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ASSET INTEGRITY MANAGEMENT AND FITNESS-FOR-SERVICE ASSESSMENT OF A PIPE ELBOW WITH METAL LOSS

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ABSTRACT

The objective of this paper is to describe the inspection process and examine a piping elbow found to have metal loss within the context of Asset Integrity Management (AIM). During the last five years, Industry 4.0 technology involving mobile tablet and cloud technology has merged with the proven concepts of AIM enterprise systems. Before this shift, inspectors, engineers, and managers relied on unreliable and time-consuming methods. New technologies allow inspectors and mangers to think, react, and communicate quickly and proactively when integrity threats are discovered.

A piping elbow was identified at a thickness monitoring location (TML) within a larger system due to existing internal corrosion and/or erosion. Since the metal loss is internal, an external visual examination was not sufficient to monitor the metal loss. External ultrasonic (UT) inspection was used to measure the thickness at multiple points on a grid pattern drawn on the elbow's external surface. The thickness measurements provide the data needed for a local metal loss assessment.

An AIM program was used to assess the risks, aid in inspection, and develop an assessment for ascertaining the degradation pattern. With a heightened understanding of the asset's degradation pattern, the risk to the asset is reassessed continuously until it has been reduced to an acceptable level as defined by the stake holders.

Keywords: Elbow, metal loss, corrosion, fitness-for-service, API 579, asset integrity, cloud computing, condition monitoring locations, risk, inspection, technology.

NOMENCLATURE

AIM	Asset Integrity Management
CML	Condition Monitoring Location
CTP	Critical Thickness Profile
FCA	Future Corrosion Allowance
FFS	Fitness-for-Service
IOW	Integrity Operating Window
MAWP	Maximum Allowable Working Pressure
MAWPr	Reduced MAWP
NDT	Non-Destructive Testing
RSF	Remaining Strength Factor
TML	Thickness Monitoring Location
UT	Ultrasonic Testing
VT	Visual Testing

1. INTRODUCTION

Recall the explosions and fires at the Philadelphia Energy Solutions refinery in June of 2019. The U.S. Chemical Safety Board released a factual update in October indicating the cause of the incident was a failed elbow on a piping system. During the investigation following the incident, the thickness of the elbow was found to be only 0.012 inches, half the thickness of a credit card! Condition Monitoring Locations (CMLs) were located along the straight sections of piping and recent measurements indicated minimal corrosion. There were no CMLs on the failed elbow **[1]**.

Certainly this accident could have been avoided had any number of events occurred differently. Electronic and cloud based data management systems facilitate much more extensive asset integrity management to ensure that producers are monitoring all assets, not just high-risk ones. Thorough, well-defined integrity management programs that include risk-based inspection and fitness-for-service assessment recommendations can dramatically improve the safety of operating high-risk equipment.

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2. MATERIALS AND METHODS

The process described here walks through an instance where industry 4.0 technology was used for safer and more accurate integrity management. The project included the implementation of an AIM program, inspection of a piping elbow, and the FFS assessment recommended based on the inspection data.

2.1 Asset Integrity Management

To ensure safe and reliable design, operation, and maintenance of equipment used in oil and petrochemical processes, operators and contractors are required to practice and execute industry best practices. The incorporation of risk-based inspection, corrosion control documents, integrity operating windows, non-destructive testing, and fitness-for-service assessments encompass asset integrity management.

As the practice of asset integrity management has evolved and improved, the strategies that were formerly standalone tasks have become integrated into software databases. Users configure the databases to reduce to the inherent equipment risk to within acceptable tolerances or defined targets.

2.2 Implementation of Industry 4.0

Within the last five years, Industry 4.0 technology such as mobile tablets and cloud technology (see Figure 1), has merged with AIM enterprise systems. The technological advancement of management programs has greatly improved the process of inspection reporting for inspectors and operators. New technology has changed the formerly labor-intensive process into a more efficient one, allowing individuals to problem-solve in the field [2].

The advancement of digitalization and automation has improved key metrics across inspection reporting, planning and execution of inspection and repair work, risk-based inspection studies, and Fitness-for-Service assessments. As an overall result, cycle time for decision making by managers and inspectors has decreased. Based on the best practices in API and ASME standards, AIM software has created a logical, repeatable, and automated workflow. Such software can be used both at the office on desktop computers and on mobile tablets in the field. The tablets allow faster exporting and importing of inspection reports and provide recommendations and results from the processing facility back to the office. In addition, data between AIM software can be configured to communicate with one another at the appropriate time and decision points when triggered by the user. The data, when reviewed by more senior stakeholders can be reviewed, approved, and when necessary, revised.

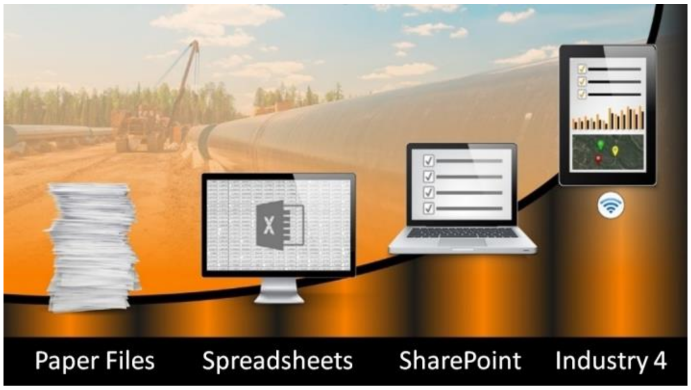

FIGURE 1: INDUSTRY 4.0 TECHNOLOGY HAS ALLOWED FOR NEAR REAL TIME DATA COLLECTION AND DATA SHARING BY INSPECTORS TO COLLEAGUES TO VIA CLOUD CONNECTIVITY.

Providing a digital twin of the inspection report to the inspector while on site allows for information to be collected in real time. As a result, the owner-user can be confident all information will be accessible when decision-making.

Today, an in-service inspection report can be completed while working within a process facility. Initial inspection findings can be shared with third party NDE inspection crews, crew coordinators, owner-users, engineering teams, and management via a cloud computing connection. This can all be accomplished while providing an accurate historical record for all participants. Figure 2 shows the interactions that can occur between inspectors and clients even when working at different locations within a facility.

The AIM process initiates by assessing the operational and inherent risk of all assets according to an approved model. Inspection planning based on the level of risk is developed and scheduled. The inspector can venture out using a mobile tablet and cloud connection to inspect, report, and communicate back to the head office. Inspection findings such as visual (VT) and NDT results can be shared in real time. NDT results collected with the use of a datalogger and key metrics (corrosion rates, expiry dates, and scheduled inspection dates) can be downloaded. If the NDT results and analyst deem necessary, a Fitness-for-Service (FFS) assessment can be applied. In this case, a pipe elbow is used as an example of inspection leading to an assessment calculation. When necessary, a repair scope of work can be developed and used with the mobile tablet to validate that the work in the field has been performed correctly.

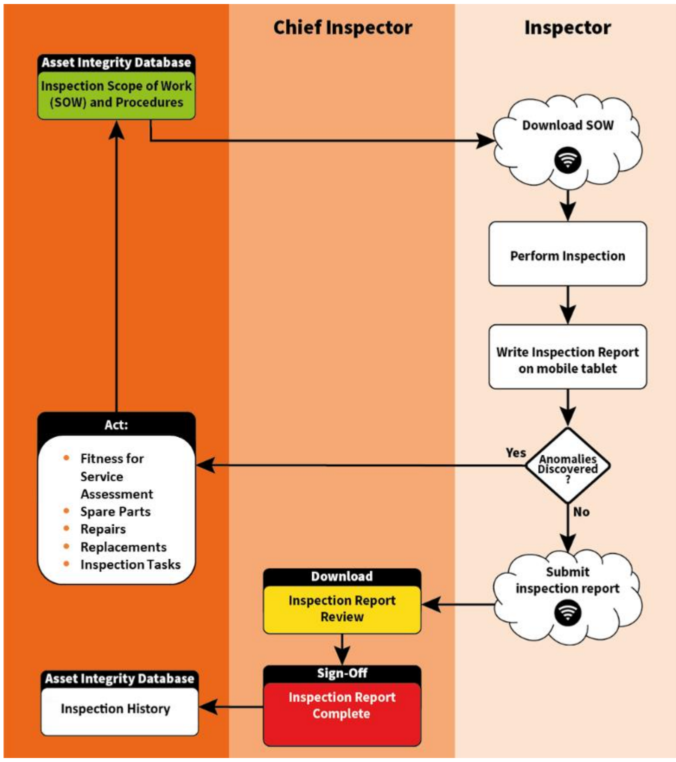

FIGURE 2: THIRD PARTY NDE CONTRACTORS, INSPECTORS AND CHIEF INSPECTOR USING AIM SOFTWARE BE CONSTANT CONNECTION AND YET BE WORKING IN DIFFERENT LOCATIONS.

2.3 Assessing the Risk

A piping circuit was assessed according to its design, material of construction, known degradation mechanisms and consequence of failure according to the accepted standard API 581 [3].

2.4 Inspection of Piping Elbow

Based on the results of the risk assessment, an inspection plan was developed in the AIM software to assess piping elbows, deadlegs and tees using ultrasonic (UT) measurements. The purpose of the examination was to confirm the measured corrosion rate, remaining life, and identify fittings approaching the design minimum thickness from AIM after uploading UT data.

UT readings were prescribed for a TML on the elbow and along the piping on a regular inspection schedule derived from the AIM and risk based inspection results. UT technicians collected thickness readings at the TML for immediate logging in Industry 4.0

2.5 Interpreting the Results

The AIM program flagged the elbow thickness readings as being below the minimum required thickness. The inspection, engineering, and management groups concurred with the decision to perform a Fitness-for-Service (FFS) assessment. FFS assessments provide quantitative guidance on whether to rerate, repair, or replace equipment that has experienced damage or degradation while in service. Elbows can be particularly susceptible to corrosion metal loss depending on the product and operating conditions. Flow accelerated corrosion and additional stresses on elbows make timely assessments even more critical.

In order to complete the FFS assessment, a thickness grid was recommended. API 579 [4] provides guidance on the spacing between readings for a local metal loss assessment to ensure adequate readings based on the thickness and diameter of the component. An FFS/TML grid was created on the elbow and the UT thickness readings were uploaded from the datalogger and saved in the AIM software. The UT thickness were measured using the grid shown in Figure 3. The readings were initially downloaded from UT datalogger to the AIM quarantine for review and acceptance. The thickness readings were then sent to the AIM software for corrosion rate and remaining life calculations. The AIM software flagged readings that were below the calculated minimum thickness and identified that there was no remaining life for the grid, requiring further analysis.

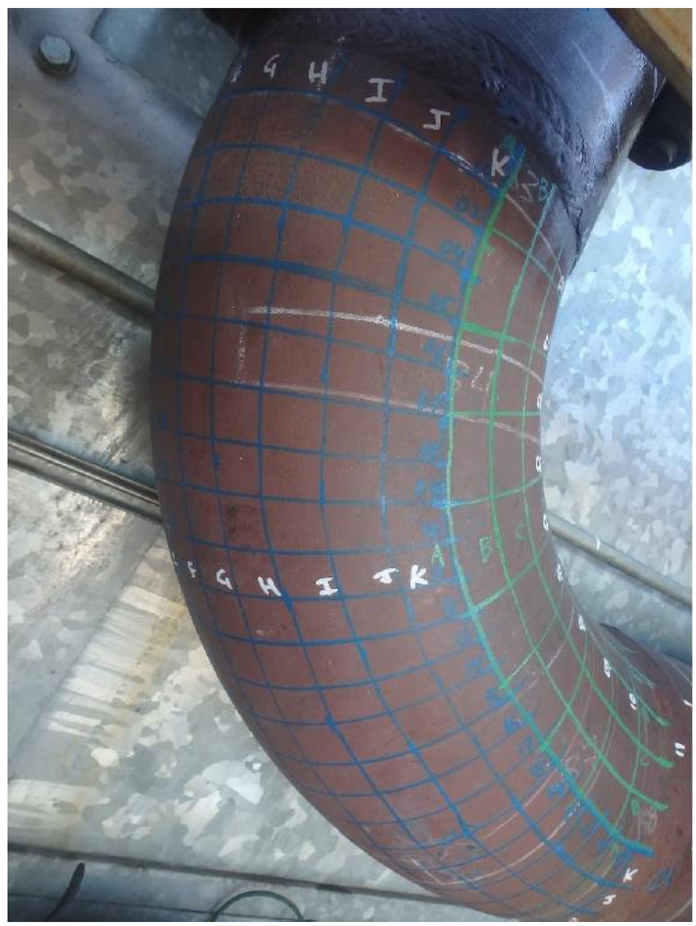

FIGURE 3: ULTRASONIC THICKNESS READING ON GRID ACROSS ELBOW. READINGS USED IN FFS ASSESSMENT.

3. RESULTS AND DISCUSSION

An FFS assessment is a multi-disciplinary approach to determine if a given structure is fit for continued service. The outcome of an FFS assessment is a decision to operate as is, repair, retire, or re-rate.

3.2 FITNESS-FOR-SERVICE METHODOLOGY

Comprehensive guidelines for FFS assessments are contained in the API 579-1/ASME FFS-1 standard [4], which is jointly published by the American Petroleum Institute (API) and the American Society for Mechanical Engineers (ASME). This includes three levels of assessment for each damage mechanism.

1. Level 1 is a simplified and conservative analysis that is used for initial screening purposes.
2. Level 2 is an engineering analysis that uses standard formulae to perform the FFS assessment. Typical Level 2 FFS calculations can be performed with more complex spreadsheets or custom software. This is the analysis level used to assess the elbow metal loss in this paper
3. Level 3 is an advanced assessment that may include computational fluid dynamics and finite element simulation to obtain a detailed response from a structure or a system of structures composed of complex geometries and subjected to complex applied loads. These analyses may involve two-dimensional (2D) or three-dimensional (3D) modeling to accurately determine the stresses in the damaged areas. These stresses can then be evaluated to determine the suitability of the component for continued service.

The measured thickness grid, pressure, system supplemental loads (if any), and material data provide the input needed for a local metal loss assessment per the API 579/ASME FFS standard. The local metal loss assessment methodology uses critical thickness profiles (CTP) from the thickness grid in the circumferential and sweep/longitudinal directions to compute a remaining strength factor (RSF) and to compute the reduced maximum allowable working pressure (MAWPr). The computed RSF and MAWPr were found to be acceptable for the current amount of metal loss, but would not pass with an additional corrosion allowance for anticipated continuing future metal loss. A further decrease of thickness or a change of operating conditions, such as internal pressure, could easily change the assessment result. Knowledge of the metal loss rate is needed to determine when the next inspection would need to be scheduled. The analysis results and inspection methodology help to provide specific data needed to make a decision about when and how to repair the elbow.

3.3 FFS ASSESSMENT

Since metal loss reduces the wall thickness of the elbow and could lead to a structural failure, the goal of this assessment was to determine whether the elbow is safe for continued operation in its current condition, and if a postulated additional amount of metal loss is acceptable. The Level 2 local metal loss assessments were completed using Quest Integrity's commercial software package *Signal™ FFS* [5], which follows the API 579 (2016) Part 5 Level 2 calculations for local metal loss corrosion.

The UT inspection measured the elbow wall thickness using a 1 inch by 1 inch grid on the extrados (refer to Figure 3). The UT inspection grid on the intrados also had a 1-inch spacing around the circumferential direction, but had an approximately 2-inch grid spacing where it meets the extrados grid on the side of the elbow. The two measurement grids were combined into one table for this assessment. The final grid used in the assessment is illustrated in Figure 4.

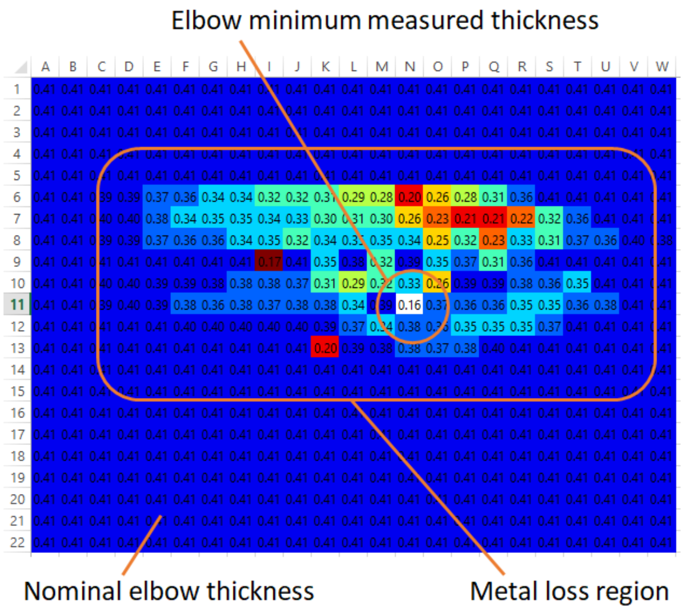

FIGURE 4: ULTRASONIC THICKNESS READINGS FROM INSPECTION SAVED TO A GRID; THICKNESS VALUES ARE USED IN THE FFS ASSESSMENT; THE COLOR MAP SHOWS THE RELATIVE THICKNESS GRID VALUES.

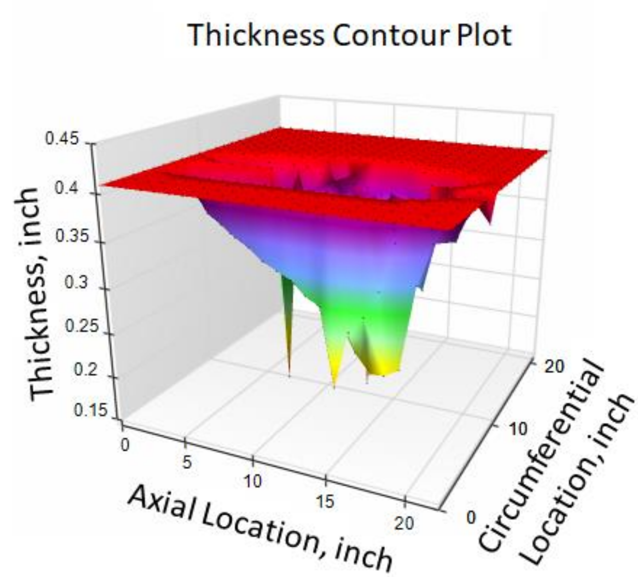

FIGURE 5: 3D CONTOUR PLOT OF THE THICKNESS GRID; THICKNESS VALUES ARE EXAGGERATED IN THIS PLOT.

The same thickness grid is shown as a 3D contour plot in Figure 5. The measured thickness is exaggerated in the vertical direction of the plot, which can help to visualize the metal loss being evaluated.

Part 5 of API 579 provides procedures for evaluating local metal loss in a component. When UT thickness measurements in a grid are available, a CTP approach is used. Two CTPs are obtained from the thickness grid: longitudinal (sweep) and circumferential. The longitudinal CTP is the minimum thickness in each column of the thickness grid. Likewise, the circumferential CTP is the minimum thickness in each row of the thickness grid. A remaining strength factor, RSF, is calculated at each incremental span along the longitudinal CTP, which assesses the hoop stress capacity of the damaged elbow cross-section. Figure 6 shows the longitudinal CTP, and Figure 7 shows the circumferential CTP for this elbow. The thickness grid is 22 inches long for the longitudinal CTP, and the thickness grid is 21 inches wide for the circumferential CTP.

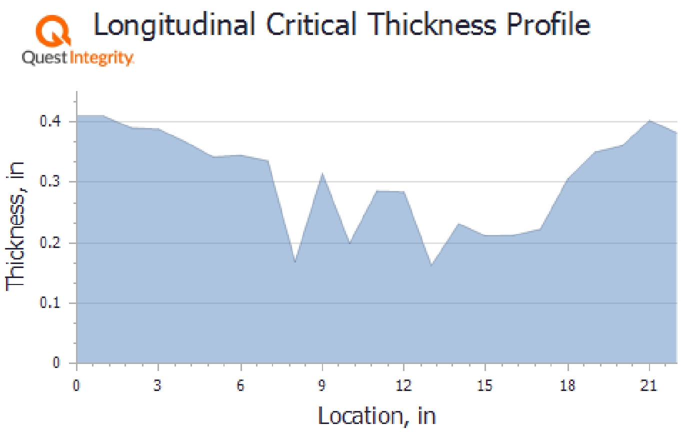

FIGURE 6: LONGITUDINAL CRITICAL THICKNESS PROFILE.

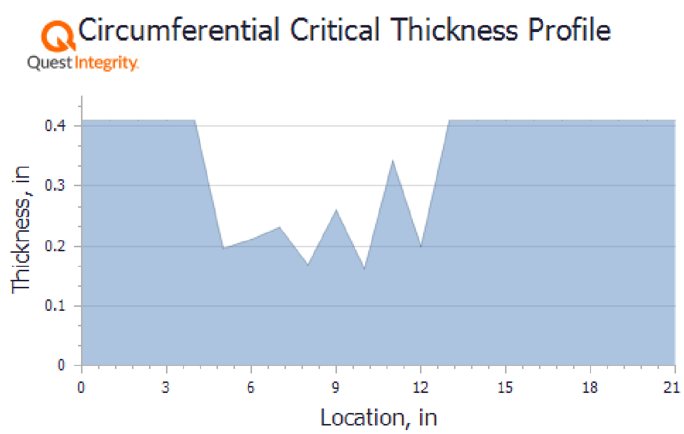

FIGURE 7: CIRCUMFERENTIAL CRITICAL THICKNESS PROFILE.

Using the longitudinal CTP, the lowest RSF value in the local metal loss area is compared with an allowable RSF, RSFa, commonly 0.9. If the computed value is less than the allowable value, a reduced maximum allowable working pressure, MAWPr, is computed. If the MAWPr is less than the design pressure, a de-rate or repair is required. The reduced MAWPr can be calculated using the computed RSF and the allowable RSFa values given in Equation 1.

$$MAWPr = MAWP\left(\frac{\mathrm{RSF}}{RSFa}\right) \tag{1}$$

In the case of the elbow examined here, the calculated RSF was 0.640, leading to a reduced MAWPr. However, the piping was designed with extra thickness and is operated at a pressure less than the computed MAWPr, so the Level 2 assessment criteria were satisfied for the current condition of the elbow. Figure 8 shows a comparison of the elbow design pressure, the computed MAWP, and the reduced MAWPr values. The higher MAWP value shows the extra original capacity in the elbow design before the metal loss damage occurred. The reduced MAWPr value is still slightly above the design pressure, so some additional future metal loss can be tolerated and still satisfy the Level 2 local metal loss assessment. The remaining life analysis is discussed in the next section.

Within the AIM database, an integrity operating window (IOW) was defined using the MAWPr from the assessment to monitor and alert the operator of any pressure exceedance. The system is designed to inform the user of the moment, volume, and length of time for each pressure exceedance, so that these values are recorded.

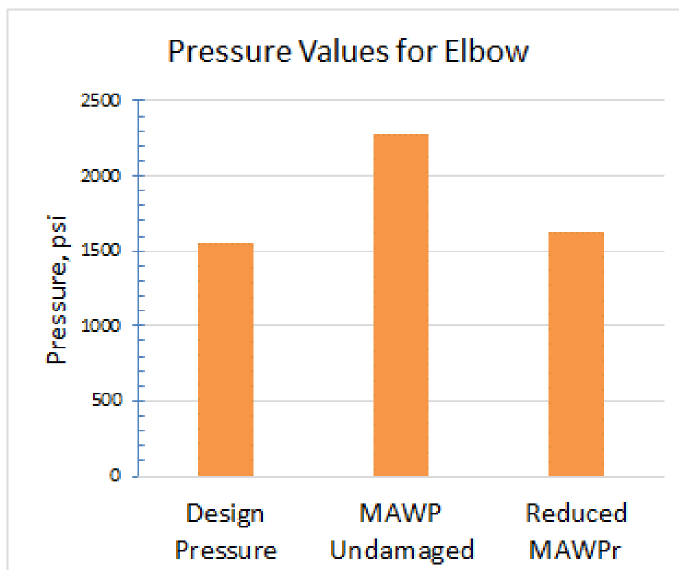

FIGURE 8: COMPARISON OF THE ELBOW'S DESIGN PRESSURE, COMPUTED MAWP AND REDUCED MAWPr VALUES.

3.4 Remaining Life Assessment

A significant advantage of using commercially testing and verified AIM software for FFS assessments is the ability to run multiple assessments to evaluate possible future conditions. A remaining life can be estimated by applying a future corrosion allowance to the current metal loss. The results can then be used to define an inspection interval accounting for future corrosion.

For the elbow assessed here, the actual measured thickness inspection grid was used and the future corrosion allowance (FCA) was increased until the results no longer satisfied the Level 2 FFS criteria. Increasing the FCA reduces the remaining thickness by a uniform amount for all points in the thickness grid. The CTP is updated for the new thickness values to compute the RSF and MAWP. This method provides an estimate for the postulated allowed amount of additional corrosion before a de-rate, repair, replacement or a Level 3 FFS analysis is conducted.

Based on the UT readings described here and the corrosion rate estimated by the operator, the elbow was estimated to have 3.5 years of remaining life or 0.011 inches of allowed future corrosion. Figure 9 shows the updated longitudinal CTP where the estimated FCA has been subtracted from the measured thickness readings. The tolerable FCA is a relatively small amount compared to the elbow's nominal thickness and current thickness measurements. This result allowed the operator to confidently adjust the inspection schedule for the TMLs at the elbow and along the same piping system.

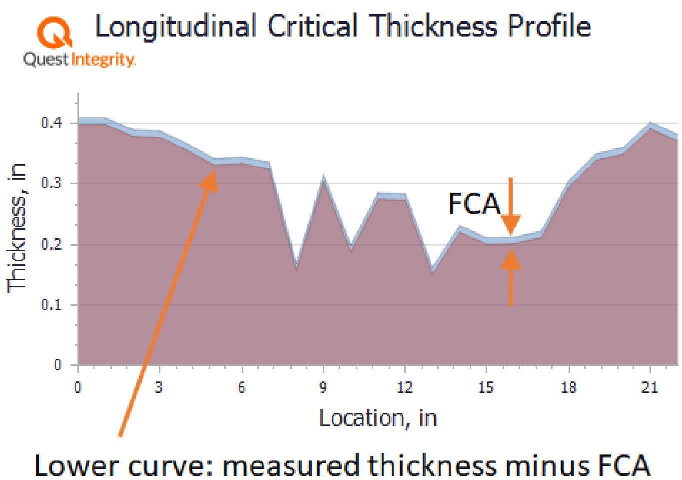

FIGURE 9: TWO LONGITUDINAL CRITICAL THICKNESS PROFILES: MEASURED CTP AND UPDATED CTP WITH ESTIMATED FUTURE CORROSION ALLOWANCE.

4. CONCLUSION

The combination of using AIM to inspect and gather data, and then conduct an FFS assessment to evaluate damaged equipment was described using an example of a piping elbow with local metal loss. The inspection measured the remaining thickness in the elbow at multiple locations on a grid. The thickness grid was used in a Level 2 metal loss assessment according to the API 579/ASME FFS standard. The assessment result indicated the elbow is fit-for-service but needs to be monitored for additional metal loss. The AIM software was updated with an integrity operating window to alert the operators of the operating conditions and internal pressure changes. This result allows the operator to confidently adjust the inspection schedule for the TMLs at the elbow and along the same piping system.

ACKNOWLEDGEMENTS

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REFERENCES

[1] U.S. Chemical Safety Board, "Fire and Explosions at Philadelphia Energy Solutions Refinery Hydroflouric Acid Alkylation Unit - Factual Update," CSB, Washington, 2019.

[2] S. Webb, "Achieving Digital Transformation in Pipeline Construction with Quality Management Systems and Industry 4.0 Technology," *Inspectioneering*, March/April 2019.

[3] The American Petroleum Institute, "RP API 581 Risk-Based Inspection Methodology," The American Petroleum Institute, 2016.

[4] The American Society of Mechanical Engineers, "API 579-1/ASME FFS-1 Fitness-for-Service," ASME International, New York, 2017.

[5] Quest Integrity Group LLC, "Signal Fitness-for-Service Commercial Software".