What’s Next – Establishing Reassessment Intervals

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Topics Covered

- Focus is ECDA
  - Reassessment Methodology,
  - Corrosion Growth Rate Analysis,
  - Relationship Between Corrosion Growth Rates and “Pitting Factor”,
  - Special Considerations for MIC, Stray D-C and A-C,
  - Remaining Life Calculations,
  - Reassessment Intervals, and
  - Corrosion Rates with CP Applied.
Nature of the Problem

- A wide variety of unqualified corrosion rates exist in the public domain.
  - Often misapplied

- Default Rates in NACE SP0502-2002 ECDA Standard (16 mpy) can be excessive.
  - Helps to insure conservative analysis.
  - Hurts when it results in unreasonably frequent reassessment intervals.

- SP for Normally Dry Gas ICDA Standard has no default.
  - Offers suggestions on methodologies for corrosion growth.

Direct Assessment Success

- The successful application requires
  - Reliable and defensible reassessment interval
  - Establishing the remaining life of un-repaired defects remaining in the pipe wall.

- An accurate assessment of corrosion growth rates is required to predict the remaining life of such defects.
In an effort to ensure a conservative estimate, NACE RP0502-2002 establishes the maximum reassessment interval as one half (1/2) the remaining life of the most severe remaining anomaly.

- Assumes remaining anomaly has not been repaired.
- Very conservative since standard requires mitigation
  - Do we need to reconsider as we develop more information
  - Is “Half Life” Too Conservative.
What if Direct Examination Detects No Corrosion?

- Assuming Process is Sound
  - Indirect Surveys were effective.
  - Controls and validation are reliable.

- If no corrosion defects are found during the direct examination step, it may be assumed that corrosion growth rates are sufficiently low (< 1 mpy)[1] that the remaining life calculations are not needed, and the remaining life can be taken as that of a new pipeline.

[1] For the purposes of this analysis, effective cathodic protection is defined as a reduction in corrosion rates to < 1 mpy (0.001 in/yr).
What if Direct Examination Detects Only “Inactive Corrosion” Defects

- Inactive Corrosion Defects defined as *pre-existing corrosion that is currently mitigated*.
  - Must ensure that it remains mitigated.
  - Must ensure that it is not a temporary cessation in corrosion activity.
    - Such as seasonal variation

- Then it is reasonable to conclude that corrosion growth rates are < 1 mpy (0.001in/yr).
What if Direct Examination Detects “Active Corrosion”

- Active Corrosion Defects defined as *A State of electrochemical activity which will promote corrosion growth and continued wall (metal) loss.*

- The remaining life of the pipeline in the ECDA region must be estimated in order to be able to determine the reassessment interval.

- Corrosion growth rate must be established.

- Assumes That
  - *The most severe corrosion anomaly remaining in the pipeline is of the same dimensions as the most severe corrosion damage found during the direct examination step.*
What if Conditions at this Location are Unique?

- If it is determined through detailed analysis that the most severe corrosion was due to isolated conditions, is not representative of the region, and has been mitigated then,
  - The next most severe corrosion anomaly should be identified and relied upon for establishing the re-assessment interval.
Methodologies to Establish External Corrosion Growth Rate

- **Method 1**: Historical corrosion growth rates can be utilized for pipelines with similar characteristics (coating, CP, wall thickness, grade) that are installed in similar environments (terrain, soil type, drainage).

- Difficulty arises when data and the conditions under which they were obtained are misapplied.
  - Attempts should be made to ensure reliability of data and to implement a conservative approach.
  - Typical historical data would include corrosion rates from buried coupons on the specific pipeline segment or a pipeline with similar characteristics (age, grade, coating and cathodic protection) and environments.
Methodologies to Establish External Corrosion Growth Rate (Cont’d)

**Method 2:** Electrochemical (Linear Polarization Resistance (LPR)) measurements can be used to establish corrosion growth rates.

- LPR measurements obtained in the soil environment around the pipe or on laboratory specimens using soil from around the pipe can yield meaningful results from which to characterize corrosion growth rates.
- The technique involves the application of a small (± 10-20 mV versus \(E_{corr}\)) DC polarization at a specified rate.
- Defined as The Slope at \(E_{corr}\) of the Linear Plot of voltage vs. current density.

Polarization Resistance can be related to Rate of Corrosion via Stern-Geary

\[
P_r = \frac{DE}{DI}_{E_{corr}}
\]

\[
i_{corr} = \frac{1}{R_p} \beta_a \beta_c / 2.303 (\beta_a + \beta_c)
\]

Where:  
\(i_{corr}\) = Corrosion Current Density  
\(\beta_a\) = Anodic Tafel Constant  
\(\beta_c\) = Cathodic Tafel Constant
Corrosion Rate via Faraday’s Law

- Faraday’s Law

\[ CR(mpy) = i_{corr} \times 129 \times \frac{WT}{n \times d} \]

- Where:
  - WT = equivalent weight of carbon steel (27.93 g/equivalent)
  - \( n = 2 \) for carbon steel
  - \( d = \) carbon steel density (7.86 g/cm\(^3\))
Cylindrical Rod Coupon
Nearby Temporary Reference Electrode

9 cm² Coupon
Experimental Set-Up for LPR
Methodologies to Establish External Corrosion Growth Rate

- **Method 3**: Linear growth rates (or alternative modeling) can be used to establish the annual corrosion growth of external corrosion anomalies based on the peak metal loss depth divided by the years of exposure (Years since installation).

- Establishing a linear corrosion growth rate based on measured wall loss divided by years of exposure.
  - Least precise approach to predicting future corrosion growth
  - Uncertainty in when corrosion initiated.
    - The effect of seasonal variation and CP effectiveness contribute to errors in this approach.
    - The fact that metals exposed to soils experience a range of corrosion rates also greatly affects the accuracy of an assumed linear corrosion rate.
Methodologies to Establish External Corrosion Growth Rate

**Method 4:** If no known corrosion growth rate information is available, and it cannot be approximated by any of the above three methods, industry published corrosion growth rate data can be relied upon.

- The most comprehensive source of corrosion data is contained in the National Bureau of Standards Circulars
  - Bureau Circular C401, Abstracts and Summaries of Bureau of Standards Publications on Stray Current Electrolysis - 1933
  - Bureau Circular C450 Underground Corrosion – K.H. Logan - 1945
  - Bureau Circular C579 Underground Corrosion – M. Romanoff - 1957
### Steel in Soil According to Soil Resistivity and Drainage

<table>
<thead>
<tr>
<th>Environmental Factors</th>
<th>General Corrosion Rates, mpy</th>
<th>Pitting Corrosion Rates, mpy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td><strong>Soil Resistivity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less Than 1,000</td>
<td>2.5</td>
<td>0.7</td>
</tr>
<tr>
<td>1,000 to 5,000</td>
<td>2.3</td>
<td>0.2</td>
</tr>
<tr>
<td>5,000 to 12,000</td>
<td>1.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Greater Than 12,000</td>
<td>1.4</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Drainage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Poor</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Poor</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Fair</td>
<td>2.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Misconceptions Regarding “Pitting Factor”

- Factor was introduced during the interpretation of these data and was intended to establish the relative propensity of a material to experience localized corrosion.

- It is defined as the ratio of the average penetration rate to the average overall general corrosion rate.

- This concept is often misapplied when considering corrosion rates in soils.
  - Often general corrosion rates are multiplied factors of 5 -10.
    - Not Defensible
Romanoff on Pitting in Soil

- The rate at which pits grow in soil under a given set of conditions tends to decrease with time.

- The predominant mechanism for the development of localized corrosion is deferential aeration.
  - One can concluded that this mechanism would have been much more prevalent in the uncoated specimens used in these studies than on coated pipelines (barring mechanisms associated with disbonded coating).
Logan on Pitting

- Logan concluded that the Pitting Factor was an indication of the uniformity of corrosion and that it tends to become less as the specimens grow old.
- This would suggest that pitting rates decrease with time.
Logan Critical Observations

- (1) “The pitting factor when plotted against soil drainage indicates the pitting factor is the lowest for poorly drained soils, and

- (2) The pitting factor gives no indication of the depth of corrosion or the number of deep pits, and it is not an adequate expression of the seriousness or the distribution of corrosion.”
Using Pitting factors is Not Reasonable

- Operating history does not support the concept.
  - 5 mpy uniform corrosion rate with a 5 -10 x Factor
    - 25 - 50 mpy (Unreasonable)
    - 0.250 Wall Pipe would fail in 5 -10 years
      - History does not support this.
Special Considerations for Corrosion Rates

- Root cause Determined to be from
  - MIC
  - Stray D-C
  - Stray A-C
Special Considerations

MIC

- MIC in soils has been documented to occur at rates approaching 150 mpy.

Dish shaped pitting
Special Considerations D-C Stray Current Corrosion

- The effects of stray direct current on established corrosion rates can not be readily quantified due to the significant metal removal power of D-C currents.

Sharp Edged Pits
The authors have documented field and laboratory A-C corrosion rates of 60 mpy.
Reassessment Intervals for These Root Causes

- Adequate reassessment intervals can not be established (MIC, Stray D-C, Stray A-C if corrosion is active)
  - A mitigation strategy is required to reduce these rates to a reasonable rate in order to establish reasonable reassessment intervals
Remaining Life Calculation

- The remaining life of the pipeline in an ECDA region is the time it will take for the most severe remaining corrosion anomaly still remaining within ECDA region to grow to either leak or failure.

- The remaining life is determined on a per region basis and applied on a segment basis to establish the Reassessment Interval of that segment.
Time-to-Leak and Time-to-Failure Methodologies (Remaining Life)

- TL = Time Until Leak (years) (Grown to a maximum 80% deep defect representing an immediate condition)

\[
TL = \frac{0.8t - d}{GR}
\]

- TF = Time Until Failure (years)

\[
TF = C \times SM \frac{t}{GR}
\]
Parameters Considered

- $t =$ Nominal Wall Thickness (inches)
- $d =$ Corrosion depth (inches)
- $C =$ Calibration Factor = 0.85 (dimensionless)[1]
- $GR =$ Growth Rate (inches per year)
- $SM =$ Safety Margin = $FPR - MPR$

[1] The Calibration factor is intended to account for the increase in the length of a given anomaly at a certain corrosion depth increase. A 0.85 calibration factor assumes that the length of a corrosion anomaly increases at 15% or the increase in depth.

- $FPR =$ Failure Pressure Ratio = $P_{FAILURE}/YP$
- $MPR =$ MOP or MAOP Ratio = $MOP/YP$
- $MOP =$ Maximum Operating Pressure (PSI) of the pipeline segment
- $P_{FAILURE} =$ Predicted Failure Pressure (PSIG)
- $YP =$ Yield Pressure
Yield Pressure Calculation

\[ YP = \frac{2 (t) (SMYS)}{OD} \]

Where:
- \( OD \) = Outside Diameter (inches)
- \( SMYS \) = Specified Minimum Yield Strength (PSI)
Reassessment Interval

- Reassessment Interval is $\frac{1}{2}$ the Remaining Life.
  - Can not exceed Regulatory Limits for Maximum Allowable Reassessment Intervals.

- Applied on a region basis.
  - Dictates the reassessment interval of a segment.
What’s Next ??

- Large Body of data Now Compiled

- Do we reconsider
  - ½ Life?
  - Default rates of 16 mpy?
  - Corrosion Growth rates with Corrosion mitigated?
  - Time-to-Leak Criterion
Half Life Scenario

- Accounts for a conservative approach.
- Will instill regulatory confidence.
- Is it reasonable to incorporate a 100% Safety Factor
  - No other integrity measure introduces this margin of safety
  - Does it cause us to divert resources from where they are needed?
- Probably too much regulatory “push back” but TG-041 should address and either confirm or revise.
Default Growth Rates

- Established default rate is based on statistical analysis of 900 data point randomly selected.
  - Data sets are not entirely clean.
  - 80% confidence interval with a large standard deviation

- Is 16 mpy too conservative?
  - Literature and Field Data Suggests yes
  - Does it result in unusually short reassessment intervals
    - Yes!

- TG-041 should address
  - Revisit data set.
  - Consider a lower default rate.
For ECDA reassessment intervals and for CDA corrosion growth rates with mitigation must be considered.

- Coupons can be beneficial in estimating polarization.
  - Selectively installed at Direct examination Sites
  - Considered on a Region Basis

- Polarization can be related to a reduction in corrosion rates.
Coupon Placement

- Top of Pipe
- Side of Pipe
- Bottom of Pipe
Native Coupon Corrosion Rate
- Indicative of the general corrosion rate of bare steel exposed to the local soil environment and is not influenced by the application of cathodic protection.
- Can estimate the rate at which steel may be corroding under the influence of CP.
  - Determine or assume the Tafel behavior of the steel (defines the reduction of corrosion based upon the potential and current relationship) in the environment.
  - Once known, one can extrapolate from the corrosion rate observed on the native coupon to the level of polarization on the protected coupon, and estimate a corrosion rate under the influence of the CP.
Data Comparison Pipe Off vs. Coupon Off

4.2 cm²: Instant-Off Potential

y = 1.0157x
R² = 0.9006
S_y = ±39 mV

1:1 Reference Line
Regression Line

PIPE OFF POTENTIAL, -mV (Cu/CuSO₄)
COUPON OFF POTENTIAL, -mV (Cu/CuSO₄)
## Example

<table>
<thead>
<tr>
<th>Description</th>
<th>Corrosion Rate (mpy)</th>
<th>Polarization (mV)*</th>
<th>Rate Reduction Factor**</th>
<th>Corrosion Rate Under CP (Corrosion Rate / Rate Reduction factor) (mpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choate Road</td>
<td>2.2</td>
<td>78</td>
<td>6</td>
<td>0.4</td>
</tr>
<tr>
<td>Bay Area</td>
<td>1.9</td>
<td>57</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>34th Street</td>
<td>4.0</td>
<td>209</td>
<td>122</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>FM 1764</td>
<td>4.1</td>
<td>122</td>
<td>17</td>
<td>0.2</td>
</tr>
<tr>
<td>38th Street Valve</td>
<td>5.7</td>
<td>99</td>
<td>10</td>
<td>0.6</td>
</tr>
<tr>
<td>Atwater Street</td>
<td>4.5</td>
<td>90</td>
<td>8</td>
<td>0.6</td>
</tr>
<tr>
<td>FM 517</td>
<td>1.4</td>
<td>105</td>
<td>11</td>
<td>0.1</td>
</tr>
<tr>
<td>Cattle Pens</td>
<td>6.4</td>
<td>551</td>
<td>319017</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>FM 646</td>
<td>5.0</td>
<td>103</td>
<td>11</td>
<td>0.5</td>
</tr>
<tr>
<td>Water Tower</td>
<td>3.1</td>
<td>161</td>
<td>41</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>FM West 96</td>
<td>1.0</td>
<td>125</td>
<td>18</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>FM 518</td>
<td>10.1</td>
<td>353</td>
<td>3358</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>West 4th Street</td>
<td>1.2</td>
<td>390</td>
<td>7864</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>3rd Street</td>
<td>0.4</td>
<td>120</td>
<td>16</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Repsdorf Street</td>
<td>2.4</td>
<td>117</td>
<td>15</td>
<td>0.2</td>
</tr>
<tr>
<td>Red Bluff Valve</td>
<td>0.4</td>
<td>128</td>
<td>19</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Port Road</td>
<td>2.8</td>
<td>112</td>
<td>13</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Average:** 3.3 172 19444 0.2

*Polarization of Protected Coupon as measured by short term depolarization

**Based upon an order of magnitude reduction in corrosion rate per 100mV of polarization.
Time to Leak Remaining Life

- Small cross sectional area corrosion defects cannot be analyzed using a pressure failure criterion
  - Localized “pitting” corrosion cannot be accurately assessed with B31 or Rstreng.

- Growing the defect to an 80% “immediate indication” is more appropriate for remaining life calculation

\[
TL = \frac{0.8 \times t - d}{GR}
\]
Summary

- The successful application of DA Process requires
  - Reliable and defensible reassessment interval
  - Establishing the remaining life of un-repaired defects remaining in the pipe wall.

- An accurate assessment of corrosion growth rates is required to predict the remaining life of such defects.

- A wide variety of unqualified corrosion rates exist in the public domain.
  - Often misapplied.

- Default Rates in NACE SP0502-2002 ECDA Standard can be excessive.
  - Helps to insure conservative analysis.
  - Hurts when it results in unreasonably frequent reassessment intervals.
Summary (Cont’d)

- Adequate reassessment intervals can not be established when active MIC and/or Stray D-C/A-C assisted corrosion exists due to the unpredictably high corrosion growth rates.
  - Mitigation must be implemented.

- Four Methodologies are available for use in establishing External Corrosion Growth Rates to establish Reassessment Intervals.

- TG-041 should examine
  - Validity of half life (100% safety margin)
  - Validity of Default rates
  - Corrosion Growth rates with CP Applied
  - Adding a Time-to Leak Criterion