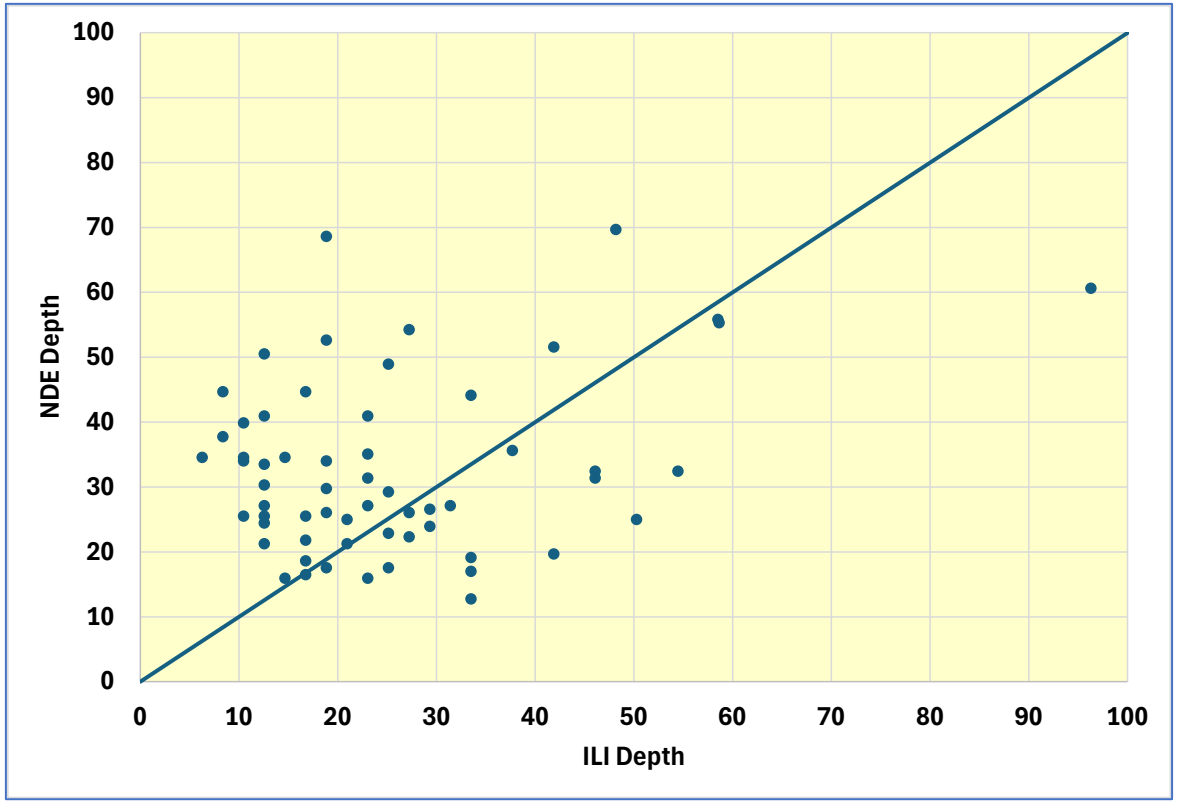
$$\text{Var(ILI-Field)} = \text{Var(ILI-truth)} + \text{Var(Field-truth)} - 2 * \mathbf{r} * \text{SD(ILI-truth)} * \text{SD(Field-truth)}$$

- When the ratio of Var(field – truth) / Var(ILI – truth) is known or assumed – i.e., for different values of "A" – we can solve for Var(ILI – truth) using Var(ILI – field):

$$\text{Var(ILI - truth)} = \text{Var(ILI - field)} / (1 + \mathbf{A} - 2 * \mathbf{r} * \sqrt{\mathbf{A}})$$

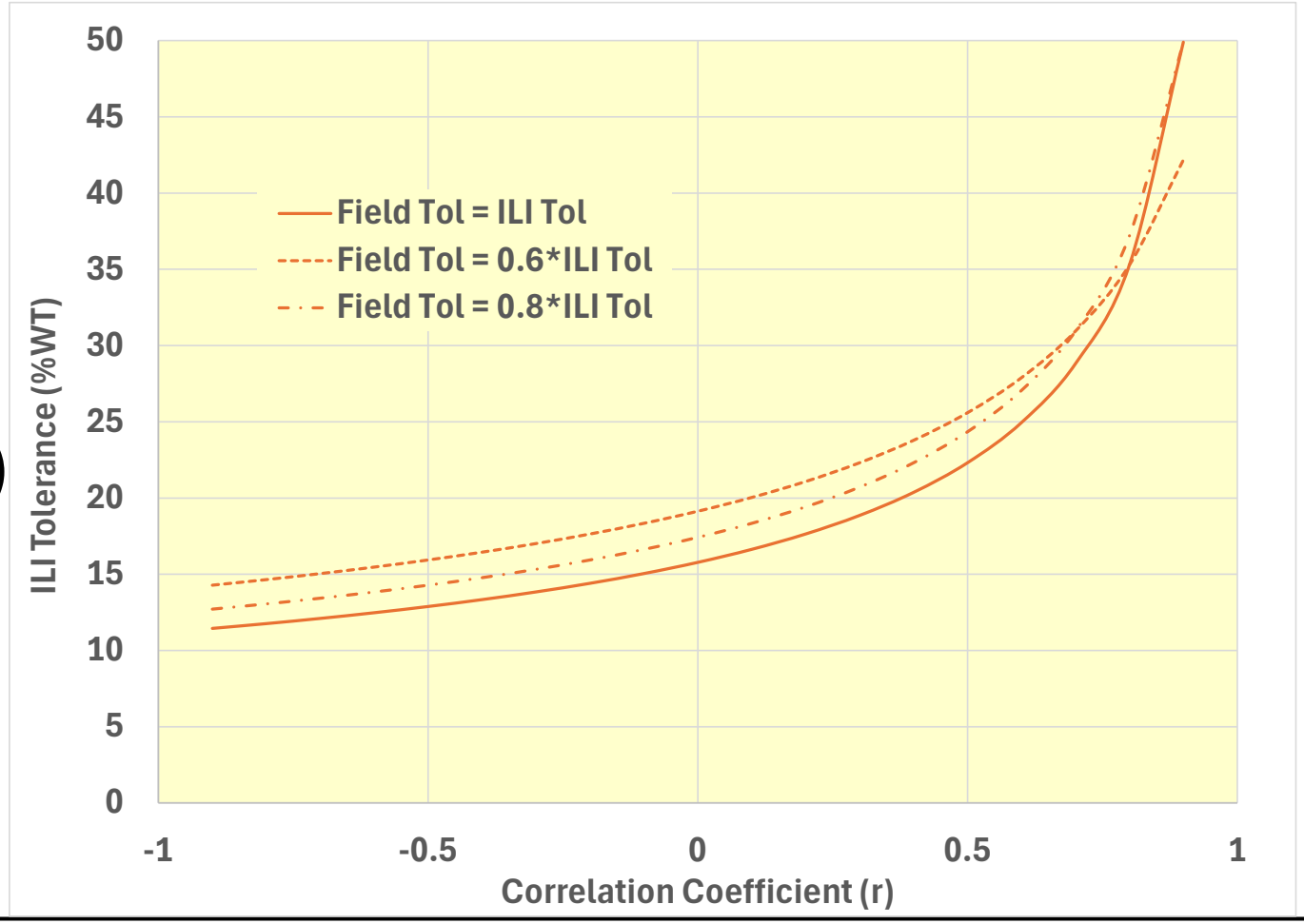
Example Case

- Actual ILI and NDE depth data
  - 60 matched pairs
  - Correlation coefficient between ILI and NDE *measurements* is 0.311 (may not equal correlation between ILI and NDE *errors*)
- The combined ILI/field tolerance is ±22.32% WT



Effects of Correlation Coefficient and Accuracy Multiplier

- We can calculate the tolerance of ILI – truth knowing
  - The correlation coefficient (“r”) between ILI errors and NDE errors
  - The accuracy multiplier (“A”)
- For r=0, and assuming the field tolerance equals the ILI tolerance, the estimated ILI tolerance is ±15.8% WT (versus 22.32% from the ILI-field data)



Results and Comparisons

- Estimated ILI tolerances, which are based solely on the ILI and field depths, depend on the correlation coefficient ("r") and the field accuracy multiplier ("A")
  - "A" varies between 0.6 and 1.0, while "r" varies between 0 and 0.5
  - The estimated "actual" ILI tolerances are between ±15.8% WT (A=1.0, r=0) and ±25.6% WT (A=0.6, r=0.5)
- For comparison, based on (limited) destructive test data, the destructive (truth) data gives an actual tolerance of about ±17.7% WT

		Multiplier, A		
		0.6	**0.8**	**1**
Correlation Coefficient, r	**0**	19.4	17.4	15.8
	0.3	22.3	20.7	18.9
	0.5	25.6	24.3	22.3

Conclusions

- Progress is being made on quantifying the actual (ILI – truth) tolerance based on ILI and field measurement data. The ability to validate (ILI – truth) tolerances from ILI and field NDE depth measurements only (i.e., no truth data) depends on:
  - The relative accuracy of the field NDE measurements and
  - The correlation between ILI errors and field NDE errors
- The methodology outlined in this paper provides a way of determining the ILI tolerance based on ILI and field data alone

Thank you for listening!

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