



Improvements in the Engineering Assessment Process of Metal Loss in In-Line Inspections

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Abstract:

Data analysis results from in-line inspections (ILI) are commonly used by pipeline operators to guide and support integrity management decisions. Presentation of data analysis results are typically presented in a report and delineated spreadsheet. For metal loss inspections in particular, it is common to apply remaining strength pressure calculations (e.g. B31G, 0.85dl, effective area) to those flaws identified in the spreadsheet.

Improvements in data processing make it possible for continual improvement in automated processing of ILI data. Automated processing is necessary to traverse the exceedingly large ILI data sets acquired today. The combination of automated processing and human expert involvement form the basis of the data analysis process. Thresholds and boundaries are set during this process in order to present the data analysis results in a spreadsheet or database format. Since engineering assessments often follow the data analysis process, the engineering assessment process is only applied to what is found in the spreadsheet or database format.

By utilizing compression-wave, ultrasonic ILI data and API 579 Fitness-for-Service Part 5 Level 2 methodology, the engineering assessment process can be applied directly to the ILI data set. The API 579 methodology evaluates the remaining strength of the entire pipeline, using all of the ultrasonic wall thickness measurements, not just assessing areas where metal loss has been identified and boxed through data analysis process. By assessing the entire ILI data set, thresholds and boundaries no longer limit information the pipeline operator receives about the pipeline. Advantages of this approach include accuracy, no dependence on metal loss interaction criteria, repeatability and more informative run comparisons.

This presentation will demonstrate the application of an all-inclusive ILI data set engineering assessment using API 579 Fitness-for-Service methodology and a comparative analysis to the traditional data analysis/engineering assessment approach.

Main Paper:

1. INTRODUCTION

Inspection and assessment capabilities in the pipeline industry are constantly improving thanks to competitive technology developments. More advanced ILI tools yield better data on pipeline condition, which drives the need for advanced assessment capabilities to leverage the improved data quality and accuracy. Damage mechanisms such as internal and external corrosion, dents



and cracks can now be accurately quantified. The combination of more advanced inspection and superior assessment procedures is rapidly demonstrating the weaknesses in older procedures. Using these more advanced assessment technologies, which are validated and supported through extensive field research, operators can now assess defects in pipelines and determine fitness-for-service (FFS) quickly and confidently.

Fitness-for-service assessments have become increasingly accepted across the pipeline industry over the past few years. FFS standard API 579/ASME FFS-1 (API 579-2007) provides guidelines for assessing types of damage affecting pipelines across all industries. These damage mechanisms include corrosion, weld misalignment, dents, laminations and cracks, among others.

Metal loss flaws may develop in pipelines for a variety of reasons and in a variety of locations. External corrosion may occur at locations where external coating and cathodic protection break down. Internal corrosion may occur due to corrosive products and ineffective corrosion control programs. Arc burns may occur during pipe installation. Other manufacturing or construction flaws may have been ground out.

As described above, metal loss can be present in the base metal, weld metal or the heat-affected zone. Depending on the origin and mechanism, metal loss can be internal, external or in some cases, both. Metal loss may be in the form of isolated pitting, general corrosion, can be axial or circumferentially oriented, or combination of those geometries. The high number of variables makes assessing metal loss flaws complex and highlights the need for a more comprehensive metal loss assessment method.

2. DATA ANALYSIS PROCESS

ILI tools have been used to detect metal loss for over 50 years. Magnetic Flux Leakage (MFL) ILI tools were the first to gain widespread acceptance. Traditional data analysis processes and subsequent engineering assessment are based on the legacy of MFL's indirect measurement data set.

Ultrasonic thickness measurement (UT) ILI tools perform direct wall thickness measurements. It is not uncommon for UT data sets to be analyzed using traditional data analysis processes that do not take advantage of the strength of direct thickness measurements.

2.1 Traditional Data Analysis Process

To identify and size metal loss flaws, the ILI data is reviewed through a data analysis process. When a metal loss flaw is identified, the extent of the metal loss is bounded by a box which establishes the length and width of the flaw. Depth predictions are then made for each metal loss flaw.



A metal loss reporting threshold is determined, and the most prevalent threshold is that all metal loss with a predicted depth of 10% of nominal wall thickness and greater will be reported. The absolute number of metal loss flaws does vary greatly depending on the condition of the pipeline.

Adjacent metal loss flaws may be combined into clusters based on interaction rules. There are several different sets of rules for interacting metal loss flaws but for all of them if metal loss flaws are closer than the criteria they are combined into one large cluster. Some of the more common interaction criteria are that flaws are considered to interact if they are within:

1. Three times the nominal thickness in either axial or circumferential dimensions,
2. One inch in axial dimension or six times the nominal wall thickness in the circumferential dimension, or
3. If the spacing, either axial or circumferential, is less than the respective dimension of the smaller of the two flaws.

The maximum depth of the combined flaws is equal to the greatest depth of the individual flaws included in the cluster. The length is equal to the total combined length of the cluster.

After the data analysis process is complete, results are reported in a spreadsheet format. The three dimensions that are reported for metal loss flaws, including both individual flaws and combined clusters, are maximum depth, length and width. Assessment calculations can then be applied to these values.

Only metal loss flaws that have been identified and meet the reporting threshold will be included in the report spreadsheet. Any metal loss flaws that are either less than the reporting threshold or not identified as metal loss flaws will not be boxed and therefore will not be included in the subsequent metal loss assessment.

2.2 Improved Data Analysis Process

Improvements have been made to the data analysis process that makes the results of the analysis both more consistent and better utilized in engineering assessments and run comparisons and more efficient to complete. Figure A shows a comparison of the two processes.

The basis of the improved data analysis process is the concept of validating thickness data as opposed to the traditional approach of relying upon the data analysis process to identify flaws from the data. The validation process will reject wall thickness values that do not represent true thickness readings by interrogating the ultrasonic signal parameters and using human expert intervention. Improvements in data processing have made it possible for continuous improvement in automated processing of ILI data and the capture of ultrasonic signal parameters. Automated processing is necessary to traverse the very large ILI data sets acquired today.



Once the validation process is complete, the data set will contain thickness values that may represent either the original wall thickness or one that has been reduced due to a damage mechanism such as corrosion or mechanical damage. This represents one strength of the improved process, where validating wall thickness, as opposed to identifying metal loss flaws, ensures that misclassifying a feature will not result in it being included in the results.

Metal loss flaws can be boxed and combined in a manner similar to the traditional approach. Metal loss depths will be established using the validated wall thickness within the flaw box. Minimum depth and other reporting criteria may be different than those used in the traditional data analysis process, in order to focus on only including flaws that will provide value as part of the pipeline integrity program.

In the improved data analysis process, reporting thresholds and criteria can be easily modified after a review of the data to ensure that a meaningful list of metal loss flaws is provided as part of the FFS report. The advantage is having an uncluttered list that is focused upon metal loss flaws that may be excavated or used in future run comparisons, and can be delivered in a timely fashion. Figure B shows a pipeline with extensive external metal loss and has over one hundred small pits within one pipeline joint. Trying to understand this data from a spreadsheet listing alone would be difficult; there are more effective ways of representing areas of metal loss that will be discussed later in the paper.

Manufacturing related, wall thickness variations that are outside of manufacturing tolerances may be very prevalent in some pipelines. In general, knowing the location and dimensions of these wall thickness variations provides very little value to the pipeline operator. With improved data analysis, process manufacturing related, wall thickness variations can be omitted from the reporting criteria, as they have already been captured as valid thickness data, and therefore not rejected from the data analysis process. Figure C shows an example of ILI data from a pipe joint with many manufacturing related, wall thickness variations due to the extrusion process that would exceed a traditional reporting threshold of 10% depth.

3. COMPARISON OF ASSESSMENT METHODOLOGIES

Performing an engineering assessment on the results of an ILI survey provides an understanding of the condition of the pipeline and whether it is capable of safe operation.

3.1 Traditional Assessment Methodology

The traditional approach is to apply remaining strength pressure calculations (e.g. B31G or 0.85dl) to those flaws identified in the spreadsheet. The length and depth that have been established through data analysis and reported in the ILI report spreadsheet are the only metal



loss flaw inputs into the metal loss remaining strength assessments. The modified B31G 0.85 dl method is illustrated in Figure D.

While these Level 1 assessments have been established through burst pressure data and verified through years of use throughout the pipeline industry, they are only as good as the dimensions that are used. Any differences between actual and predicted defect dimensions will be reflected in the results of the assessment. Since these results are used in pressure de-rating and flaw repair decisions, any inaccuracies can impact the safety of the pipeline. Additionally, if a metal loss flaw in the data is not reported in the spreadsheet, it is not subjected to an engineering assessment.

3.2 Advanced Assessment Methodology

A more advanced method of assessment of ILI thickness data is to perform a continuous effective area calculation, as described in API 579-2007, directly to the complete data set. In this method, all of the validated wall-thickness data is used in the pressure assessment.

The validated thickness data is used to establish the critical thickness profile. Due to the nature of ultrasonic wall thickness data, boxing is not required. Figure E illustrates the process for establishing the thickness profile in an area of metal loss. The metal loss assessment is performed upon each slice of data and minimum calculated pressures can be reported for each metal loss flaw, pipe joint or length of pipe.

In performing the effective area calculation for each slice, the critical area is determined by iterating through all of the possible effective lengths until the minimum missing area is determined. In the API 579-2007 assessment, the Remaining Strength Factor (RSF) is used to evaluate the impact of any metal loss at each location along the pipeline. Figure F shows the RSF calculation.

This process accounts for any interaction between metal loss flaws without the requirement for interaction rules. Figure G shows two external metal loss flaws and the results of the continuous pressure assessment and the dynamic interaction between the two separately identified flaws.

Since an effective area calculation uses all of the critical thickness values to determine the reduced pressure capacity, it is less sensitive to any inaccuracies in overall depth prediction. The critical thickness profile approach is not limited to just one metal loss damage mechanism. It applies to any cause (corrosion, mechanical damage or manufacturing) that results in a reduced wall thickness.

3.3 Impact of Flaw Boxing on Assessment Results



One weakness in the traditional engineering assessment process is the often subjective nature of flaw boxing and impact of metal loss interaction during data analysis.

Two fully qualified data analysts, when working on an area of complex metal loss, may view the extent of metal loss flaws differently, primarily due to the uncertainty of the extent of low level metal loss, and therefore yield different results. Figure H shows an example of external corrosion that has low-level metal loss where the correct boxing, either one or multiple flaw boxes, is ambiguous and the impact upon the assessment results.

Metal loss interaction rules are sensitive to small differences in how a series of small areas of metal loss are boxed and therefore how metal loss anomalies are clustered. The difference in maximum length between a series of separate metal loss or one cluster will have a significant impact upon a Level 1 pressure assessment where length and depth are the only parameters.

An example of the impact of metal loss interaction rules on the assessment results is shown in Figure I. In this example, the metal loss flaws would be interacted by two of the common metal loss interaction criteria, but not by the other one. There is a significant difference in the assessment results between the individual metal loss flaws or the one cluster. This difference in results may be an impact on the safety of the pipeline or may be an example of unwanted conservatism.

An effective area assessment of areas of complex metal loss is not only more simple, it also yields more consistent results as there is no impact of flaw boxing upon the assessment results. Figure J shows the API 579-2007 process for evaluating the same area of metal loss shown in the previous example.

3.4 Impact of Depth Predictions on Assessment Results

A second weakness in the traditional assessments of ILI data is the impact of depth predictions in the pressure assessments. Any errors in the maximum predicted depth will have a direct impact upon the accuracy of the calculated reduced pressure due to the flaw. This is because only the maximum depth, and not a depth profile, is used to perform the assessment. Effective area calculations where a critical depth profile is established based upon the river bottom profile of a flaw are, by their nature, less sensitive to inaccurate depth predictions where critical locations are not correctly measured or due to errors in the data analysis process. Figure K shows an example of external metal loss and the impact of a change in the maximum depth prediction upon the engineering assessment results.

4. RUN COMPARISONS

By removing the dependence on flaw boxing in order to perform engineering assessments, reporting can be focused upon areas of interest as opposed to strict reporting criteria. For



example, pipeline locations with the lowest remaining strength factor can be identified per metal loss flaw, per pipe joint, per length of pipe (such as dynamic segmentation) or any combination of the three. This flexibility in reporting can allow for more informative run comparisons.

One of the difficulties in performing run comparisons based strictly upon a comparison of ILI spreadsheets is correlating metal loss flaws. It is not always clear if changes in metal loss flaw dimensions are due to growth, data analysis algorithm changes, reporting thresholds or changes in interaction criterion.

Being able to compare locations with lowest RSF can provide a more meaningful picture of metal loss growth. For example, instead of trying to match metal loss flaws (seen in Figures B, H or I) that may be reported differently between two traditional spreadsheets, comparing the RSF for that joint of pipe between two ultrasonic wall thickness inspections will present a more representative picture of potential change that may have occurred between the two inspections. This is an especially valuable run comparison approach if only the spreadsheets, and not the ILI data, are utilized for the comparative analysis.

5. CONCLUSION

Traditional data analysis processes and subsequent engineering assessment are based on the legacy of MFL's indirect measurement data set. As ultrasonic wall thickness in-line inspections are becoming prominent, consideration of advanced data analysis processes and engineering assessments should be considered.

When performing a continuous effective area calculation as described in API 579-2007 directly to the complete data set, all of the validated wall thickness data is used in the pressure assessment. By removing the dependence on boxing, interaction and thresholds, some of the subjectivity and human error in the analysis process can be eliminated, and reporting can focus on those areas that may impact the pipeline's pressure containing capabilities.

List of Figures

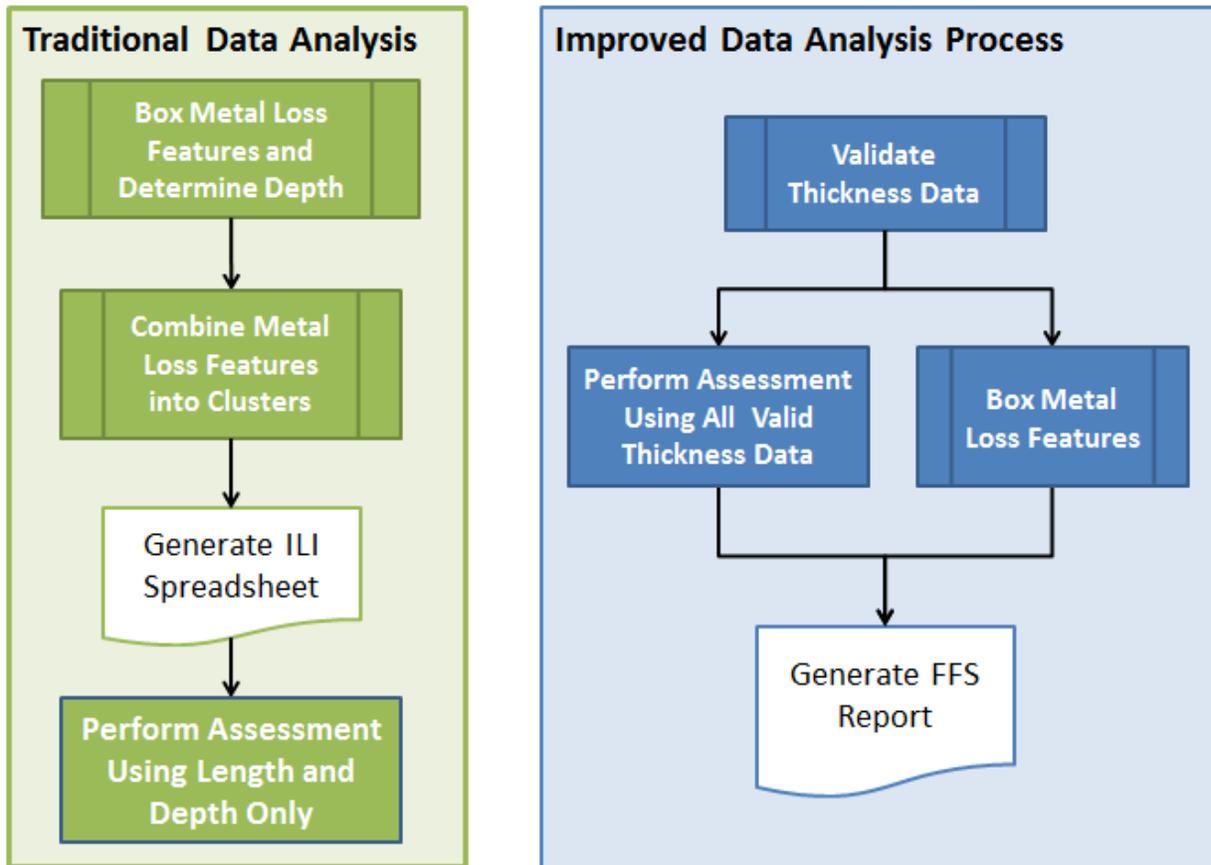


Figure A. Comparison of traditional and improved data analysis processes

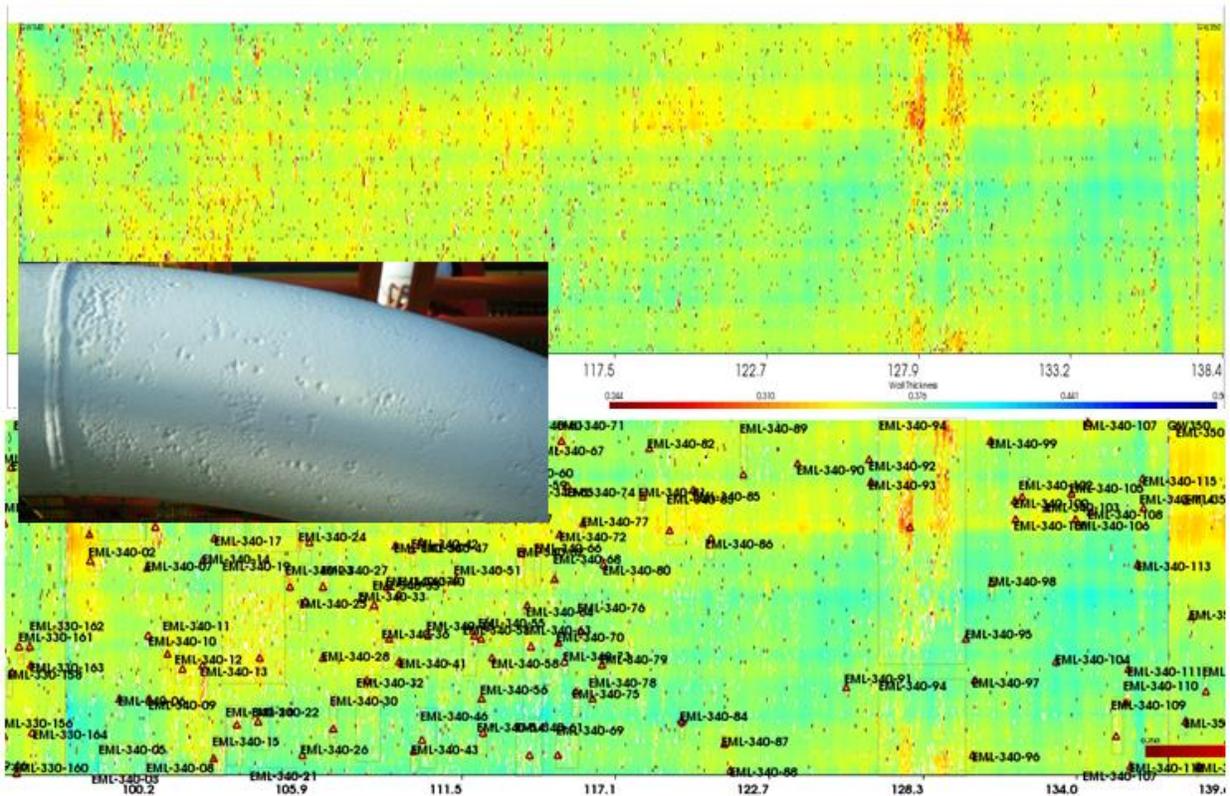


Figure B. Example of ILI data with extensive external metal loss flow boxes

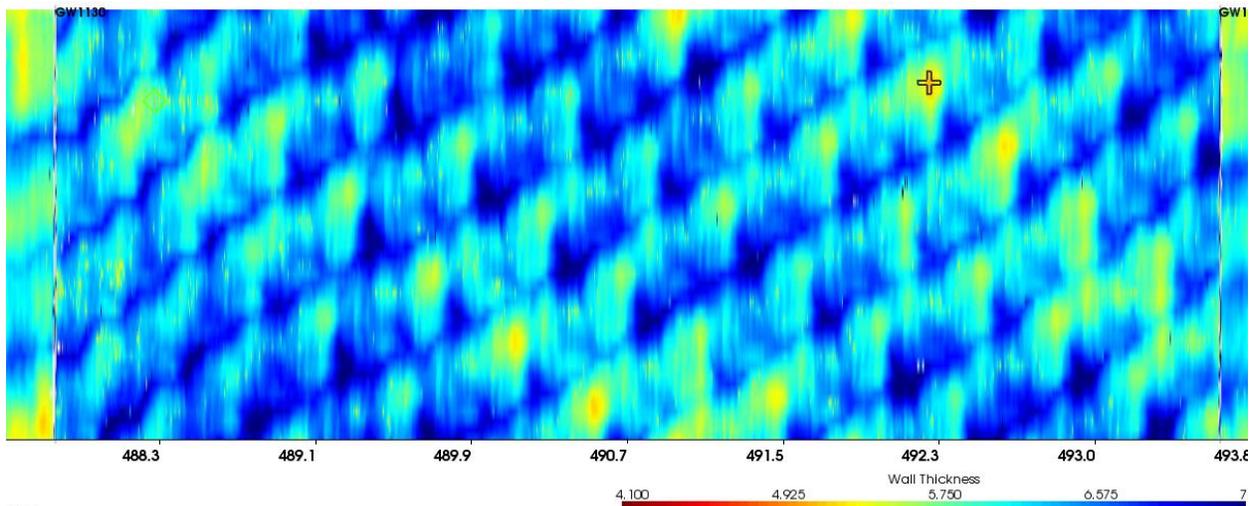
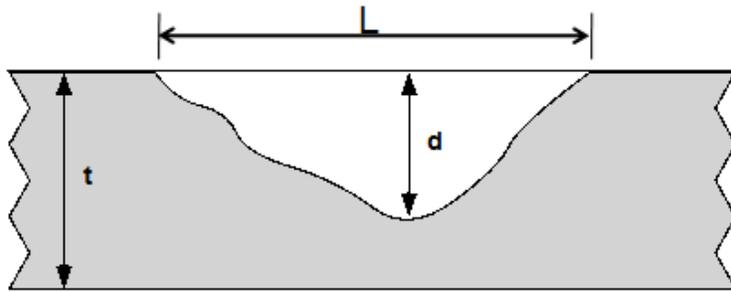


Figure C. Example of ILI data with extensive wall thickness variations that exceed traditional 10% depth reporting threshold



$$\frac{\sigma_f}{\bar{\sigma}} = \frac{1 - 0.85 \left(\frac{d}{t} \right)}{1 - \frac{1}{M_t} 0.85 \left(\frac{d}{t} \right)}$$

Figure D. Modified B31G 0.85 dl Metal Loss Assessment Method

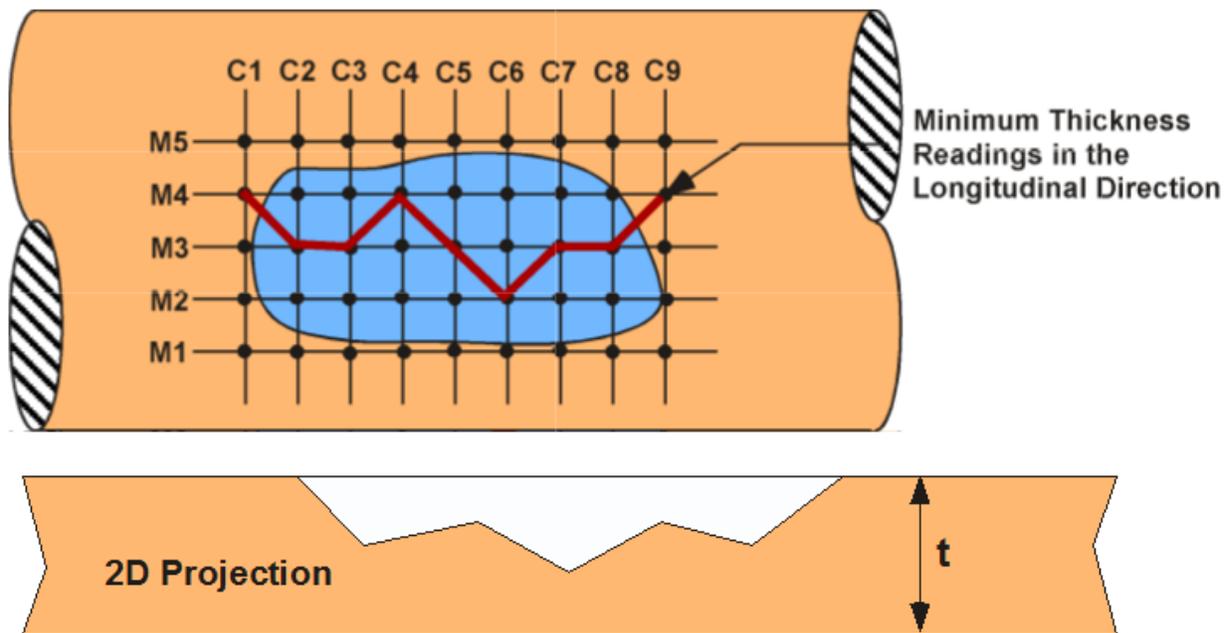


Figure E. Method for establishing the critical thickness profile in areas of metal loss for effective area assessments

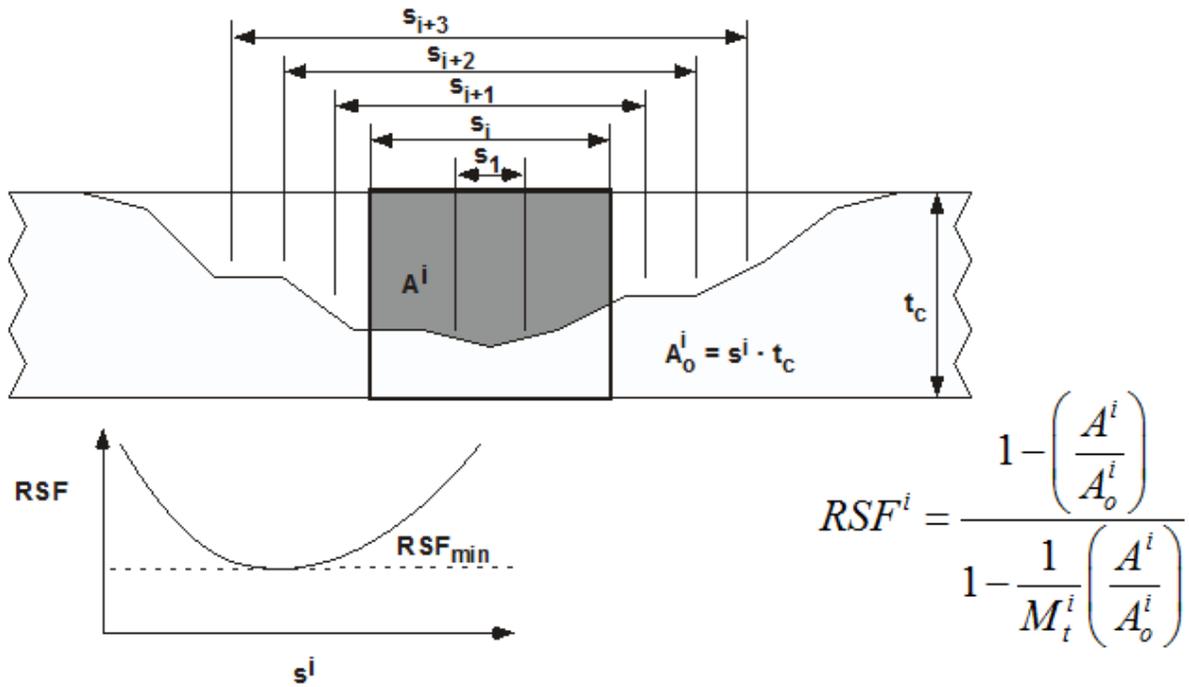


Figure F. API 579-2007 Part 5 Metal Loss Remaining Strength Factor calculation

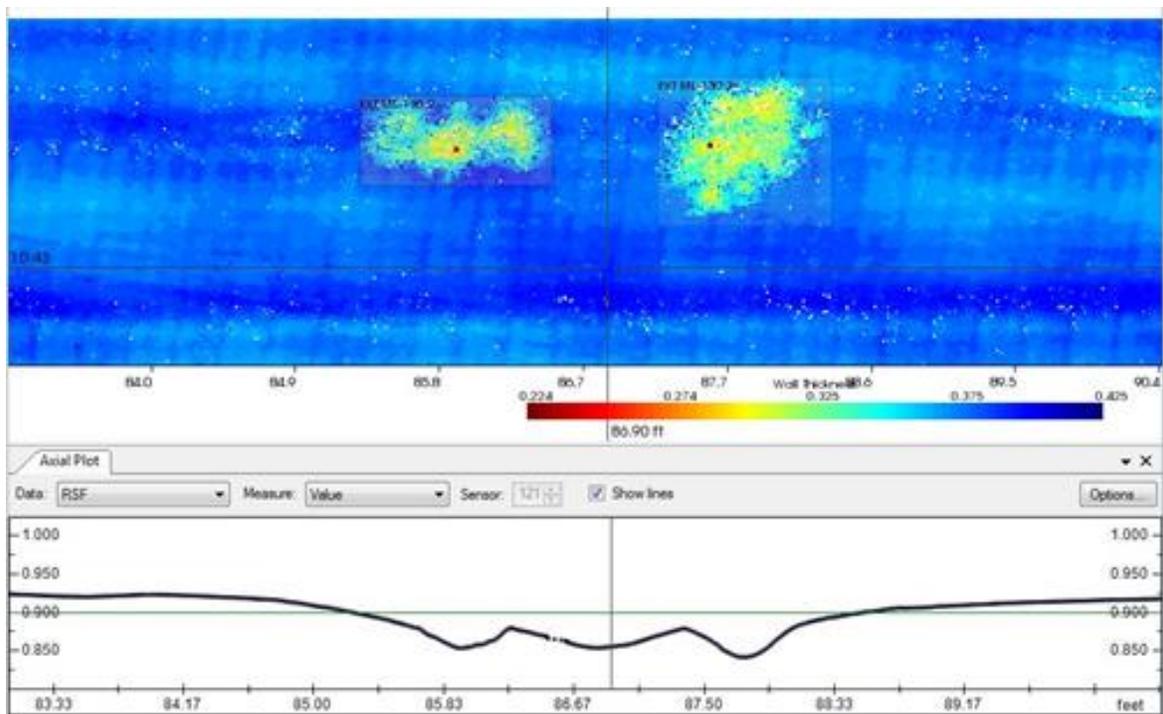


Figure G. API 579-2007 Part 5 RSF results on multiple metal loss flaws

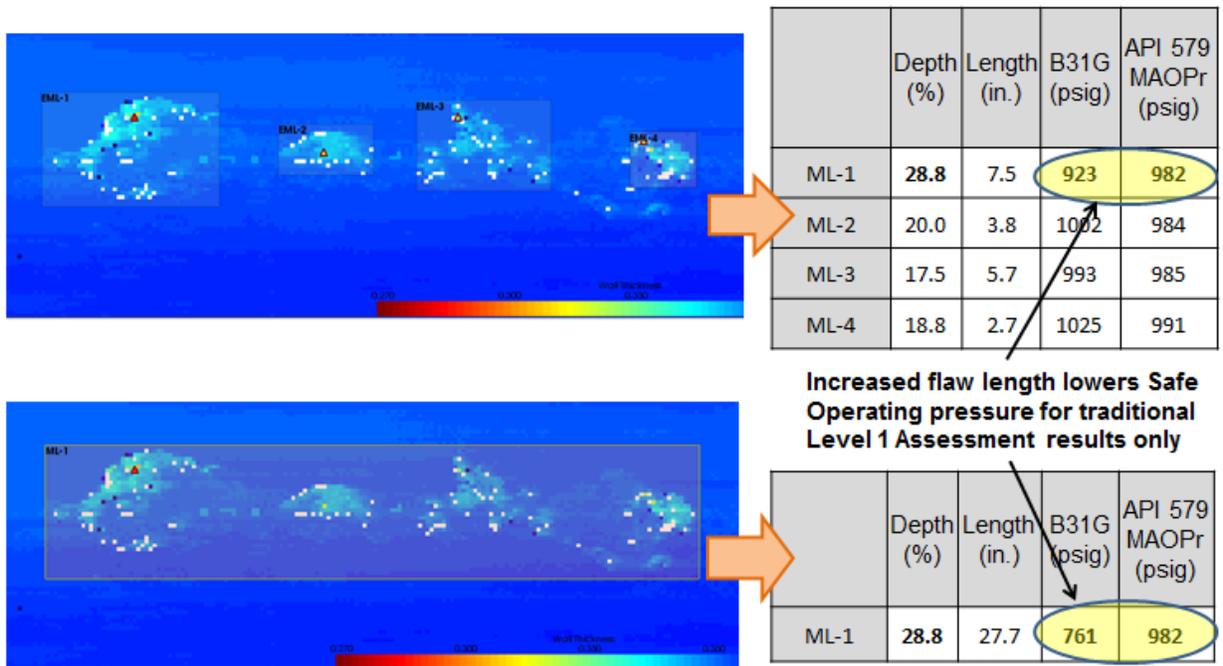


Figure H. Impact of low-level metal loss on engineering assessment results

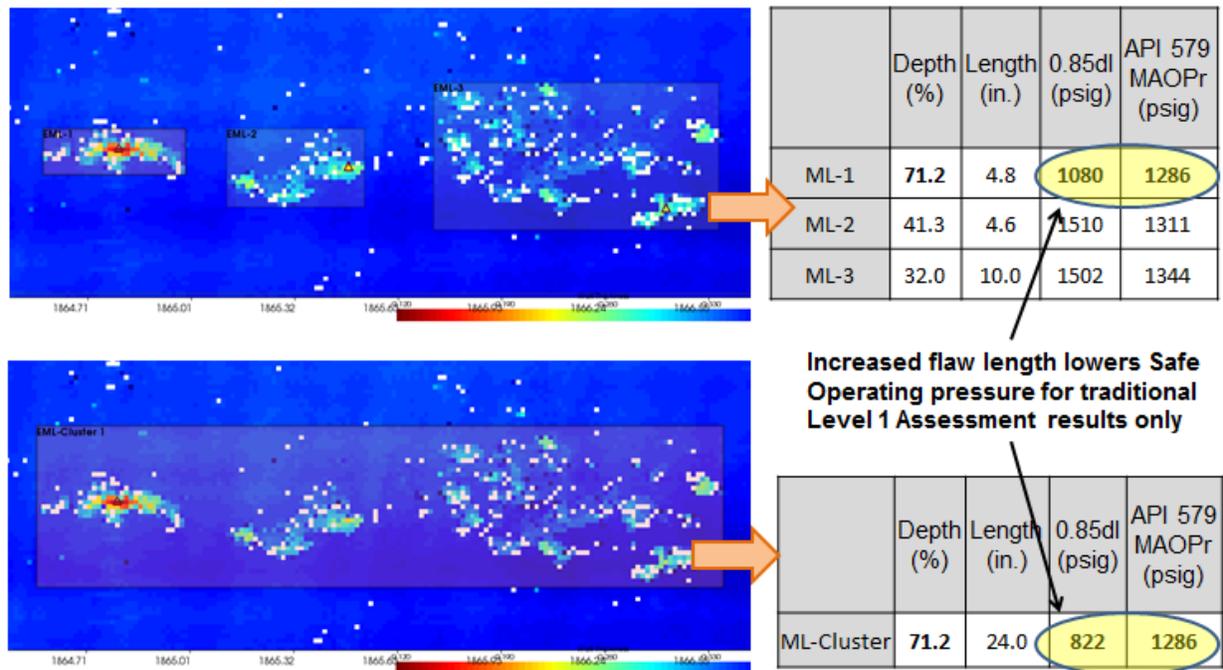


Figure I. Impact of metal loss interaction on engineering assessment results

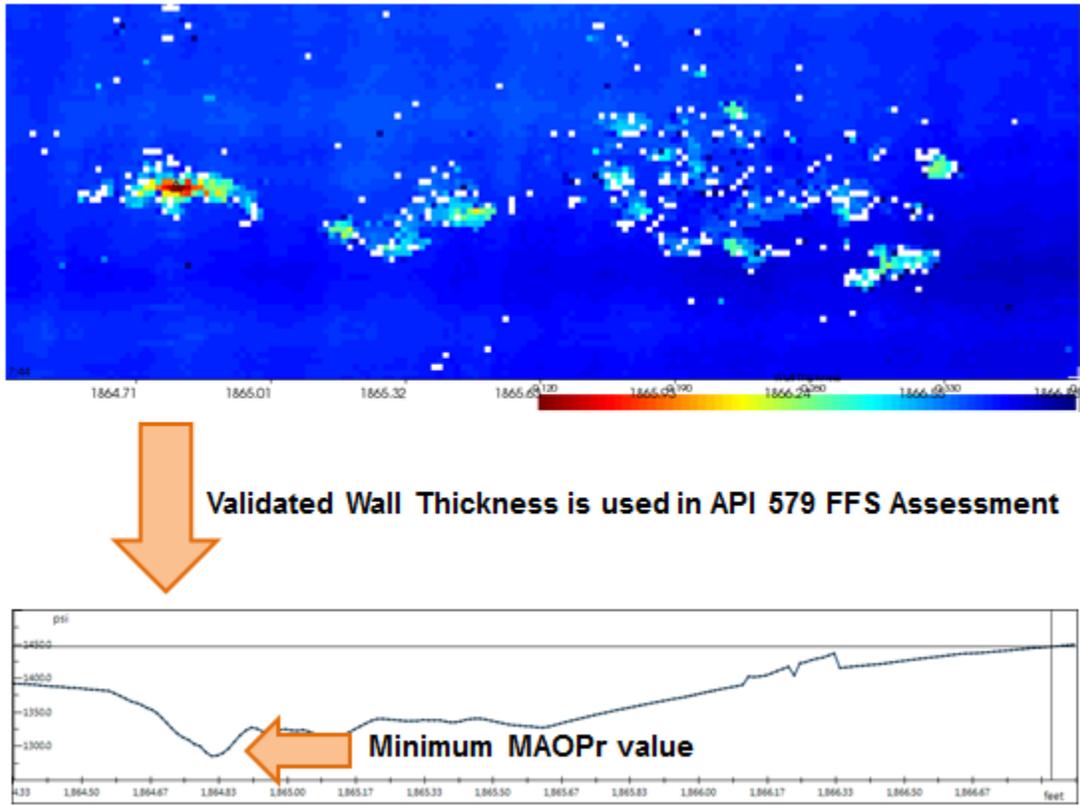


Figure J. API 579-2007 process for assessing complex metal loss regions

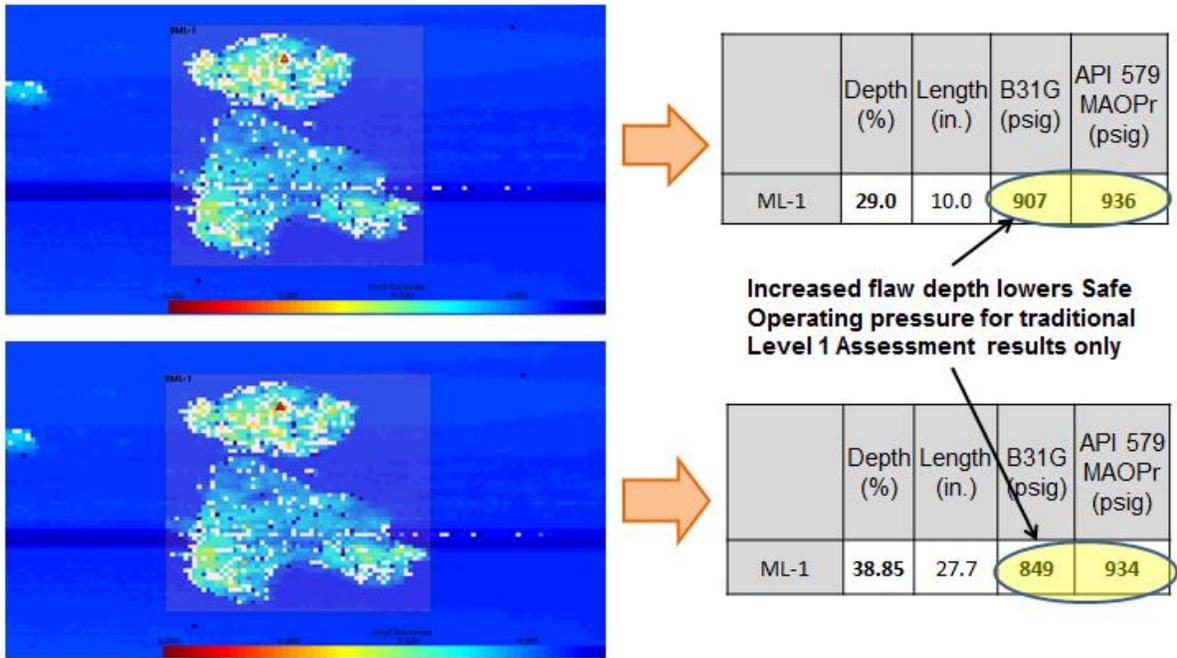


Figure K. Impact of maximum depth predictions from a single wall thickness reading on engineering assessment results