PIPELINE INTEGRITY

CORROSION GROWTH RATE PLAN

Enbridge Pipelines Inc.
Enbridge Energy Partners Inc.
Pipeline Integrity
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1.0 INTRODUCTION

As described in the *Integrity Management Framework Document*, Enbridge uses a defect management approach to ensure safety of the pipeline system. Integral to an understanding of overall defect behavior is an understanding of the rate at which defects propagate or “grow” within the pipeline. Enbridge is committed to corrosion growth rate (CGR) analysis to support the Corrosion Integrity Management Plan.

Through time, Enbridge has employed progressively more sophisticated approaches to assist with the understanding of CGRs. The precision of these CGR analysis techniques continues to improve through statistical validation, back-to-back high-resolution inspections and field verification. Enbridge continues to improve its knowledge on how to best use the results derived from CGR analysis.

This document summarizes present Enbridge CGR analysis methodologies. As each methodology has its own strengths and weaknesses, for each analysis the most suitable CGR will be chosen after consideration by a subject matter expert. Pipeline integrity procedures that require CGR include recommended CGR methodologies that are most applicable.

2.0 DETERMINING A CORROSION GROWTH RATE

Currently, Enbridge uses three main analysis techniques to calculate a defect specific CGR:

1. Historical
2. Pit matching
3. ILI signal matching

The following section of this document contains an overview of each approach. Once a defect specific corrosion growth rate is established, a population of defects can be used to determine a statistically significant CGR distribution. Enbridge also uses R&D to further expand its understanding of corrosion growth rates.

Industry published CGRs may be used but are not considered as being representative as the CGR values calculated from data collected on the Enbridge pipeline system.

2.1 HISTORICAL-BASED CGR BACKGROUND

Historically, qualitative processes were employed in determining re-inspection intervals for pipeline segments. These processes involved Enbridge pipeline integrity engineers and technicians consolidating and analyzing all available information including causal factors, line conditions, defect behavior, failure history and prior in-line inspection (ILI) results (as available) to develop estimates regarding corrosion growth rates. In general, the maximum corrosion growth rate was established for any given pipe segment and was translated into an appropriate inspection interval.

One of the earliest methods used to estimate maximum corrosion growth rate for a particular section of line was to assume linear corrosion growth between the installation date and the last inspection or failure date. For instance, in 1989 a report was prepared in response to a corrosion leak on Line 3 (MP 792.20). Assuming linear corrosion growth between 1977 and 1989 low-resolution MFL runs, the average corrosion rate was estimated to be 0.09 mm/yr and the maximum was 0.20 mm/yr. The maximum corrosion rate was confirmed by calculating the corrosion rate for the leaking feature, which was also estimated to be 0.20 mm/yr.

Similar to the example provided above, in an operational reliability assessment prepared in 1997 for Line 3, comparable corrosion rates were estimated. The corrosion rate of the first pure external corrosion failure on Line 3 (MP 518. 87), which ruptured on June 1995 when corrosion reached 83% through-wall, was estimated to be 0.22 mm/yr assuming linear corrosion between the installation date and failure date.

2.1.1. HISTORICAL-BASED CGR CALCULATION

Historical defect specific CGRs can be determined by using known measurements of a defect from ILI or field data and dividing it by an assumed age of the defect. The year of construction of a given pipeline segment can be used as the defect initiation date. One of the biggest advantages of the historical method is its defensibility. The CGR that is determined is defect specific, based on the entire historical CGR a particular defect has seen, often over a long period of time, and is calculated using known inputs (age of the pipeline and depth of a pit at a point in time). Depending on the age of the pipeline, the assumption that internal and external corrosion features initiated during construction may not be accurate. As a result a safety factor is used to increase the CGR assumption to a conservative level. For example:

$$\text{Depth CGR} = \frac{\text{\%depth based on ILI data}}{\text{(Year of ILI run – Year of Construction)/Safety Factor}} = \frac{\text{30\%wt}}{(2001 - 1954)/2} = 1.3\text{\%/yr}$$

The historical based defect specific CGR using an appropriate safety factor has been validated to be conservative through various analyses and comparisons of back-to-back in-line inspection results. See the **Historical-Based CGR Validation Analysis** for further information.

Areas of accelerated corrosion, potentially due to such things as MIC, will be accounted for by the historical defect specific CGRs in that these features will be deeper and therefore assigned a higher CGR. The threat specific risk associated with the higher CGR is addressed in the Corrosion Engineering Assessment.

2.2 PIT MATCHING

Pit matching involves taking a corrosion feature with known parameters at two different points in time to calculate a CGR. For example, using the depth of a corrosion feature as identified in two back-to-back ILIs and the time interval between the inspections a CGR can be determined. In-house pit matching can be done using MS Excel Macros that automatically match pits from two consecutive inspections. This method provides an accurate representation of the CGR of a defect between two points in time. When using this method to determine CGRs changes and improvements to tool technology, threshold settings in earlier tools, tool measurement tolerances, and changes to automatic defect sizing algorithms are considered.

2.3 SIGNAL MATCHING

A signal matching analysis reprocesses the signal received by two back-to-back ILIs and identifies change in the amplitude of the signal in order to determine a change in depth. This is then compared to the time interval between inspections to generate an accurate CGR. Recently this methodology of determining CGRs has been automated by some ILI vendors allowing all corrosion features in a given ILI to have a defect specific CGR assigned.

2.4 CGR DISTRIBUTIONS

CGRs are either represented as deterministic values (e.g. 0.22mm/yr) or as a statistically significant CGR distribution (e.g. mean = 0.22mm/yr, standard deviation=0.10mm/yr). A CGR distribution accounts for the uncertainty or error of the CGR value to be accounted for and is important when performing any kind of probabilistic or quantitative analysis. A CGR distribution can also be used to define a defect specific CGR or the CGR for an entire population of defects.

CGR distributions for entire population of defects are used for high-level comparisons between pipeline segments. For defect specific analysis, a defect specific CGR is determined using one of the three CGR techniques.

3.0 CORROSION GROWTH RATE ANALYSIS

Three levels of CGR analysis, using the techniques outlined in Section 2.0, can be applied to every corrosion ILI data set in order to further enhance the understanding of CGR behavior on the Enbridge system and continually improve CGR assumptions used for analysis purposes. At a minimum, all corrosion ILI data will have a Level 1 analysis completed. Depending on data availability and the importance of understanding the CGR on a given pipeline segment, a Level 2 or Level 3 analysis may also be conducted. In cases where more certainty in growth rate is needed – such as engineering assessments or choosing additional excavations further work can be done to separate actual CGR and error related to the tool measurement tolerance. To separate actual CGR and tool error, the unity plot statistics can be used to find the typical offset in depth and/or RPR. When the defects are deterministically grown out, the offset or tool error is added once, while the actual CGR portion is added year-by-year.

3.1 HIGH DENSITY SEGMENTATION: LEVEL 1

A Level 1 CGR analysis involves determining a depth and RPR CGR mean and standard deviation based on a normal distribution for the internal and external CGRs on a given pipeline segment. This provides a high level characterization of the CGR on a trap-to-trap segment and can be used for further trending and comparisons improving the overall understanding of CGR on the Enbridge system. Level 1 CGR are not typically used for detailed analysis unless no other data is available.

If a previous high-resolution ILI is available, then an excel spreadsheet with a specifically designed macro is used to compare the new high resolution ILI data to the old ILI data. This macro allows the depth of the worst corrosion depth and lowest RPR on a girth weld between the two inspections to be identified and compared. An example of this is outlined in Chart #1.

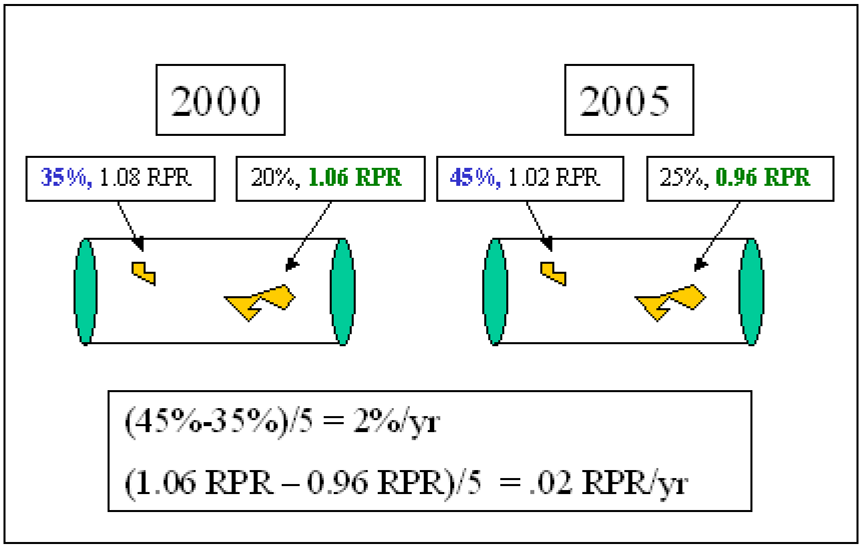

Chart #1 – Example of Level 1 CGR analysis.

If a previous high resolution CGR is not available, a historical based defect specific CGR, using the age of the pipeline, with a safety factor is determined and modified into a representative mean and standard deviation CGR distribution to define the population.

See the **Level 1 CGR Analysis** chart for further pipeline segment specific CGRs. In some cases, automatic and manual pit-matching are used to validate Level 1 results.

3.2 FEATURE MATCHING: LEVEL 2

A Level 2 CGR analysis involves additional comparisons between back-to-back high resolutions ILI data to identify corrosion features that have experienced upper bound CGRs. These features are flagged and further investigation, analysis and trending is completed in order to identify any specific drivers or trends (e.g. soil, microbial influenced corrosion, proximity to surface water) that may have contributed to the accelerated CGR. The defects are first screened to remove any obvious errors due to interaction changes or automatic matching errors. Any findings are re-applied to the CGR assumptions used in order to ensure the continual improvement of corrosion repair and assessment programs.

An excel spreadsheet, with a specifically designed macro, aligns and compares corrosion features in both inspections. Features that are appropriately matched and meet the criteria specified in the PI-23 Upper Bound Corrosion Growth Rate Analysis procedure are targeted for further CGR analysis.

Output of the **Level 2 CGR Analysis** report are maintained in accordance to PI-23.

The results from the Level 2 CGR Analysis are retained to allow for future trending to identify any specific correlations between accelerated CGR and site specific attributes. This trending may result in changes to the CGRs used for threat specific risk assessments completed in accordance with the Corrosion Assessment Interval Plan.

3.3 SIGNAL MATCHING: LEVEL 3

A Level 3 CGR analysis involves using ILI signal-to-signal defect matching comparisons (e.g. RunCom) to generate CGRs. The signal captured by the ILI tool in two consecutive inspections of the same pipeline are reprocessed, aligned and normalized. By comparing the raw tool signal in both inspections, an increase in the depth of the feature can accurately be calculated. This increase in depth is then compared to the time between inspections in order to determine a defect specific CGR. This Level 3 CGR analyses are also used for special projects to enhance general knowledge of CGR behavior (e.g. internal corrosion mitigation effectiveness, effect of temperature on CGR, etc.).

Since 2008, MFL to MFL RunCom analysis is supplied by GE when they have completed both the previous and the recent inspection.

See the **Level 3 CGR Analysis Summary** for all pipeline sections, which have had a Level 3 CGR analysis performed, and a summary of the results.

3.4 ESTIMATING TOOL MEASUREMENT BIAS

In 2008, PRCI project EC1-2 resulted is a user guide for comparing successive ILI to establish corrosion growth rates. The report recommended the same three methodologies for calculating CGR as Enbridge currently uses: segmentation, feature matching, and signal matching. The user guide contains several templates to help calculate CGR; however these are not used as Enbridge has already developed templates.

One improvement over Enbridge's current methodology that is recommended in the EC1-2 report is the comparison of static features in two inspections to help calculate tool bias. For the majority of the pipelines in the Enbridge system, the majority of static features are low depth and severity, more severe features have been repaired. One disadvantage of this is that tool measurement error becomes more important for features close to the measurement threshold. In addition, it may not be valid to apply a trend based on low-level features to features that are much more severe. Because of these issues, tool measurement bias is not typically considered, unless there is evidence that the tool bias is large and non-conservative. In those cases, the EC1-2 report can be used as a guideline.

4.0 APPLICATIONS OF CGR

It is widely known that there is extreme variation in CGRs on a pipeline system based on coating type, site-specific influences, product transported and prevention programs that are implemented. Even the CGR of individual corrosion features occurring within inches of each other have been identified to have significantly different CGRs. As a result, it is important to carefully consider the CGR assumption that will be used to model corrosion feature growth.

For example two corrosion features occurring within inches of each other are field verified to be 40% and 10% deep. Based on the depths, the 40% deep feature has had a higher historical CGR than the 10% deep feature. For this reason, when growing individual corrosion features, the assumption that both these features will grow at equal rates into the future would likely be incorrect. For this reason when applying CGRs to enhance repair and assessment programs a defect specific CGR should be used.

4.1 CORROSION RE-ASSESSMENT INTERVALS

One of the main uses of CGRs is to support the determination of appropriate corrosion re-assessment intervals that will ensure the safety of a pipeline. CGRs are often used to approximate how long it will take the worst remaining corrosion features to grow to an unacceptable severity level. These are used to determine an acceptable corrosion re-assessment interval.

Historical based CGR's with an appropriate safety factor are used when completing probabilistic analysis to determine re-assessment intervals. In this case, each defect is grown out individually, taking into account possible errors in the reported defect measurements and other pipe attributes. The CGRs that are used within the probabilistic software model can be updated and continually improved based on further CGR analysis that is conducted. Level 1, 2, or 3 CGRs can be used to over-ride historical rates if they are available and it is appropriate. The re-assessment interval recommended by the probabilistic analysis for each line segment is integrated with other corrosion metrics. See the Corrosion Assessment Interval Plan for further detail.

4.2 SPECIAL PROJECTS AND ANALYSIS

CGR analysis has proved to be an important tool for special projects within Pipeline Integrity. One example of this is using RunCom analysis to try and determine inhibitor effectiveness. Defects are sampled based on their morphology and the resulting CGRs for each defect are trended to check inhibitor effectiveness on internal features with different morphologies. This can then be used to determine more effective cleaning and inhibitor programs. Other examples are engineering assessments or estimating the effect of operational changes.

5.0 FURTHER REFERENCE TO CGR METHODOLOGIES

For further reference to ongoing developments to corrosion growth rate and its uses, or for more detail on specific CGR methodologies, see the following documents:

In-House CGR Analysis Review, 2005
CAIR Table, 2006 (Part of the IMS)
PI-10 Corrosion Assessment Interval Using Reliability Based Probabilistic Analysis, 2009
Corrosion Growth Rate Analysis Improvement Plan, 2009

APPENDIX A – Published Corrosion Growth Rates

The following published rates can be found in industry literature. These rates are not used directly, but are typically used for comparison or as a baseline. Also note that the rates found in industry are primarily for external corrosion and comparable rates would be considered outlier corrosion growth on the majority of the Enbridge system.

Standard/Guideline	**Recommendations**
NACE RP0502 (Ext)	0.3mm/yr: 80% confidence max rate with 'good' CP
ASME B31.8S (Ext)	0.31mm/yr max rate for active corrosion in low resistivity soils
GRI-00/0230 (Ext)	0.56mm/yr for pitting; 0.3mm/yr for general corrosion

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