Interstate Natural Gas Association of America

INGAA FOUNDATION

TECHNICAL GUIDANCE: INTEGRITY ASSESSMENT FOR STRESS CORROSION CRACKING (SCC) USING ELECTROMAGNETIC ACOUSTIC TRANSDUCER (EMAT) IN-LINE INSPECTION

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Editorial Comment

This document contains references to many industry standards, guidelines, recommended practices, and regulations. For ease of reading, these will be referred to by their "short name", e.g., API RP 1173, within the text. A full citation of each document will be provided in the reference list at the end of the document. Footnotes are used to expand the context of a citation.

Government regulations often incorporate by reference industry standards and recommended practices that may not be the latest edition. This document references the latest edition incorporated by reference in the relevant regulations.

Abbreviations

BWMPI	Black on white magnetic particle inspection
CVN	Charpy V-notch
DPMPI	Dry powder magnetic particle inspection
DQA	Data Quality Assessment
DQR	Data Quality Report
EAC	Environmentally assisted cracking
ECA	Engineering critical assessment
EMAT	Electromagnetic acoustic transducer
ERP	Estimated rupture pressure
ERW	Electric resistance weld
FBE	Fusion bonded epoxy
FFS	Fitness-for-service
FLMPI	Fluorescent magnetic particle inspection
FPR	Failure pressure ratio
HCA	High consequence area
ILI	In-line inspection
INGAA	Interstate Natural Gas Association of America
JIP	Joint industry project
KPI	Key performance indicators
MPI	Magnetic particle inspection
MFL	Magnetic flux leakage
MPI	Magnetic particle inspection
PAUT	Phased array ultrasonic testing
PHMSA	Pipeline and Hazardous Materials Safety Administration
PLQ	Pipeline questionnaire
POD	Probability of detection
POI	Probability of identification
QC	Quality control
RCFA	Root cause failure analyses
SCC	Stress corrosion cracking
SH	Shear horizontal
SME	Subject matter expert
TVC	Traceable, verifiable, and complete
UT	Ultrasonic testing
WVMPI	Wet visual magnetic particle inspection

Background

In 2022, the Interstate Natural Gas Association of America (INGAA) established a joint industry project (JIP) managed by The INGAA Foundation, Inc. to develop an industry technical guidance document specific to the use of Electromagnetic Acoustic Transducer in-line inspection (EMAT ILI) for the management of Stress Corrosion Cracking (SCC). This Joint Industry Project (JIP) was formed with seven pipeline operators, three ILI service providers, and the principal consultancy.

Over the last two decades, various operators and ILI service providers have collaborated to develop EMAT ILI technology for the management of pipeline cracking. The bulk of the development was based on feedback from thousands of in-field examinations. At the time of this report, EMAT ILI has reached a level of maturity where confidence level in the performance specifications and response planning may be standardized for qualified EMAT ILI systems.

Prior to the Pipeline and Hazardous Materials Safety Administration's (PHMSA) gas pipeline systems final rule published on October 1, 2019[1], EMAT ILI technology was used by several pipeline operators as an integrity assessment through means of Special Permit via Title 49 CFR §190.341 [1]. EMAT ILI was being utilized as complementary to other integrity activities (i.e., pressure testing or direct assessment), or as part of research and development. Now that EMAT ILI technology is being used regularly in the industry, the development of a technical guideline for prudent use of EMAT ILI will help ensure that pipeline operators benefit from the experience of the early adopters and the recognized industry practices. Therefore, the aim of this document is to improve the safety and reliability of the pipeline industry as the use of EMAT ILI technology expands.

The guidelines presented in this document do not supersede or replace regulatory requirements, nor are they intended to be all inclusive of the applicable regulatory requirements. Instead, they are intended to be supportive and complementary to such requirements. For the purposes of this document, the term "should" indicate that the action or methodology is preferred or recommended, while "could" or "may" indicates the action is to be considered.

Structure of the Document

This document is structured following the workflow common with the overall process of identifying EMAT as an integrity approach through validation, acceptance, and continual evaluation and improvement. Each section is structured to present essential considerations from industry standards, recommended practices, and where possible industry knowledge and lessons learned collected from interviews with the JIP participants.

Each section or subsection includes a "quality gate" that provides a simple check list of considerations that may need to be addressed.

[1] Pipeline Safety: Safety of Gas Transmission Pipelines: MAOP Reconfirmation, Expansion of Assessment Requirements, and Other Related Amendments, 84 Fed. Reg., 52180 (October 1, 2019) (to be codified within Title 49, Code of Federal Regulations Parts 191 and 192)

1. Introduction

This document was developed as a practical guide to provide process and knowledge transfer to augment in-line inspection (ILI) and crack management procedures with a focus on the use of Electromagnetic Acoustic Transducer (EMAT) ILI systems to assess the threat of axially oriented Stress Corrosion Cracking (SCC). This guidance document leverages the experience of early EMAT ILI technology adopters and years of technology development and validation. The aim of this document is to be a companion to existing industry guidance and assumes that the pipeline operator has reviewed and understands the application of such documents as API STD 1163 [2], NACE SP0102 [3], API RP 1176 [4], and CEPA Recommended Practice [5]. The workflows, guidance, and recommendations are based on knowledge-sharing of the EMAT JIP participants. Each participant (pipeline operator and ILI vendor) was interviewed to capture EMAT ILI experience, lessons learned, existing processes, and general EMAT ILI performance history.

This guidance document is developed with the understanding that actionable anomalies are determined as a result of the ILI data analysis and data integration per API STD 1163. The design of this guidance document is sequential in nature for ease of use and is organized according to the illustration in **Figure 1** below.

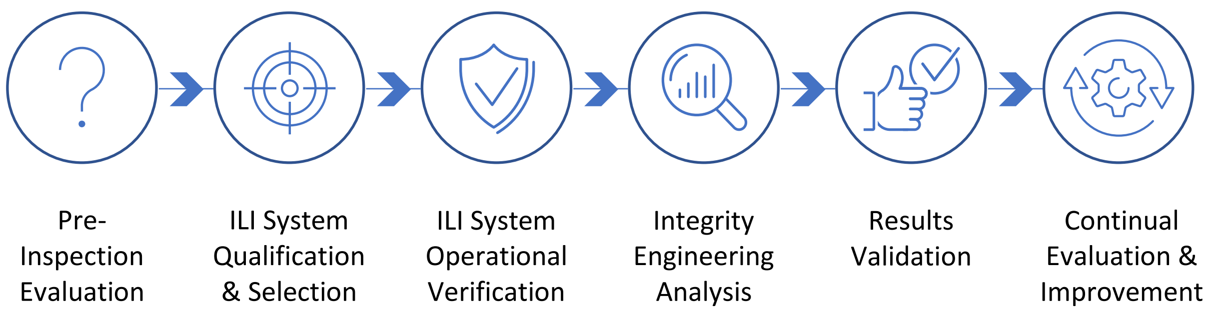


Figure 1: Guidance Document Workflow

Performing integrity assessments using ILI offers a reduced impact to pipeline operations when compared to other methods (e.g., hydrotesting) that require blowdown or shutdown. ILI also provides significant information about the pipeline, which promotes data integration, engineering analysis, and continual evaluation. Therefore, an ILI-based integrity approach is often the preferred assessment if the ILI system's ability to provide the characteristic data for the target anomaly types are verifiable and reliable when performing an engineering assessment. This allows actionable anomalies to be addressed in a timely manner. Managing the threat of SCC using EMAT ILI becomes an iterative process of inspection, verification, data analysis, in situ direct examination, data integration, ILI performance validation, and remediation.

1.1. Electromagnetic Acoustic Transducer (EMAT) ILI Fundamentals

EMAT is an ultrasonic (UT) technique that generates the ultrasound wave in the material being inspected (i.e., the pipe wall) using electromagnetic principles instead of a piezoelectric transducer. Conventional piezoelectric UT sensors require a liquid couplant to transmit the UT waves into the pipe whereas EMAT does not, therefore, EMAT tools can be used in both dry gas and liquid pipelines.

There are two basic components of the EMAT system: a magnetic field and a system of coils. The magnetic field may be generated from an electromagnet or a permanent magnet. The system of coils may be the generating source of electromagnetic fields in the material as well as act as the receiver(s). The coil(s) will be driven with an alternating current (AC) that induces an alternating electromagnetic eddy current in the material being inspected. In the presence of a static magnetic field, this surface eddy current produces electromagnetic forces that produce the desired acoustic waves. The excitation of the pipe wall is through either the Lorentz Force phenomenon or Magnetostriction phenomenon. Once the ultrasonic waves are generated, general UT inspection principles apply. The EMAT forms the basis for a reproducible system for generating and detecting ultrasonic waves. An illustration of traditional liquid coupled UT versus EMAT UT is shown in **Figure 2**.

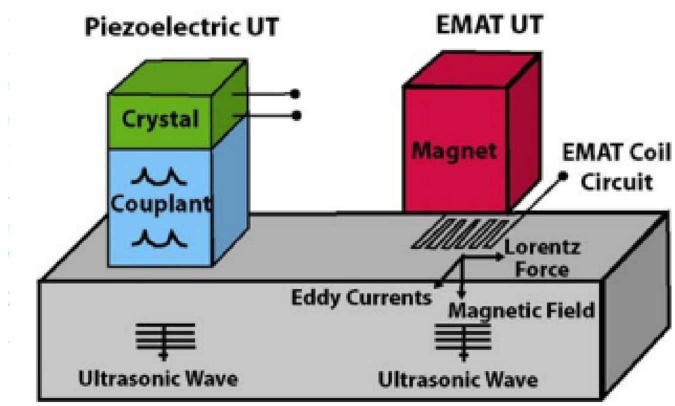


Figure 2: Piezoelectric UT versus EMAT UT Principle[2]

On the EMAT tool, the measurement system is a sensor, or an array of sensors that contact the inner pipeline wall. These sensors can be arranged to obtain the pipe-wall surface coverage such that the performance specifications are achieved. There may be various sensor types configured to produce different ultrasound modes, wave types, and frequencies. A variety of different sensors may be designed in various geometries and arrangements to allow propagation in almost any direction, including around the circumference of the pipe.

The ultrasonic wave propagates through the material and will be influenced by the presence of defects (such as cracks) that interrupt its travel. This physical interruption may reflect some of the wave energy back to the originating coil location and be received and recorded, known as the pulse-echo technique. The same defect may also interrupt the forward travel of the ultrasonic wave and be detected at other locations through other sensors, known as the through-transmission technique. EMAT tools may be configured to operate in both pulse-echo and through-transmission modes.

A key element in measurement system design is the proper consideration of measurement capabilities for the threats of interest and the characteristics and location of target defects in the pipe wall. For example, detecting SCC within the base material of the pipe may be an easier task than detecting SCC within the long seam weld. While dealing with changes in pipe wall thickness for pipe body inspections is well-understood, the inspection of long seam welds and reporting of SCC may be more challenging due to

[2] Figure 6-5, TTO8 [9]

the geometric discontinuity between the pipe wall and long seam weld. The transduction process occurs within an electromagnetic skin depth reflector, thus requiring additional data rendering and interpretation.

1.2. Application for In-Line Inspection

EMAT tools for ILI application is an evolving technology. The first EMAT prototypes for pipelines were constructed in the 1980s and the functional commercial systems available in the 2000s. Reflection based ILI systems centered on piezoelectric sensors were already available for crack detection in liquid pipelines. With the application of the EMAT technology, crack detection also became available for assets like gas transmission and distribution pipelines. Early EMAT implementations for crack detection had limited measurement as well as restricted mileage capabilities. Solutions available at the time of this report are mature and continue to improve.

EMAT sensors can be set up to scan using short range and long-range measurement implementations. Both options can be found in the portfolio of different ILI technology and service providers. Different implementations utilize a variety of wave modes and capabilities that can deviate between the individual realizations. Miniaturization and decreased power consumption as well as faster and more versatile integrated circuits are the main drivers in the advancement of the technology. More sensors on the circumference at the inner pipe wall can enable the application of smaller sensor setups and are the foundation of detection, identification, and sizing of smaller defects in the steel. The overlap of sensors is a common approach to ensure proper detection values and repeatability of the measurements under harsh conditions.

The increasing sensitivity of the EMAT solutions in the industry may be helpful to better understand smaller defects. However, this may also lead to cross sensitivity and difficulty in separating geometry, metal loss, material properties and cracking features centered on a reflection-based technology only.

1.3. Availability

ILI service providers continue to extend their EMAT capabilities, including the ability to inspect smaller pipe sizes (down to nominal pipe size (NPS) of 8-inch). The ability to traverse bends with a radius of 1.5 times the pipe diameter may be accommodated for many of the available solutions enabling pipeline operators to use the technology for many of their assets. The size of EMAT transducers currently challenges implementations for pipe diameters smaller than 8-inch NPS. At the time of this report, solutions from 8-inch up to 48-inch NPS are commercially available. Due to the variety of possible EMAT implementations from different ILI service providers, each EMAT ILI system should be understood, qualified, and validated.

1.4. Roles and Responsibilities

Using EMAT technology requires close cooperation between the pipeline operator and ILI service provider. Having an explicit understanding of the pipeline operator's and ILI service provider's roles is fundamental to an effective collaboration.

1.4.1. ILI Service Provider Responsibilities

It is the ILI service provider's responsibility to provide a clear and written performance specification and collaborate with the pipeline operator to understand the targeted expectations versus the performance specification. The ILI service provider will configure the tool to navigate the pipeline safely, collect complete data, and perform according to the specification within the limits of the essential variables.

Therefore, any deviations from the conditions of the specification and essential variables as associated with the tool's configuration and the pipeline physical and operational characteristics should be communicated to the pipeline operator. The qualification of a performance specification should be considered valid for the range of essential variables defined for the specification. If data provided to the ILI service provider prior to the inspection indicates that the ILI system does not meet the performance specification for any variables or combinations of essential variables, the essential variables should be redefined (such as operating conditions), or the performance specification should be restated. If the data collected in the inspection indicates that the ILI system will not meet the performance specification for some areas, variables, or combinations of essential variables, then the ILI service provider should notify the operator if any of the essential variables are out of specification for an inspection, including options as a revised performance specification for the affected areas, enabling the operator to make an informed decision as to run acceptance and/or data use.

1.4.2. Pipeline Operator's Responsibilities

The pipeline operator should understand that each ILI system has a qualified performance specification for a set of essential variables, and that using an ILI system to detect, identify, and report all crack-like anomalies in all conditions is not reasonable. It is the pipeline operator's responsibility to understand and communicate accurate pipeline characteristics and characteristics of the targeted SCC defects through a completed pipeline questionnaire (PLQ), and the characteristics of SCC morphology (if known by the operator). The pipeline operator should also provide pipeline facilities and operating conditions as agreed with the ILI service provider. In addition, the pipeline operator should understand the performance specification and if the associated essential variables allow for the successful use of EMAT ILI as an integrity approach for SCC.

1.5. Summary

Due to the nature of how EMAT ILI data is collected and interpreted, each system's performance should be well understood, documented, and validated according to the operator's experience with each EMAT ILI system, pipeline, and goals of the inspection.

The decision to use an EMAT ILI system as an integrity assessment method requires process management, written procedures, technical competency, relevant experience, and quality control. These elements will promote pipeline safety, a successful inspection, and integrity assessment.

- Having an established written process and terminology that is consistently used is the best practice to promote consistent results when using EMAT ILI as an integrity assessment for SCC.
- Having a sound understanding of the pipeline's history and the EMAT ILI system's historical performance will promote accurate decision-making related to ILI system selection and determining actionable anomalies.

- Performing a comprehensive pre-inspection evaluation through proactive collaboration with ILI service providers will enable the best possible results.

Keep in mind that the performance and capabilities of the EMAT ILI system may not be fully understood until the EMAT ILI tool has been deployed, the data quality examined, evaluation results delivered, and exploratory in situ direct examination results are rendered. EMAT ILI results may vary between inspections and a process for validating ILI results is fundamental.

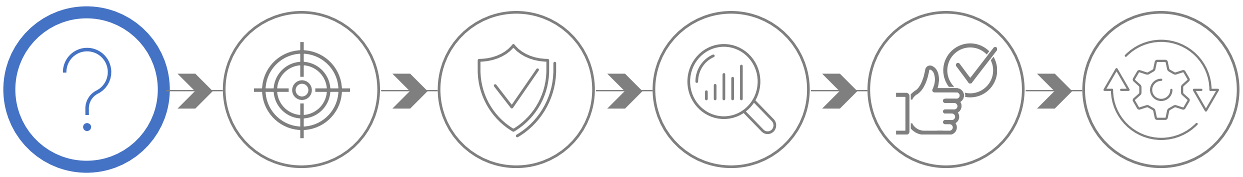
As with all processes, performance monitoring and continuous improvement is recommended. This will establish confidence in the pipeline operator's criteria and approach, as well as highlight potential areas of improvement of the ILI service providers tool and their services.

1.6. Quality Gate – Section 1: Introduction

- Review API STD 1163 [2].
- Review NACE SP0102 [3].
- Review API RP 1176 [4].
- Review CEPA *Recommended Practices for Managing Near-neutral pH Stress Corrosion Cracking* [5].
- Review ASME-STD-PT-011 [6].
- Review SCC JIP Phase 2 Final Report [7].
- Review PRCI. PR-460-134506-R02 [8].
- Review TT08 [9].
- Review applicable regulatory and industry requirements associated with written ILI and integrity management procedures, personnel qualification/competency, and quality control, i.e., Title 49, CFR Part 192, §192.911(o), §192.710(d) [1], and ASME B31.8S §12.2 [10].
- Establish and/or review written crack management program and EMAT ILI assessment specific procedures.
- Identify experience and competency gaps to make appropriate resources available.
- Review of all operating and performance specifications of the EMAT tool under consideration.

2. Pre-Inspection Evaluation

The objective of this section is to provide guidance on the information necessary to evaluate the effectiveness of the use of EMAT ILI as an integrity assessment method for SCC. The activities in this section should be completed prior to selecting an EMAT ILI system for the ILI Assessment and establishing the inspection goals and objectives. The Pre-Inspection Evaluation section is highlighted in **Figure 3**.



Pre-Inspection Evaluation

- Pipeline Characteristics
- Threat Analysis
- Integrity Engineering Analysis
- ILI Planning
- Quality Gate

Figure 3: EMAT ILI Assessment Landscape: Pre-Inspection Evaluation

In accordance with API STD 1163, the pipeline operator is to select an inspection system suitable for the conditions under which the inspection will be conducted. This includes, but is not limited to, the pipeline characteristics, pipeline operating conditions, and the types of anomalies expected to be detected and characterized. Equally important, the information collected should be shared with the ILI service provider(s) through their pipeline questionnaire and any other information relevant to the inspection. Each EMAT ILI system considered for the ILI assessment should be expected to have a unique response to the pipeline segment as a function of its material (manufacturing type, coatings), cleanliness, operating conditions, and SCC morphology.

2.1. Threat Analysis

This section focuses on understanding what is known and unknown related to the type of SCC as an integrity threat and to be assessed prior to the inspection. The objective of the threat analysis for SCC is to reduce the amount of unknown information related to the presence and morphology of SCC on the pipeline being inspected. According to ASME B31.8S, SCC is a "*form of environmental attack of the metal involving an interaction of a local corrosive environment and tensile stresses in the metal, resulting in formation and growth of cracks*". SCC is often found to include small adjacent cracks that form a colony and coalesce as they grow, becoming equivalent to a larger crack. **Figure 4** provides an image of SCC in the base pipe material. SCC can also be found within or associated with the pipe longitudinal seam as shown in **Figure 5**. Additional information related to the SCC threat mechanism can be found in API RP 1176 and CEPA. It should be noted that SCC surface characteristics (e.g., surface breaking length determined via magnetic particle inspection) should not be expected to be consistent with the EMAT ILI reported crack and crack-like characteristics (e.g., reported length) and more details can be found in **Section 3.3: Reporting Requirements**. The following topics should be considered when using EMAT ILI to address the SCC threat:

- **Susceptibility** – The pipeline's SCC susceptibility analysis is initially generated independently of the EMAT ILI results. These results are integral in the API RP 1176 likelihood classification component of Anomaly Sentencing. Once EMAT ILI results are validated, they should be used as part of the next susceptibility analysis. The objective is to understand which segments of the piggable pipeline segment have the highest likelihood of having SCC. Industry guidance such as ASME B31.8S and API RP 1176, coupled with the pipeline operator's experience with their own systems could be used for guidance on SCC susceptibility analysis.
- **Morphology** (Shape, Orientation, Location, Interaction, and Crack Types) – The crack characteristics related to principal orientation, radial deviation, shape, grouping, interaction, length, and depth profile can influence the ILI system and data interpretation. The objective is to identify the crack morphologies that may exist and how they will compare to what the EMAT ILI system is expected to reliably detect and report crack-like anomalies.
- **Inter-linking** (Targeted SCC) – EMAT ILI systems will typically report individual crack-like anomalies or groups of crack-like anomalies. Identification of inter-linking of crack-like anomalies is subject to EMAT signal characteristics and data analyst experience. The individual surface breaking defects, as seen in **Figure 4**, may not be discretized individually by the current EMAT technology but it may be reported as a "group" or "colony" of crack-like anomaly.
- **Anomalies (other) – Co-located Anomalies (Other)** – The detection of SCC (crack-like anomalies) may be influenced by interacting anomalies, co-located anomalies of other anomaly types or geometries. For example, variations in the long seam geometry or steep-sided corrosion can both resemble crack-like anomalies in the EMAT signal data. Cracking in corrosion can influence the ILI system's ability to accurately size the crack depth. Geometric deformations, such as dents, ovalities, and bends can influence the signal data. From an engineering assessment perspective, collocated anomaly interactions can also directly impact the remaining life of the crack-like anomaly and should be considered in the integrity engineering analysis. The presence of co-located anomalies will also influence EMAT signal data interpretation. The objective for this threat analysis is to define which anomalies the EMAT ILI System should report. This may require more than one ILI system to be deployed and the data integrated.

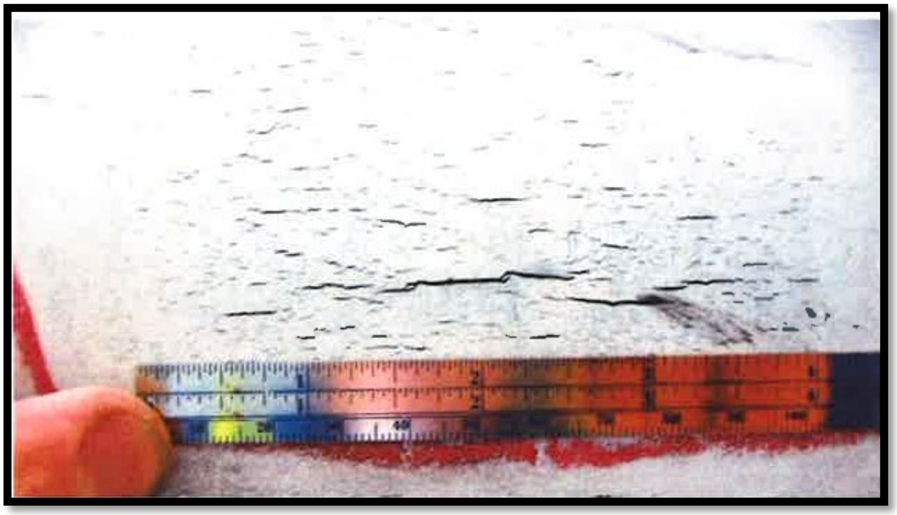


Figure 4: Stress Corrosion Cracking in Pipe Body[3]

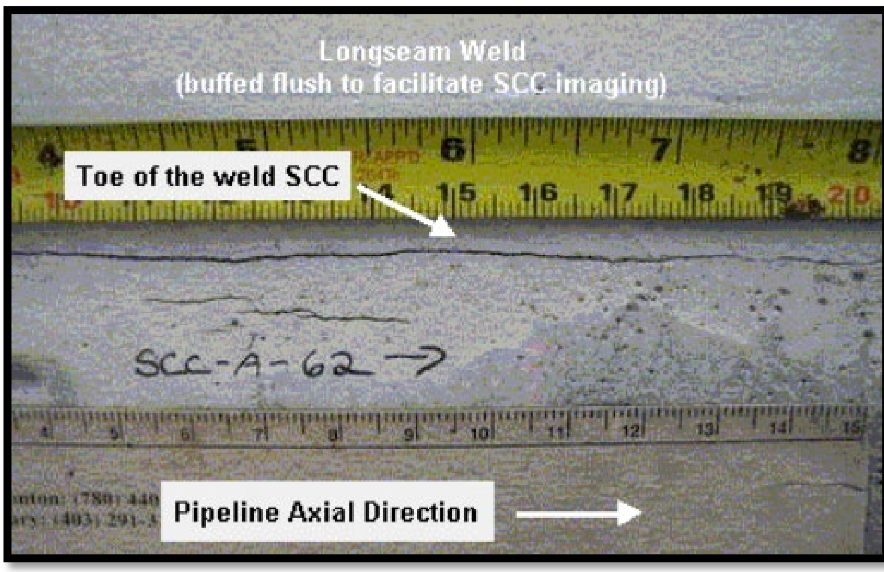


Figure 5: SCC Aligning to the Toe of the Long Seam[4]

2.2. Pipeline Characteristics

This section focuses on establishing what is known and unknown about the pipeline to be inspected. The objective is to reduce the amount of unknown information related to the pipeline attributes and condition. This activity will enable an appropriate review of each ILI system's essential variables during ILI system selection.

Pipeline operators should review API STD 1163 Section 5.3 *Physical and Operational Characteristics and Constraints* and NACE SP0102 Section 3: *Tool Selection* and Section 4: *Pipeline ILI Compatibility Assessment*

3 Figure 12 in API RP 1176 [4]

4 Figure 2.2 in CEPA Stress Corrosion Cracking Recommended Practices [5]

to gather an understanding of what attributes and conditions the ILI tool will have to accommodate and navigate. Below are considerations specific to EMAT ILI technology:

- **Operations** – EMAT ILI systems may require slower inspection velocity than traditional magnetic flux leakage (MFL) and geometry based technologies due to their design and operating specifications. Therefore, emphasis should be placed on understanding pressure, flow rates, inspection timing, elevation changes, and conditions for tool tracking. Because EMAT ILI technology employs a magnetic circuit much like MFL ILI technology, previous inspections using MFL tools historical pigging dynamics should be reviewed, as they may be helpful to approximate the tool's behavior under similar conditions and a pigging plan for the EMAT ILI tools should be reviewed with the ILI service provider.

- **Mechanical Pipeline Features and Components** – EMAT technology's measurement principle relies on electromagnetics and ultrasonics and therefore pipeline geometries and wall thickness influences performance. Additionally, mechanical features and components can have an impact on the tool's dynamic behaviors in the operating pipeline, including speed excursions (e.g., wall thickness transitions or back-to-back fittings).

- **Pipeline Product** – EMAT ILI technology does not require the pipeline product to be a liquid for coupling, as EMAT relies on electromagnetic generation of ultrasonics waves within the pipe wall. However, some pipeline fluid constituents can have an impact on tool reliability and introduce accelerated tool degradation. For example, electronics packages may require additional sealing elements for inspection in liquids, and exposure. Exposure time to certain products, such as sour systems that contain hydrogen sulfide, may reduce the tool's survivability and overall integrity.

- **Pipeline Cleanliness** – Pipeline cleanliness has a significant impact on EMAT data quality. Debris in the pipeline may increase the distance between the EMAT sensor and the inner surface of the pipeline and result in EMAT data degradation. If a line is known to have extensive internal mill scale, sticky residue like dried compressor oil, or black powder, this should be discussed with the ILI service provider as it could also have an impact on the tool performance.

- **Facilities** – EMAT tools are often longer than MFL and geometry ILI tools. Launching and receiving facilities need to be adequate for the EMAT ILI tool, including traps lengths, pull ports and workspace associated with ancillary activities including tool insertion, extraction, and cleaning. Tool launching and receiving procedures should be reviewed with each ILI service provider as to requirements of the specific EMAT ILI tool. For example, different pulling forces may be required to introduce the tool into the launcher barrel.

- **Pipeline Material Properties and Attributes** – Understanding the pipeline's attributes is fundamental to achieving the inspection objectives and performing the integrity engineering analysis. Material properties verification (MPV) efforts should be considered and aligned with the EMAT ILI Assessment. Pipe manufacturer, long seam type, and long seam condition per spool can influence weld zone anomaly classification. Assumed or specified material properties (e.g., material toughness) will influence the methodology used to estimate failure pressures and critical flaw sizes. Pipe material properties and geometric attributes can also influence an EMAT sensor's response and data quality. For example, pipe surface roughness, long seam geometry, and certain coating types can have an impact on data quality.

- **ILI Service Provider Pipeline Questionnaire** – The pipeline ILI questionnaire (PLQ) historically addressed the details associated with the pipeline characteristics related to the pipeline's piggability. Now as a contractual commitment, it extends beyond piggability and includes reporting requirements, assessment criteria, interaction rules, etc. When considering EMAT ILI as an assessment method, a compatibility assessment should be performed to understand the pipeline's piggability, identify if the EMAT specifications can be met, and where alternate specifications may be applicable. An emphasis should be placed on understanding each EMAT ILI system's essential variables and the expected pipeline characteristics is essential.

2.3. Integrity Engineering Pre-Assessment

This section focuses on understanding what is known and unknown with respect to the information required to perform the integrity engineering analysis. The objective is to reduce the amount of unknown information to perform an assessment on the reported anomalies and determine an appropriate response to the actionable anomalies. As part of demonstrating that the EMAT ILI can be used for an integrity assessment, the EMAT ILI system's ability to detect and report critical defects should be evaluated. The process for determining actionable anomalies should be defined and available in a written procedure. The pipeline operator should define personnel qualifications and identify which of the following tasks require input and oversight from a subject matter expert (SME) responsible for each element of the Crack Management Program and EMAT ILI assessment procedures. An appropriate level of conservatism in the integrity assessment should be achieved through estimated failure calculation methodologies, reasonable material properties, and ILI system tolerances to reported depth and length.

2.3.1. Estimated Rupture Pressure Calculations

The following are the set of parameters necessary to estimate anomaly rupture pressure:

- the pipe material properties (known, assumed, or derived) at the location of the anomaly,
- a quantitative understanding of how the EMAT ILI reported results may be interpreted as an anomaly's depth and length, including consideration of morphologies and essential variables,
- the operating stresses (or Maximum Allowable Operating Pressure - MAOP), and
- considerations for interacting anomalous conditions such as welds and secondary features.

The applicability and limitations of each rupture pressure calculation methodology should be understood. Either deterministic or probabilistic approaches may be used in the analysis to sentence anomaly response. API RPI 1176 and 49 CFR §192.712 should be reviewed and understood when performing crack-like anomaly rupture pressure calculations. Some commonly used methodologies are Modified Log-Secant [11], CorLAS [12], API 579-1/AMSE FFS-1 [13], and MAT-8 [14]. A PHMSA sponsored comprehensive study [15] to understand ERW seam failures also provides additional information about identifying an appropriate model for prediction of rupture pressure.

The Modified Log-Secant model is an improvement from the original NG-18 [16] [17] or Log-Secant Model developed by Battelle (ASTM STP 536 [18], Kiefner [19]). It is a reasonable model for failures controlled by plastic collapse. This model was validated for Charpy V-notch (CVN) values of at least 15 ft-lb and should be considered when default values are used per 49 CFR §192.712.

The CorLAS model is a proprietary offering by DNV which uses two independent failure criteria: flow stress for plastic collapse and a toughness-based criteria. CorLAS uses a J-integral as the input to describe the pipe material's fracture toughness and J_{IC} for crack growth. If data for J_{IC} is not available, then it may be estimated from CVN. The CorLAS model is applicable for pipe material with CVN values of at least 15 ft-lb.

The API 579-1/ASME FFS-1 Part 9 uses a failure assessment diagram (FAD) and provides three assessment levels. The Level 2 approach is the most common for pipeline applications. The FAD is used to evaluate anomalies with failure modes between brittle fracture and plastic collapse. Anomalies plotted inside the curve are considered acceptable, and anomalies outside the curve are considered unacceptable. See **Figure 6** for an illustration of the FAD.

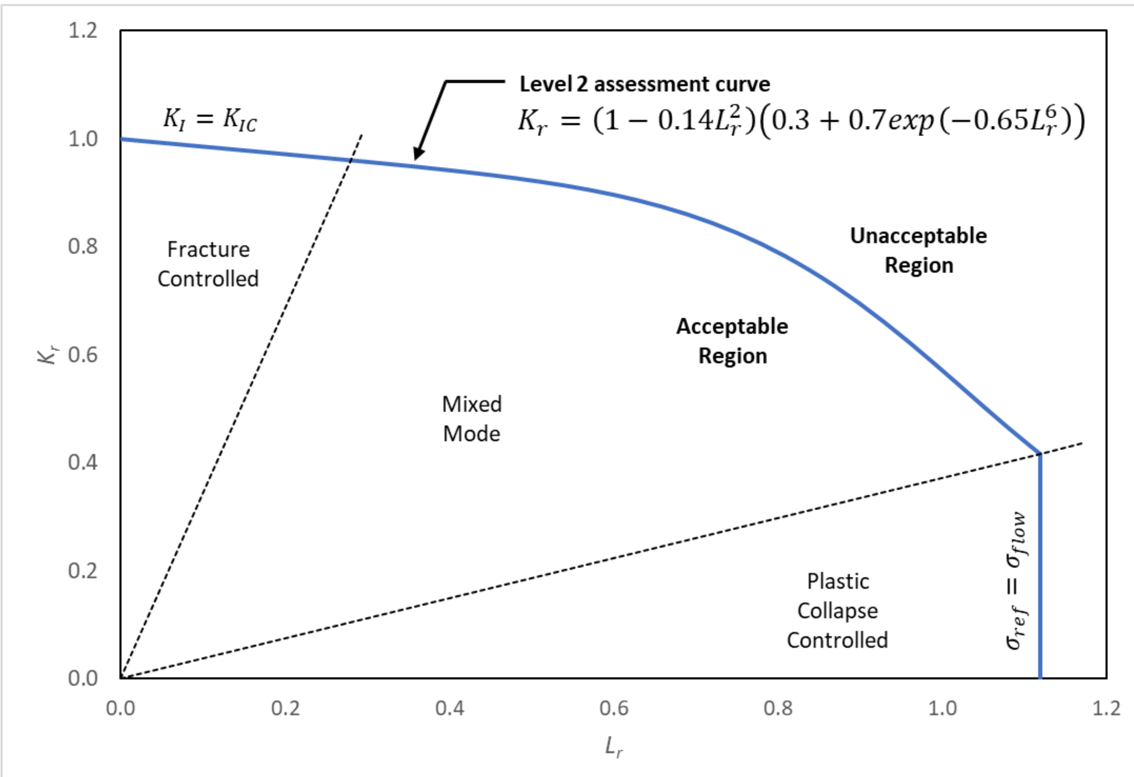


Figure 6: API 579-1/ASME FFS-1 Failure Assessment Diagram

MAT-8 was developed in conjunction with PRCI, based on the principles from API 579 and J-integral solutions derived from nonlinear FEA (Finite Element Analysis). It was developed to address cracking in pipeline longitudinal seam welds.

2.3.2. Fracture Toughness and Charpy V-notch (CVN)

The CVN or fracture toughness values used in calculating estimated failure pressures should consider the pipe body, heat affected zone (HAZ), and long seam (bond line) based on the anomaly location. The available information for fracture toughness should be understood prior to the EMAT ILI, and the need for additional information should be determined prior to the inspection. As CVN is not a measure of fracture toughness, caution should be taken when correlating CVN results to fracture toughness values.

This evaluation should be reviewed by an SME with competency in materials and crack assessment. API RP 1176 provides several useful annexes which should be reviewed; Annex C *Assessment Methods for Crack-Like Flaws* provides a brief overview of commonly used fracture mechanics methodologies and Annex E *Toughness* provides guidance related to toughness correlation to CVN data. See **Table 1** for a summary of fracture toughness properties and tests.

Table 1: Basic Fracture Toughness Properties and Tests[5]

Mode	Test	Standards	Property	Application
Static	J-resistance (J-R) curve	ASTM E1820 [20] ASTM E813 [21] ASTM E1737 [22]	Elastic-plastic fracture toughness J_{IC}	Failure assessment diagram (FAD) per API 579-1/ASME FFS-1
	Crack tip opening displacement (CTOD)	ASTM E1820 ASTM E1290 [23] BS 7448 [24] ISO 15653 [25]	Fracture initiation resistance, ductility	Girth weld engineering critical assessment (ECA) per API 1104, Annex A
Dynamic	Charpy V-notch impact (CVN)	ASTM A370 [26] ASTM E23 [27] ISO 148-1 [28]	Fracture propagation resistance; absorbed impact energy and fracture surface shear appearance	Pipe manufacturing quality control per API 5L; fracture control plan, critical flaw size evaluation
	Drop weight tear test (DWT)	ASTM E436 [29] API 5L3 [30]	Full scale transition temperature, ductility based on fracture surface shear appearance	Fracture control plan

2.3.3. Critical Flaw Size

For SCC, an EMAT ILI-based integrity assessment (ILI Assessment) is the product of the combined efforts of in-line inspection, engineering assessment, and pipeline rehabilitation. An alternative approach is to use a hydrostatic pressure test (hydrotest) as a means of providing evidence of pipeline integrity by failing those defects that may be injurious at a pressure higher than the operating pressure. There are advantages and disadvantages of both methods, but they can also be complimentary in that the hydrotest is a destructive test and will only find defects that fail at the test pressure on the day of the test. Defects that just survive will not be identified. ILI can provide information on defects that would fail at the hydrotest but also those that remain that may be injurious in the future. However, ILI has a probability of detection (PoD) that means that some defects may be missed.

As part of the decision process for selecting an SCC integrity assessment approach, a comparison of methods can be used to assist in the selection of the most appropriate approach or a combination of

[5] API RP 1176 (2016) Table E.1

methods. One approach is to use the detection specifications of the ILI tools to be used and compare this against the defects that would fail at an equivalent hydrotest pressure. An example comparison is given in **Figure 7** for a 24-inch pipeline with various assumed Charpy (CVN) values.

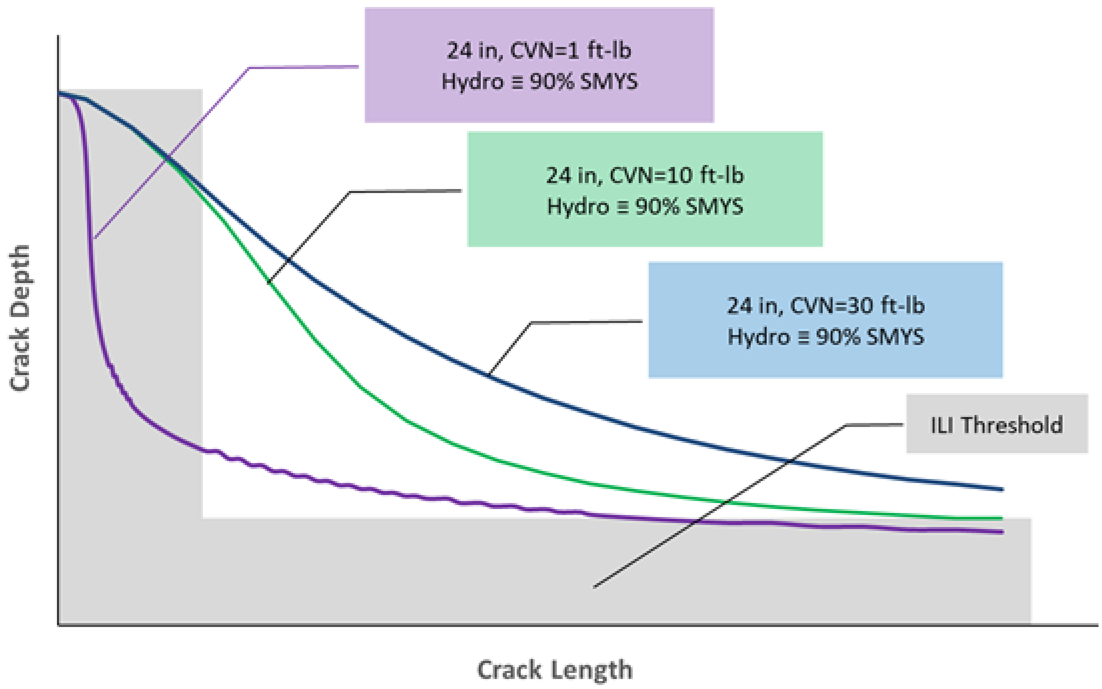


Figure 7: Critical Flaw Curves Compared to EMAT ILI Specification

The grey area indicates the capability of the EMAT ILI tool. Anomalies with dimensions in the grey area would be deemed outside of the EMAT ILI systems performance specification. The capabilities of each EMAT ILI system may be different between the long seam and pipe body and hence the grey area may change.

A set of curves (critical flaw curves) can be produced using a suitable fitness-for-service approach (e.g., API 579, PRCI MAT-8) to graphically represent anomalies that would be considered “unacceptable” (above the curve) or “acceptable” (below the curve) with respect to the considered operating pressure (in this case the hydrotest pressure). Each curve is derived for a set of loads (internal pressure), geometry (pipe dimension), and material properties (pipe grade, fracture toughness). Multiple curves can be generated to represent assumed pressures (e.g., MAOP and test pressures) as well as to accommodate different properties on the pipe (e.g., base pipe material, long seam weld, and HAZ).

This analysis can support the evaluation of different EMAT ILI system’s performance during the selection process. Additionally, this evaluation may be used to support decision-making processes associated with the selection of the overall integrity approach for SCC management.

The selection process also needs to factor in the prevailing regulations and internal policy and procedures of the operator.

2.3.4. Data Integration

The process of data integration serves multiple functions during the integrity assessment. Integrating relevant information about the pipeline and the SCC threat landscape is critical for the successful interpretation of EMAT ILI results. Incomplete data and insufficient accuracy can significantly impede the ability to develop an understanding of the pipeline's integrity. As a result, there may be increased uncertainty related to the threat of SCC. Therefore, the success of an EMAT ILI system is the ability to detect, identify, and size crack and crack-like anomalies. Uncertainty will increase the appropriate level of conservatism associated with the response to the EMAT ILI results. Excavation results may also be compromised and rely on in situ direct examination to predicate subsequent actions.

The objective of data integration is to collect sufficient information about the pipeline's historical integrity and SCC susceptibility prior to the EMAT ILI. As a minimum, the data which should be available for integration would include:

- Pipe type,
- Year of manufacture,
- Coating type and condition,
- Hydrotest pressure levels and duration,
- Hydrotest failure history,
- Historical operating stresses,
- Pipe mechanical properties and fracture toughness (or CVN),
- In-service failure history,
- Cathodic protection effectiveness,
- History of SCC, considering previous inspections and in situ direct examinations, and
- ILI history and past performance.

2.3.5. Anomaly Response Criteria – Methodology

Prior to engaging ILI service providers and receiving EMAT ILI results, the pipeline operator should have established anomaly response procedures associated with determining actionable anomalies, issuing discovery, and assigning appropriate response criteria. The guidance in this document follows API STD 1163 Figure 1, *Inspection Terminology,* and API RP 1176 section 11.6, *Crack Tool Response Methodology,* to assign each reported EMAT ILI anomaly a likelihood classification and response criteria. This approach integrates information from interpretations of the ILI results, anomaly characteristics, the anomaly's propensity to be the targeted crack morphology (such as SCC), and calculated rupture pressure. Actionable anomalies are established by using the combination of data integration, likelihood classification, estimated rupture pressure, and in-ditch evaluations.

The anomaly response methodology is a process-oriented effort to respond to EMAT ILI results by classifying (per API RP 1176) each reported anomaly as either: Likely Crack, Possible Crack, or Unlikely Crack. This process can be iterative based on the available historical data, findings from excavations, (i.e., in situ direct examination), and overall performance. The likelihood classification process requires frequent collaboration between the pipeline operator and the EMAT ILI service provider, operator experience and knowledge of the specific ILI system, and the pipeline characteristics. Initially, this is a post-inspection process. Conservative assumptions should be used (e.g., assigning classification of Likely Crack) when there is uncertainty in the data. Once the likelihood classification is assigned to each anomaly, then the rupture pressure calculations follow. If the EMAT ILI reported anomalies interact with other feature types (dents, corrosion, etc.), then these anomalies would be addressed with the response criteria according to the pipeline operator's written procedures.

2.3.6. Time Dependence and Growth Parameters

Establishing time dependency and growth parameters for SCC in an inspected segment is necessary to determine the appropriate response time and reassessment interval for the reported anomalies. Guidance information related to SCC growth in pipeline, as in the recommended practices issued in CEPA's stress corrosion cracking recommended practice, should be reviewed and incorporated in an operator's procedures. CEPA describes SCC growth in four stages and represents these stages graphically in what is known as a "bathtub model" shown in **Figure 8**.

SCC growth rates should not be used to estimate remaining life up to a time point of failure, but to some point before failure where rapid mechanical growth (Stage 4 of the bathtub model) of the anomalies is not occurring. It is important for the pipeline operator to a establish a protocol for deriving the stage of SCC and its growth rate prior to the EMAT ILI, however, sufficient information may not always be available to establish an appropriate growth rate until the completion of in situ direct examinations. As ongoing efforts to develop models to examine growth rates continue, the pipeline operator should monitor any developments for use in their program.

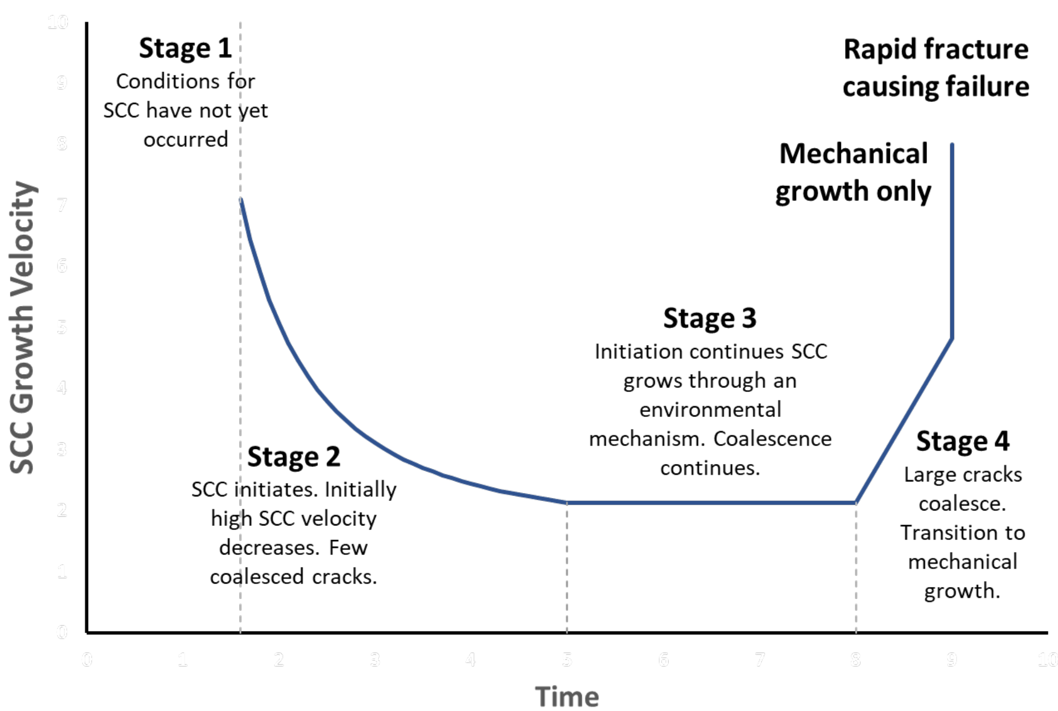


Figure 8: Bathtub Model: Life Cycle of SCC Growth in Pipelines

2.3.7. Validation

The pipeline operator should consider if the EMAT ILI system is able to reliably detect the targeted SCC defect characteristics in the pipe material, using the pipeline attributes with sufficient performance to achieve a sound integrity assessment.

The integrity assessment, based on material properties and critical flaw sizes, should be validated according to guidance in API STD 1163. **Figure 9** illustrates the three levels of validation presented in API STD 1163. The level of validation should be established based on the level of experience and risk associated with the EMAT ILI. Pipeline operators without extensive EMAT ILI experience should consider pursuing positive confirmation of EMAT ILI performance through in situ direct examination or destructive examination. Due to the extensive time and expense commitments of excavations, a prioritization schedule should be established.

Annex C (informative) Section C.2 of API STD 1163 provides guidance related to the comparison of ILI and field measurements. The validation efforts should include evaluating the accuracy of excavation results for each classification before finalizing the likelihood classifications, estimated rupture pressure calculations, and EMAT ILI performance. As additional information is collected, sentenced or opportunistic, the EMAT ILI response effort performance should be re-evaluated.

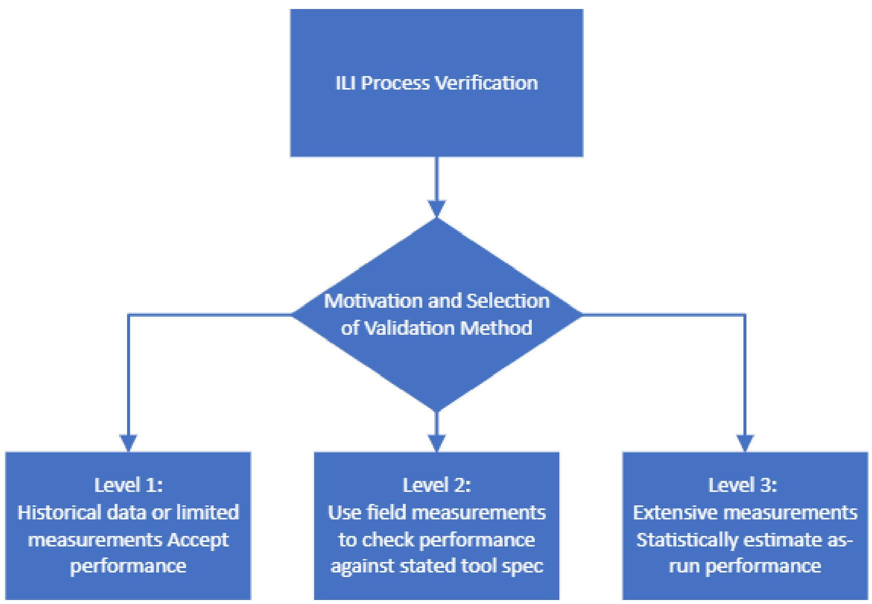


Figure 9: Overview of Three Levels of ILI Validation per API STD 1163

2.4. ILI Planning

The purpose of the ILI planning section is to provide considerations for pipeline operator specific activities which will support an overall successful ILI project. The objective is to highlight that an EMAT ILI schedule may present both operational and integrity-related challenges. Guidance in NACE SP0102 should be followed to plan, organize, and execute ILI projects.

2.4.1. Project Timeline

The time required to complete an EMAT ILI-based integrity assessment may be extensive. Appropriate time should be allocated to develop sound written procedures, collect the required information according to the pre-inspection evaluation, and review and qualify eligible EMAT ILI systems. The ILI service providers should be engaged early to understand EMAT ILI tool availability and reporting timelines as they may be significantly longer than timelines for MFL or geometry ILI technologies at the time of this report. The iterative nature of the likelihood classification methodology and results validation may have a significant impact on required excavations, which may extend the project timeline. Any modifications to pipeline facilities should also be considered in the project timeline. In addition to the Operations parameters below, the time of year, pipeline capacity and demand, and planned outages should be considered in the planning.

2.4.2. Pipeline Facilities

EMAT ILI tools may require modifications to the pipeline launching and receiving facilities. Modification or replacement of pipe and components, (e.g., bends, valves, and other fittings), may also be required to improve running conditions, tool navigation, and data quality. A review of previous ILI velocities may provide information on pipeline modifications to improve running conditions and data quality.

2.4.3. Pipeline Cleaning

Efforts and timing to establish confidence in the pipeline cleanliness is dependent on the type and volume of debris in the pipeline. The ideal condition is for the EMAT sensors to be in direct contact with inner pipe surface; during actual inspections, direct contact throughout the run may not be possible or practical to achieve. Cleaning programs in preparation for ILI should be aligned with the ILI service provider. For some pipelines, chemical cleaning may be an option to improve EMAT's data quality. Cleaning programs may be extensive and should be coordinated proactively to ensure inspection date is not compromised. Certain ILI technologies may provide debris mapping and provide location-specific debris profiling. Additional guidance on cleaning for ILI can be found through the Pipeline Operators Forum (https://pipelineoperators.org) or consultation with the selected ILI service provider.

2.4.4. Pipeline Operating Conditions

The design of the EMAT tool and potential risk of speed excursions may require a detailed plan to maintain optimum tool velocity. Activities such as line packing, maintaining back pressure, managing inspection medium flow, and actively manipulating valves are some techniques for controlling tool velocity. Pipeline operating conditions may require the inspection date to be within a specific range of dates to accommodate pipeline operations, target pressures, and auxiliary activities.

2.4.5. Tool Overspeed (Speed Excursion)

An essential variable to the success of an inspection is the tool's velocity as it inspects the pipeline. The pipeline operator should understand the tool's limits and plan activities to complete the inspection within the tool's specified velocity envelope. The pipeline operator should leverage the ILI service provider's experience to accommodate the required inspection operating conditions to achieve the optimal velocity. The pipeline operator should also integrate their own inspection experience in the pipeline to prepare for the EMAT inspection. If the EMAT ILI system has the capability to leverage a speed control system, then the pipeline operator should consider its incorporation for challenging inspections where flow conditions cannot be met or overspeed is expected.

2.4.6. Degraded ILI Data

A process and plan for addressing degraded EMAT ILI data should be considered prior to ILI. A modified performance specification may be applied to areas of degraded data. The impact of degraded data on the decision-making process may be significant depending on the location and extent of the data degradation. Processes based on data integration, including supplemental ILI data, and in situ direct examination may facilitate the assessment of areas impacted by degraded data. Collaboration with the ILI service provider to evaluate the impact of degraded data is essential. Degraded data may impact the acceptance of an ILI and the ability to meet the goals of the inspection.

2.4.7. Right-of-Way Access

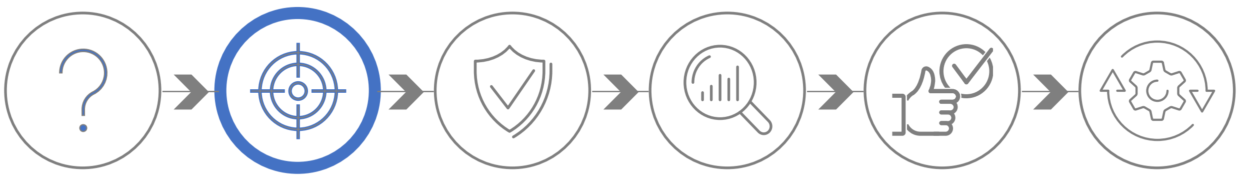
Gaining access to the right-of-way may require additional planning efforts, e.g., landowner notifications, and be considered prior to pipeline inspection.

2.5. Quality Gate – Section 2: Pre-Inspection Evaluation

- Provide the service providers pipeline questionnaire (PLQ) with complete and accurate information,
- Understand the pipeline's dynamic segmentation for SCC susceptibility,
- Identify the material properties to be used for engineering assessment and/or establish a plan for material properties verification,
- Understand the targeted SCC morphology and define,
- Calculation of critical flaw sizes,
- Gather pipeline's historical information pertinent to data integration for SCC,
- Identify the SCC susceptibility analysis and engage SME's,
- Identification of SMEs to be engaged according to management program and EMAT ILI assessment procedures to execute, support, and approve work,
- Review pipeline operating conditions and is a draft ILI project plan including developing procedures, data gathering activities, operating requirements,
- Comparing ILI versus a hydrotest based integrity assessment,
- Definition of EMAT ILI system goals and objectives, and
- Establish process for dealing with degraded data and run acceptance criteria.

3. ILI System Qualification and Selection

The purpose of this section is to provide guidance on performing an evaluation of EMAT ILI system(s) and selecting an appropriate EMAT ILI system to perform the integrity assessment for SCC. The analysis should consider the elements of each ILI system. API STD 1163 defines an ILI system as *an inspection tool and the associated hardware, software, procedures, and personnel required for performing and interpreting the results of an ILI*. The ILI System Qualification & Selection section is highlighted in **Figure 10.**



ILI System Qualifications & Selection

- Goals and Objectives
- Tool Design
- ILI Specifications
- Reporting Requirements
- ILI System Qualification
- ILI System Selection
- Quality Gate

Figure 10: EMAT ILI Assessment Landscape: ILI System Qualification & Selection

The selection of an appropriate EMAT ILI system is presented through a process map and quality control points. Completing the efforts outlined in this section will result in two primary benefits for the pipeline operator and the ILI service provider. First, the pipeline operator will establish the selected EMAT ILI system's expected performance in a specific pipeline, including its anticipated operational performance. Second, the pipeline operator will be able to establish the goals and objectives for the EMAT ILI and clearly communicate them to the ILI service provider. Collaborative efforts between the pipeline operator and the ILI service provider, to exchange accurate information, is a pre-requisite for selecting the most appropriate EMAT ILI system.

3.1. Goals and Objectives

As it pertains to this document, the principal goal of using an EMAT ILI-based integrity assessment is to achieve an effective method to integrate the ILI results into an overall integrity management program. To achieve this goal, the selected EMAT ILI system should be able to provide reliable characteristic data of the physical and operational parameters. An ILI system qualification is deemed successful when the EMAT ILI demonstrates reliable characteristic data through validation activities, such that the results of engineering assessment can be used as the integrity assessment for the pipeline segment. Additional goals for the ILI may be agreed between the pipeline operator and ILI service provider.

Objectives can be set for tool performance, data quality, reporting, and results validation. API STD 1163 provides the framework for performing ILI system qualification, the in-line inspection, operational verification, and results validation. Establishing clear objectives for the inspection enables collaboration between the pipeline operator and the ILI service provider for the selected ILI system, inspection, and pipeline. These objectives should be vetted and explicitly agreed upon between the pipeline operator and the ILI service provider prior to the inspection.

EMAT ILI system qualification is critical to establish confidence in achieving the inspection goal. The quality gates provided at the end of this section are to ensure that the project objectives are properly identified and defined.

The EMAT ILI service providers should make clear and verifiable descriptions for ILI system inspection capabilities and performance. As a minimum, the pipeline operator should review the following information to select a suitable EMAT ILI system for the integrity assessment:

- Measurement principle,
- Tool data sheet(s),
- Performance specification(s),
- Operating envelopes,
- Essential variables,
- Historical performance, and
- Reporting requirements (interaction rules, sentencing criteria).

The illustration in **Figure 11** provides a process map for the ILI system qualification and selection process, which should be exercised in collaboration with the ILI service provider(s). Quality gates with explicit criteria should be incorporated into the pipeline operator's written procedures for ILI System qualification and selection. The intent of **Figure 11** is to guide a pipeline operator through the EMAT ILI selection as a result of a compatibility assessment between the initial goals and objectives for the inspection and the results of the quality gates. Inclusion of an ILI system for EMAT ILI selection should require demonstrable evidence that the goals of the inspection can be achieved, considering the essential variables by which the ILI system's performance specification was qualified.

An ILI system is deemed qualified if the pipeline attributes, properties, and operating conditions are acceptable according to the essential variables by which the ILI system's performance specification was qualified. Institutional knowledge and validation of an EMAT ILI system may be supplemented with historical performance documented by the ILI service provider for comparable pipeline attributes, properties, and operating conditions. The goals and objectives for the EMAT ILI system should be documented as a result of the evaluation of each EMAT ILI system through the ILI system qualification and selection process. Pipeline operators are encouraged to engage the ILI service providers and other EMAT ILI users throughout this process.

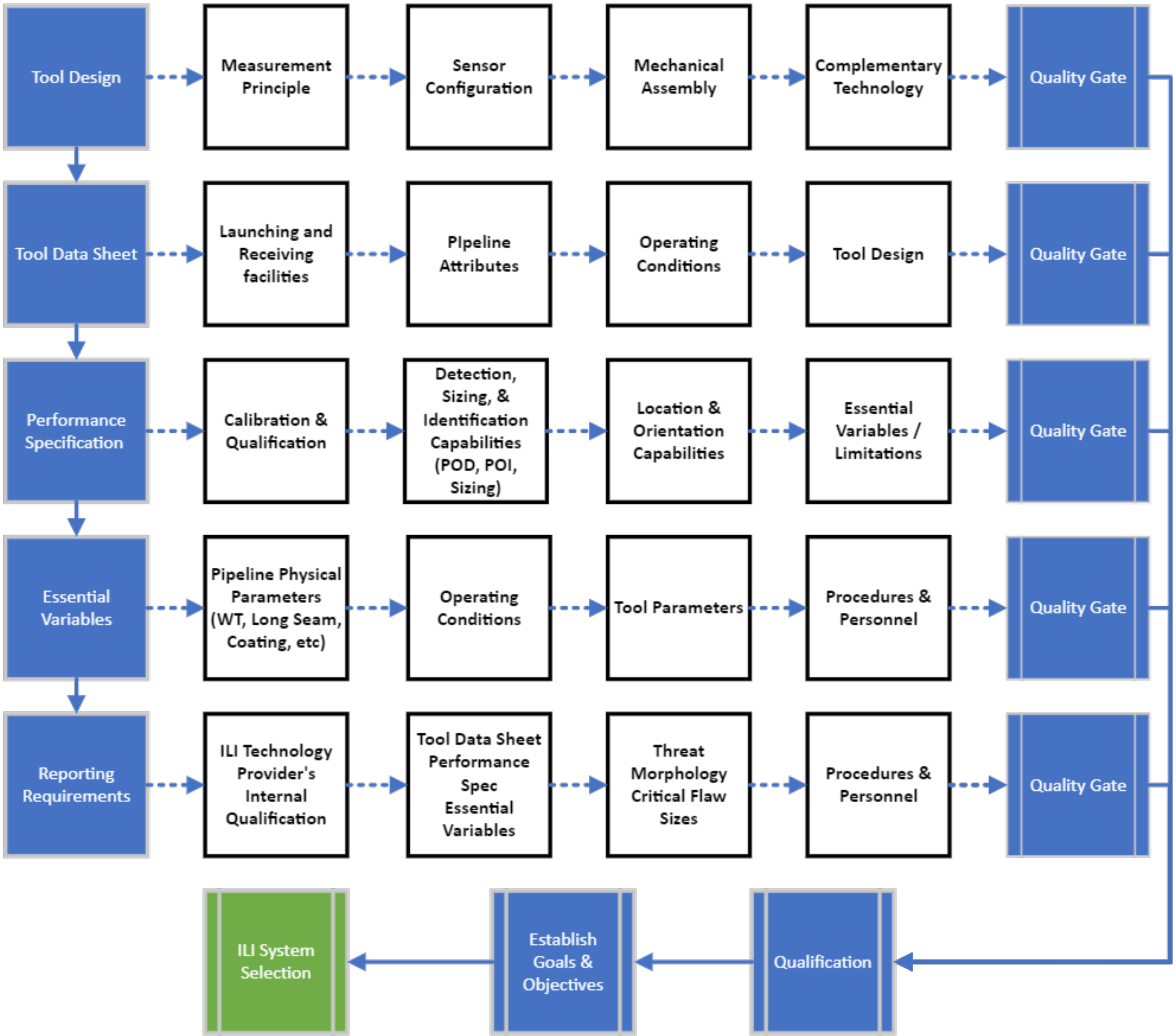


Figure 11: ILI System Qualification and Selection Process Map

3.2. Tool Design

As previously discussed, EMAT is an ultrasonic (UT) technique that generates the ultrasound wave in the part being inspected (i.e., the pipe wall) using electromagnetic techniques instead of using a piezoelectric transducer. Conventional piezoelectric UT sensors require a liquid couplant to transmit the UT waves to the pipe whereas EMAT does not. However, the acceptable stand-off distance between the EMAT sensor and inner pipe wall does have limits, and each ILI system's requirements should be understood.

A key element in measurement system design is the proper consideration of measurement capabilities for the threats of interest and the characteristics and location of target defects in the pipe wall. For example, detecting cracks within the base material of the pipe may be an easier task than detecting cracks within the long seam weld. While dealing with changes in pipe wall thickness for pipe body inspections is well-understood, the inspection of long seam welds and reporting of cracks may be more challenging due to the geometric discontinuity between the pipe wall and long seam weld. The transduction process occurs within an electromagnetic skin depth reflector, thus requiring additional data rendering and interpretation.

The performance and capabilities of each EMAT ILI system may not be understood until the EMAT ILI tool has been deployed, the data quality examined, analysis results delivered, and exploratory in situ direct examination results are rendered.

3.2.1. Sensor Configuration

On the EMAT tool, the measurement system is a sensor, or an array of sensors, that contact the inner pipeline wall. These sensors can be arranged to obtain the pipe-wall surface coverage such that the specifications are achieved. There may be various sensor types configured to produce different ultrasound modes/types and frequencies. A variety of different sensors may be designed in various geometries and arrangements to allow propagation in almost any direction, including around the circumference of the pipe. Short-range and long-range measurement setups can be found in the portfolio of different ILI technology and service providers. Different implementations utilize a variety of wave modes and capabilities that can differ between the ILI service provider's individual realizations. Examples of these ultrasonic waves modes can be in the form of Lamb or Shear Horizontal (SH) guided waves, each with particular wave patterns. Lamb waves have been generally known for use in longer search windows. Tool designs with overlapping sensor coverage is a common approach to ensure proper target defect detection values and repeatability of the measurements under harsh conditions.

The ultrasonic wave propagates through the material and will be influenced by the presence of defects (such as cracks) that interrupt its travel. This physical interruption may reflect some of the wave energy back to the originating coil location and be received and recorded, known as the pulse-echo technique. The same defect may also interrupt the forward travel of the ultrasonic wave and be detected at other locations through other sensors, known as the through-transmission technique. EMAT tools may be configured to operate in both pulse-echo and through-transmission modes. Methods for anomaly depth sizing may use various characteristics of the signals received from either or both the pulse-echo and through-transmission modes (similar to conventional piezoelectric ultrasonic methods).

The EMAT's ability to resolve crack colonies (i.e., SCC colony) is generally affected by how close the cracks are to each other. For cracks in close proximity, the current EMAT technology may interpret multiple cracks as one larger EMAT signal reflection. In this case, individual cracks would not be discretized separately, instead EMAT may report a crack group with one equivalent length and depth. As EMAT ILI technology continues to advance, it is expected that these conditions will improve over time.

3.2.2. Complementary Inspection Technology

EMAT ILI systems are designed to detect crack and crack-like anomalies (i.e., planar defects that are predominantly characterized by length and depth, with a sharp root radius). Defects with significant opening (also referred to as volumetric defects) may be reported by the EMAT ILI systems. Steep sided corrosion and sharp edged gouge, for example, may be interpreted by EMAT as a crack or crack-like anomaly due to its morphology. Co-located features with defects make discrimination more difficult, and therefore, EMAT ILI results are often paired with metal loss inspection technologies to further increase the identification and reporting of crack anomalies such as SCC. It can be observed that ILI service providers more often combine different technologies to cover the main topics of investigation (geometry, metal loss, and cracking) in multiple ILI surveys and overlay the data for a more comprehensive analysis approach.

3.2.3. Specific Advantages of EMAT ILI

The EMAT technique does not require a fluid couplant with the material under examination. Important consequences of this include applications to moving objects, in remote or hazardous locations, to objects at elevated temperatures, or to objects with rough surfaces. EMAT signals are highly reproducible because of the manner in which the acoustic waves are generated. EMAT can also produce shear horizontal polarized (SH) waves without mode conversion and can accommodate scanning while using SH waves. Additionally, EMAT can allow the user to electronically steer shear waves through the design of the EMAT sensor. For example, SH waves can be generated to travel in the circumferential direction through the wall thickness through a combination of coil and magnet designs.

3.2.4. Specific Limitations of EMAT ILI

The EMAT technology has a very low efficiency with respect to wave generation as compared with conventional ultrasonic methods, with insertion losses of 40 dB or more. The EMAT technique can only be used on materials that are electrical conductors or are ferromagnetic. Highly corroded surfaces, especially inner surfaces, may render EMAT unsuitable for use if the surface disturbs the generation of the electromagnetic forces. Some pipeline coating systems can make cracks challenging to detect because of their potential absorption of the ultrasonic wave (signal attenuation) or other artifacts in the signal data. However, some EMAT implementations can discriminate between coating types and detect coating conditions (coating disbondment).

The design of EMAT sensors is usually more complex than comparable piezoelectric transducers, and they are usually relatively larger in size and due to their low efficiency. EMATs usually require more specialized instrumentation for the generation and detection of ultrasonic signals. High transmitting currents, low-noise receivers, and careful electrical matching are imperative in system design.

3.2.5. Quality Gate – Section 3.2: Tool Design

- Review each ILI service provider's implementation of EMAT on the ILI systems considered for use.
- The operator should understand how the considered EMAT ILI system sensor package is configured and how the EMAT generated wave package is likely to generate reliable signals for detection, identification, and sizing of linear anomalies and/or groups of linear anomalies associated with SCC.
- The operator should understand if complementary ILI system is required to support the EMAT ILI (to provide an increased confidence with POI and how it is used to meet detection, identification, or sizing specifications).
- The operator should have a general understanding of how the EMAT signal data is evaluated to detect and characterize cracks (such as SCC) and crack-like anomalies.

3.3. ILI Specifications

The ILI specifications are often provided in two parts: a tool datasheet and a service performance specification. The tool datasheet describes physical characteristics, configuration, and capabilities of the ILI tool with a focus on field operations and tool passage through the pipeline. The service performance specification focuses on communicating the inspection performance capabilities for anomaly detection, identification, and sizing as a function of the prescribed essential variables. However, EMAT ILI specifications may not communicate details on the measurement principle.

NACE SP0102 provides guidance in Section 4: *Pipeline ILI Compatibility Assessment* to review the tool datasheet and evaluate the physical compatibility of the ILI tool and the pipeline facilities. It is fundamental for the pipeline operator to understand the performance specification for the ILI systems considered. While API STD 1163 governs the process of qualifying a performance specification, it does not establish a minimum performance requirement for an ILI system to be used as an integrity assessment.

API STD 1163 defines **performance specification** as, "*A written set of statements that define the capabilities of an ILI system to detect, classify, and characterize features*", and further requires that, "*The service provider shall state whether the chosen ILI system can meet the written performance specification in that pipeline and under the existing operating conditions, including the specific tool configuration for the proposed run*." However, the ability for an EMAT ILI to meet the specification is dependent on the inspected pipeline matching the characteristics of pipe used to develop the specification (e.g., cleanliness, pipe/seam geometry, surface roughness, and defect characteristics).

The following will highlight EMAT-specific details and topics which should be explicitly reviewed with the ILI service provider.

3.3.1. ILI Tool Datasheet

When reviewing the tool datasheet, it is critical to understand the tool's specifications as it relates to flow velocities, operating pressure, tool length, minimum bores, and pipeline wall thickness. Followed by understanding the required pipeline facilities associated with the ILI tool insertion, extraction, and its ability to navigate the pipeline. The following details should be noted to be incorporated in any ILI system review:

- Data quality reduces when operated outside of the specified operating envelope,
- Performing the inspection at lower pressures than specified may increase the risk of tool stoppage and speed excursions,
- Launching and receiving facilities may need to be modified to accommodate EMAT ILI tools as they tend to be longer than traditional MFL and geometry-based ILI tools,
- Wall thickness ranges need to be compatible with sensor configuration, and
- Pipe bends, reduced bore tees, and other fittings can result in tool getting lodged.

3.3.2. Performance Specification

The performance specification should clearly state a statistically derived and valid list of types of anomalies, components, and characteristics that can be detected, identified, and sized. However, the pipeline operator should understand that the definitions of some anomalies vary amongst operators and ILI service providers. The ability of the EMAT ILI system to meet its performance specification for a given inspection is dependent on the inspected pipeline matching the definitions, the pipe properties and the operational conditions used to develop the specification. An EMAT ILI system's performance specification is qualified for inspection at a range of speeds, wall thicknesses, and defects of specific dimensions, characteristics, and morphology. Variables that are outside of these parameters may not conclude in results being within the performance specification. **Figure 12** provides an illustration of various cracking morphologies and characteristics that may appear in a performance specification.

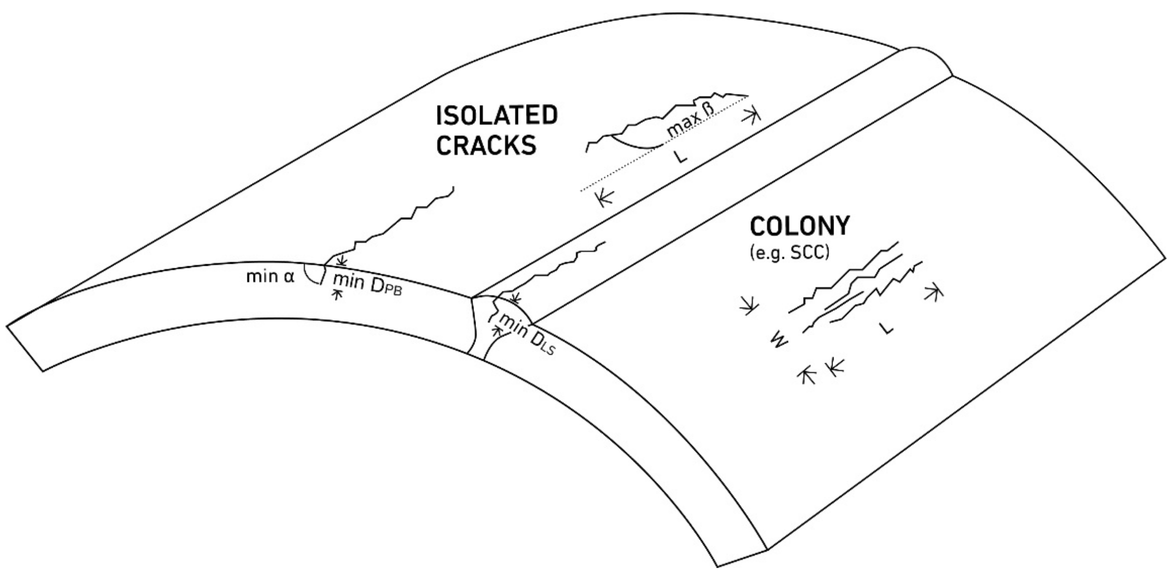


Figure 12: Illustration of Crack Related Dimensions[6]

Industry conventions for anomaly performance are provided in API STD 1163. These are statistical in nature for a given anomaly type and size. Thresholds are critical to understand, as they are the basis for detection which then affects feature identification, and ultimately sizing accuracy of the final results.

6 Illustration provided by JIP Participant ROSEN, 2022.

Identifying the targeted SCC morphologies enables an appropriate comparison of specifications and their thresholds. EMAT ILI users should compare the ILI system's capabilities to the critical flaw sizes that were determined as requirements. The EMAT ILI's performance specifications should be presented in statistical probability formats and be specific to feature types, dimensions, and conditions.

The following details and definitions should be understood by the pipeline operator and incorporated into their review of the performance specification:

- **Detection** (technology based) is the EMAT ILI's ability to obtain a measurable indication from a given feature type and its size, location, and orientation in the pipeline. A minimum detection threshold is defined as the minimum characteristic dimension for a linear anomaly to be reported by the EMAT ILI that meets the tool's performance specification.
- **Identification** is generally understood to be the delineation of a type of feature, also called "feature classification".
- **Probability of Detection (POD)** is based on the statistical performance of the ILI system's ability to interpret signals associated with a given target feature at specified thresholds for minimum depth, length, and axial and radial orientation. POD is highly dependent on anomaly location and proximity to other features. POD is susceptible to the inspection being performed within the limits of the essential variables. The POD of the ILI system is a function of the system design and data processing capabilities.
- **Probability of Identification (POI)** is the statistical specified performance for each classification type and should be understood as the data evaluation is dependent on that classification. EMAT ILI reported anomaly classification of "crack-like" can overlap types of cracks (e.g., SCC) and linear manufacturing or weld features. Evaluation protocols are based on confidence that the signal is crack-like. This is for ILI reported anomalies which is distinct from the later pipeline operator evaluation in integrity engineering analysis.
- **Sizing of anomalies** from ILI is also stated in a statistical form. The associated accuracies are dependent on the signal conditions and quality, data algorithms, morphology type, and analyst interpretation. Reported anomaly sizes from EMAT ILI (and any ILI) should consider the system's resolution needed for sizing within interacting anomalies, such as:
    - The length of the reported anomaly is a result of the EMAT signal vs. an exact profile of the crack-like defect (e.g., SCC).
    - The potential variety of cracks within an SCC colony vs. what is the deepest crack.
- **Essential variables** are the parameters by which the performance specification was qualified, and they govern POD, POI, and sizing accuracy in the written performance specification.

3.3.3. Calibration & Qualification

API STD 1163 requires that each stated performance specification should be qualified using methodologies defined by the ILI service provider. These methodologies should be available to the pipeline operator for review. There is not a specific qualification standard procedure for EMAT ILI. Therefore, the pipeline operator as an EMAT user should understand the methodology and data used to qualify the performance specification as part of evaluating an ILI system's eligibility as an integrity system. Methods to qualify a performance specification include:

- Verified historical data,
- Small-scale tests, modeling, and/or analysis (as indicators of potential performance), and/or
- Large-scale tests on real and/or artificial anomalies.

3.3.4. Essential Variables

API STD 1163 defines essential variables and their relation to performance specifications. In practice, this is to identify and address parameters that affect performance and are associated with:

- Pipeline attributes (e.g., wall thicknesses, long seam types, surface roughness),
- Operating conditions (e.g., tool velocity, contact to pipe surface),
- Tool parameters (e.g., sensor configuration, magnetization, speed control), and
- ILI technology-specific processes and procedures (e.g., personnel, data routines/algorithms, and evaluation protocols).

Essential variables can be thought of as two categories, primary and secondary variables.

- Primary essential variables are directly related to the tool's capabilities by design and the inspection conditions such as the pipeline attributes and the target threat morphology's physical characteristics. Examples of primary essential variables with EMAT ILI are sensor configuration(s), pipeline wall thickness range, tool velocity range, and the target cracking morphologies.
- Secondary essential variables are influencing conditions and factors on performance related to the ILI service provider's procedures, pipeline operating conditions, and algorithms, typically for situations of degraded data. Examples of secondary essential variables are analysis procedures and algorithm used, sensor redundancy for coverage, analysis algorithms, and tool velocity. Considering essential variables in these two categories facilitates ILI System Operational Verification (see Section 3) and ILI Assessment Results Validation (see Section 5).

The pipeline operator should have a clear understanding of the essential variables which are the basis for the ILI system's performance specification.

3.3.5. Quality Gate – Section 3.3: ILI Specifications

- Does the tool data sheet indicate the pipeline's physical and operational conditions are acceptable?
- Which essential variables are not consistent with the tool data sheet and how will they be addressed?
- How was the performance specification qualified and does it meet the requirements for anomaly detection?
- How will supporting/complementary ILI data sets be used, and how they impact the performance specification? (e.g., transverse MFL, multiple EMAT sensor technologies, etc.)
- How will deviations from the essential variables be addressed?
- Are there limitations to the EMAT ILI capabilities associated with discontinuities in the pipe surface near girth welds and long seams?
- What impact does the pipeline coating system have on the EMAT ILI's ability to detect crack and crack-like indications?
- Are any physical tests (e.g., pull test) necessary to qualify/ensure the performance specification for the specific pipeline's attributes to be inspected?
- How will the tool be configured, or evaluation be performed to achieve the objectives of the inspection and essential variables?
- How will the data be analyzed in areas of speed excursions?
- How is the pipeline determined to be sufficiently clean to ensure sound data acquisition? Does the specification indicate a pipeline cleanliness requirement, and how is it measured?

3.4. Reporting Requirements

This section provides guidance on the reporting requirements associated with EMAT ILI results and deliverables. The results of the inspection should be accurately communicated in written reports and data deliverables. Written reports should provide sufficient documentation to comply with the pipeline operator's goals for the inspection, objectives, performance specifications, and applicable regulations as a record.

Each pipeline operator should have written requirements for reporting deliverables and procedures for evaluating each ILI report. These reporting requirements should be communicated to the ILI service provider prior to selecting an ILI system to allow for collaboration and agreement. Each ILI service provider may have unique and proprietary reporting formats and styles. However, the pipeline operator should define the purpose of each report and the required data to perform data integration and integrity engineering analysis. Nomenclature and required reporting requirements should be established as part of the ILI's objectives and agreed prior to ILI system selection. The reports associated with an EMAT ILI may include:

- **EMAT Field Report** – This reporting is used to present information on the EMAT tool's behavior and performance during the inspection and its ability to collect data throughout the inspection.

This report is often the first deliverable where the inspection can be accepted or rejected due to tool's functionality. The field report will commonly provide the tool's velocity, rotation, qualitative measure of collected data, length of pipeline data collected, and general sensor functionality throughout the inspection. This reporting is typically within a couple of days after the tool is received by the field operations.

- **Data Quality Assessment (DQA)** – This reporting is used to present information on the data quality and data coverage throughout the inspection on a segment or joint wise basis. This report is fundamental for inspection acceptance or rejection. The DQA should present information associated with the EMAT's ability to report results within its stated performance specifications throughout the pipeline. For example, in areas where sensor coverage was reduced, or essential variables are not met, the data quality may be deemed degraded or reduced for some areas. Any potential degradation of performance should be identified at this stage and reported. The DQA will commonly provide the expected performance associated with POD, POI, and sizing. Reduced or degraded data quality or performance specifications can often be managed with supplemental data, integrity activities, and other assessment(s). Broad data quality or performance specification issues should be discussed with the ILI service provider, including potential issues in re-runs or other ILI field operations.
- **Preliminary Report (PR)** – This reporting traditionally identifies anomalies for either 1) verification digs or 2) priority notice of anomalies that exceed some predefined criteria of dimensions, location, or severity. The intent, format, definitions, and goals of the preliminary reports should be agreed between the pipeline operator and ILI service provider prior to infield inspection activities. The ILI data analysis processes of the ILI service provider may require in situ direct examination results to provide confidence in the stated POD, POI, and/or sizing performance. Preliminary reporting may become an iterative process depending on the objectives and EMAT ILI system performance. Preliminary reports are optional but generally recommended when essential variables and data quality goals and objectives are met. In more mature EMAT based crack programs, preliminary reports may be used to communicate anomalies which meet specific predefined criteria. For example, anomalies which are estimated to be deeper than 50% of the nominal pipe wall thickness. An arrangement between operator and service provider can be established for cases when a given anomaly meets operator-specific criteria or is deemed notable by the ILI analysts thus needing expedited communication and may replace the formality of a preliminary report.
- **Draft-Final / Final Report (FR)** – A draft-final report is issued when the ILI data analysis process is completed, and results are available for field verification. Once the field verification becomes available, a final report can be issued incorporating the in-field results. If no field verification is provided to the ILI service provider, the draft-final report generally becomes a final report. The final report is used to present the results of the analysis and document all necessary information to serve as a record associated with the ILI process, inspection goals and objectives, and compliance requirements. The final report can be accompanied by a means for the pipeline operator to document the signal data and results of the inspection and data analysis. The time and activities of both pipeline operator and ILI service provider between draft-final and final reports should be identified and agreed prior to the inspection. For example, some practical and

finite limits to timeframes should be established to allow completion of the reports and to avoid projects running across multiple years.

- **Client Viewer** – An ILI signal data viewing software is to be expected from the ILI service provider as part of the final report. This enables the pipeline operator to hold a record of the processed data that was used by the ILI analyst to generate the final report. However, this application may have limited functionality in terms of analysis capabilities.

As part of establishing reporting requirements, several topics should be vetted. These topics may vary between pipeline operators, ILI service providers, and projects. However, the following topics should be explicitly considered and addressed:

- **Reporting Thresholds** – (Operator defined) is a parameter that defines which type of linear anomalies should be reported. The reporting threshold, which may not be the same as the detection threshold, defines the smallest anomaly which will be reported to the operator. Each pipeline operator should define the reporting thresholds in the reporting requirements. It is possible that an ILI detects anomalies below the reporting thresholds that have signal characteristics that the EMAT analyst has sufficient confidence to report. These anomalies may not include reported dimensions, but they might be reported with commentary and description. Reported anomalies under the reporting threshold can support data integration activities associated with pipeline integrity management. For example, opportunistic digs can be used to confirm EMAT results. A supplemental report can be used to report only the anomalies under the reporting threshold.
- **Reported Anomaly Depth and Length** – Each EMAT ILI system will have a proprietary methodology to determine anomaly depth and length. Physical SCC surface characteristics observed through magnetic particle inspection (MPI), surface grinding, or fractography should not be expected to be consistent with the reported ILI anomaly characteristics from an EMAT ILI. The ILI service provider should provide sufficient information to the pipeline operator to communicate how their EMAT ILI system translates signals into reported anomaly depth and length. It is fundamental that the pipeline operator understands what the ILI-reported anomaly depth and length represent. The translation of EMAT ILI indications to reported anomaly depth and length may have an impact on how the integrity engineering analysis is performed and how to compare in situ direct examination validation results. The pipeline operator should understand how each EMAT ILI system detects and reports crack-like anomalies that may correlate to SCC. There are a variety of ways to assess crack anomalies that can be identified as interacting. An example is outlined in CEPA. Anomalies are defined to be interacting if they are separated circumferentially by less than 0.14 times the average of the two crack-like anomaly's length, and axial spacing less than 0.25 times the average of the two crack-like anomaly's length. Other methods can be applied that may be operator dependent.
- **Estimated Rupture Pressure Calculations** – Performing estimated rupture pressure calculations should be by a competent person. If the calculations are included in an ILI deliverable, the results should be considered preliminary and further vetted as part of discovery and data integration.
- **Interlinking** – Interlinking refers to two or more crack-like defects acting as equivalent one. EMAT ILI systems may have limited capabilities discretizing individual and groups of crack-like anomalies

in close proximately. **Figure 13** illustrates how individual crack-like defects in close proximately may be represented in the EMAT data as singular grouped anomalies, and criteria for interlinking anomalies may only be applicable between two or more “groups” or “colonies”. The pipeline operator should discuss the capabilities of the EMAT ILI system for identifying and reporting interlinking anomalies.

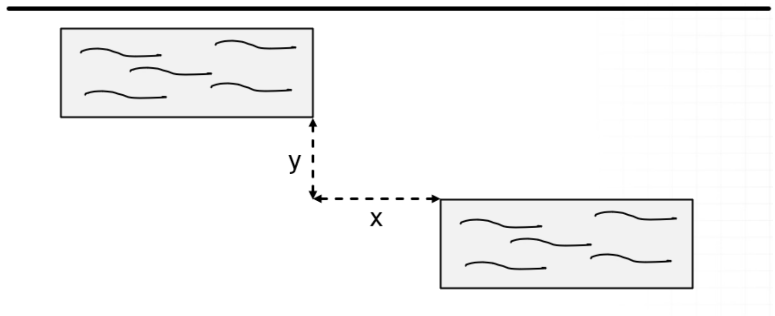


Figure 13: Interlinking Criteria

- **Nomenclature** – The pipeline operator should establish and define inspection requirements which include their nomenclature for the pipeline features (including anomalies). Each ILI service provider may have nomenclature that is unique to its EMAT ILI system to describe the results of the EMAT data analysis. The pipeline operator should identify and match the EMAT ILI system’s nomenclature as it relates to their procedures as this will impact on the integrity engineering analysis. If the pipeline operator has specified requirements for nomenclature, then these requirements should be part of the ILI system selection process and set as a project requirement. For example, ILI service provider-specific nomenclature for EMAT ILI is often categorical and limited in anomaly classifications, such as “crack-like” for singular crack-like anomaly and “crack-field” representing multiple crack-like anomalies in close proximity. In establishing nomenclature with ILI service providers, it may include additional classification options to further classify anomalies, such as “notch-like, “Linear Anomaly A” or “Linear Anomaly B” to express confidence levels in classification of crack versus crack-like anomalies.
- **Non-coverage areas** – Every pipeline segment may comprise areas where reliable detection of crack-like indications is unlikely or not possible. These areas (non-coverage areas) should be identified prior to any inspection activity. Areas of the pipeline that may not fall within the EMAT ILI system’s inspection capabilities should be recognized in the EMAT ILI system selection. For example, a short thick-wall joint may be outside the specification or geometry-related sources like girth welds, dents, and deformations.

3.4.1. Quality Gate – Section 3.4: Reporting Requirements

- Are examples of the Field Report and DQA available to review prior to the inspection?
- Does the pipeline operator understand the information presented in the Field Report and DQA?
- How will EMAT inspection performance and essential variables be reviewed?
- Are written ILI acceptance criteria established?
- Does the information presented in the Field Report and DQA suffice to achieve the inspection goals, and then ILI acceptance or rejection?
- Do the agreed reporting requirements enable achieving the goals and objectives of the EMAT ILI to be measured with the presented reports?
- How will high-confidence signals under reporting thresholds be addressed?
- Will the EMAT ILI system reliably detect and size report critical anomalies?
- Are verification digs necessary?
- Is the desired nomenclature defined?
- Are preliminary reports and/or calibration digs necessary to qualify or provide confidence in the EMAT ILI system performance?
- What is the requirement for priority notification for specific conditions?
- Is the translation of EMAT ILI signals to reported anomaly sizing understood?
- How is the signal data of reported anomalies made available for review?
- Will the estimated rupture pressure calculation be part of the reporting requirements?

3.5. ILI System Qualification

An ILI system is qualified to perform an inspection if the pipeline attributes, properties, and operating conditions are acceptable according to the essential variables by which the ILI system's performance specification was qualified. However, qualifying an EMAT ILI system for use as an integrity approach requires institutional knowledge of the particular EMAT ILI system that is based on performance validation for the targeted SCC prior to its use. Pipeline operators are encouraged to engage the ILI service providers and other EMAT ILI users throughout the qualification process to review the EMAT ILI system's historical performance.

This qualification process should be established in at least a working form, prior to ILI service provider engagement, and should include at a minimum:

- Qualification procedure and results,
- Performance specification, and
- Documented historical performance.

Each EMAT ILI system should be qualified for its respective primary essential variables and the subject pipeline to be inspected. Users with limited EMAT experience are encouraged to incorporate operator-specific qualification activities such as pull tests to facilitate familiarity with the EMAT ILI system being qualified.

When the ILI system cannot be qualified prior to inspection, then the post-ILI validation efforts should be designed to understand the EMAT ILI's actual performance to qualify the EMAT ILI system. This qualification should not be confused with the ILI verification process in Section 4, *ILI System Operational Verification,* which is intended to review the operational performance of the EMAT ILI to determine if the tool successfully operated as expected during the inspection. The pipeline operator should have a written process to qualify an EMAT ILI system for use as an integrity assessment for SCC prior to its use.

3.5.1. Historical Information

The pipeline operator is encouraged to engage ILI service providers and experienced EMAT ILI users to leverage their combined experiences. Historical information that should be reviewed and understood in qualifying an EMAT ILI system are provided below:

- Operational key performance indicators (KPIs) such as first -run success and on-time reporting
- Comparison of operational success for primary and secondary essential variables
- A record of inspection results accuracy through unity plots for pull tests/statistical data, field verified results, and destructive testing
- When applicable, consider upgrades and improvements to sensors, analysis procedures, algorithms, tool design, etc.
- Compare to prior operator experiences with the EMAT ILI service provider
- For failed runs, a review of root cause failure analyses (RCFA)
- Other pipeline operator references

Historical information will provide important insight that may be used to establish qualification activities and ILI system selection. The review of historic performance may identify operational challenges related to tool behavior such as speed excursions and challenges with analysis related to pipeline attributes, such as coating interference and non-coverage areas. When an EMAT ILI system is used for multiple pipeline segments (as is the normal case), a database of relevant data and analysis results should be established. Activities in **Section 4: ILI System Operational Verification** and **Section 6: ILI Assessment Results Validation** can benefit from integrating the historical information about the subject pipeline and the EMAT ILI system. Changes to a qualified EMAT ILI system should be explicitly communicated to the pipeline operator for review, such as tool design, specification, analysis, and/or procedures). Changes that influence essential variables in some cases may require re-qualification.

3.5.2. Quality Gate – Section 3.5: ILI System Qualification

- Was an established qualification process used to qualify the EMAT ILI system for the inspection?
- Were challenges identified in the historical EMAT information review addressed?
- Is the EMAT tool, technology, configuration, and operational capacity well suited to detect and assess the specific crack-like indications for which the inspection is intended to address (indications that may relate to SCC morphology)?
- Does the EMAT ILI system and service provider have a history of successful inspections for SCC in the pipe type being inspected?
- Are pull tests or other performance qualification efforts required prior to ILI?
- Is the inspection well-planned with adequate discussions between the operator and the ILI service provider to identify and mitigate potential issues related to previous Quality Gates?
- Are operational verification and results validation requirements understood?
- Are the responsibilities assigned respectively to the pipeline operator and ILI service provider?
- Was the EMAT ILI system qualified for the inspection?

3.6. ILI System Selection

The ILI system selection should be a result of a compatibility assessment using the Pre-Inspection Evaluation (Section 2) results and the outcomes from the quality gates. The results of the quality gates should provide the pipeline operator with an objective basis of what is known and unknown about each EMAT ILI system and its ability to meet the goal(s) and objectives of the inspection. Issues which arise from the quality gates should be reviewed with the ILI service provider and mitigative activities should be put in place and documented.

It is important to consider the overall ILI project-planning when selecting an EMAT ILI system. Circumstances may not allow for the selected EMAT ILI system to be qualified prior to ILI System Qualification. However, the operator should recognize that the EMAT ILI results may not satisfy the goal(s) and objectives for the inspection and therefore the performance of the EMAT ILI system should be validated through in situ direct examinations. The reporting requirements should have deliverables which establish that the reporting requirements should reflect the established EMAT ILI objectives are met, therefore, validating appropriate ILI system selection.

3.6.1. Quality Gate – Section 3.6: ILI System Selection

- ILI system qualification activities are well understood, defined, and planned with the ILI service provider.
- The ILI service provider should confirm gaps, inconsistencies, and/or deficiencies in the essential variables are identified and mitigated.
- Review confirms that the ILI system to be used for the inspection is consistent with that used to define the required performance specifications.
- The ILI service provider should state whether the selected EMAT ILI system can meet the written performance specification in the pipeline under the existing operating conditions, including the specific tool configuration for the proposed run.
- The reporting requirements are explicitly communicated and agreed upon with the ILI service provider.
- The goals and objectives for the EMAT ILI should be documented and agreed upon with the ILI service provider.
- The EMAT ILI system can reliably detect and report the under the critical flaw sizes for the pipeline.
- EMAT inspection acceptance criteria are established.
- A complete and accurate PLQ is available.
- A written procedure for using EMAT ILI as an integrity assessment for SCC is established.

4. ILI System Operational Verification

The objective of this section is to provide guidance on accepting an EMAT inspection and the collected data evaluated for reporting. The ILI System Operational Verification section is highlighted in **Figure 14**, and the process map is illustrated in **Figure 15**. Each sub-process would have appropriate procedural detail.

Figure 14: EMAT ILI Assessment Landscape: ILI System Operational Verification

Operational verification consists of confirming that the EMAT tool and inspection were consistent with ILI specification, objectives, and essential variables. The pipeline operator should have written procedures for operational performance verification, including acceptance criteria, sensor coverage and data quality requirements. API STD 1163 serves as the principal document for completing the ILI verification process.

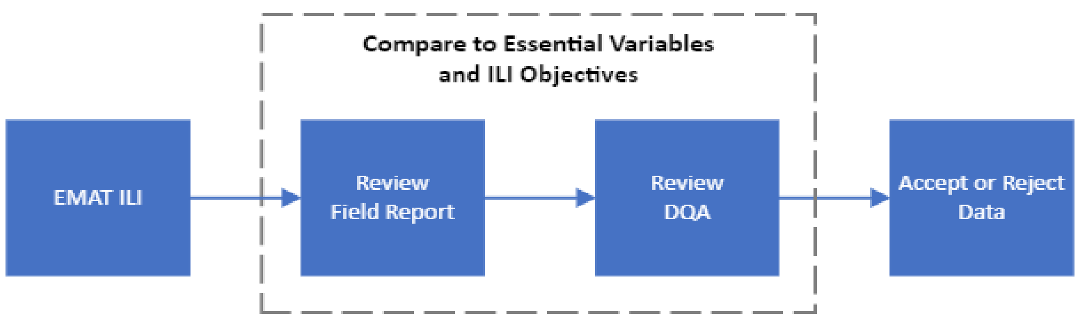


Figure 15: ILI System Operational Verification Process Map

The use of the ILI data means that the operator has verified that the inspection was successful. However, it is acceptable for only portions of the inspection's data to be verified for use. It is also acceptable for degraded data to be used with appropriate caution and risk mitigation. Supplemental data to compensate for data loss/degradation can also be used in the integrity assessment. Examples includes targeted direct examination, interrogating secondary channels on the ILI system, leveraging supplemental ILI datasets, etc. Efforts associated with the EMAT ILI operational verification process should clearly be documented.

4.1. EMAT Field Report

The EMAT Field Report is used to verify that the EMAT tool's functionality during the inspection and its ability to collect data throughout the inspection is consistent when compared to the essential variables. The Field Report typically includes:

- Information identifying the inspected pipeline segment,
- Inspection conditions including, but not limited dates, duration, product/propellant, temperature graph, pressure graph, tool velocity graph, tool magnetization graph, and tool rotation graph,
- Qualitative measure of collected data and the length and amount of collected pipeline data,
- Information regarding sensor functionality throughout the inspection within a representative graph,
- Tool condition related to cup wear, debris interference, and damage,
- Onsite pictures taken before tool launch and after extraction from the receiver,
- Tool datasheet, and
- Information related to Above Ground Marker (AGM) locations and capture during the EMAT ILI.

The pipeline operator may not have sufficient information to accept or reject the inspection. Acceptance may be contingent on the data quality assessment.

4.2. Data Quality Assessment (DQA)

Data quality assessment reports are used to review the quality and completeness of the collected EMAT data throughout the inspection. The DQA milestone is often used for inspection data acceptance. The DQA should present detailed information related to the EMAT ILI's ability to meet its stated performance specifications on a segment basis (segment-wise DQA) or on a joint basis (joint-wise DQA) for the inspected pipeline segment. Any degraded data (quality or coverage) or areas under modified performance specification should be clearly communicated by the ILI service provider. It is possible to accept degraded data or modified ILI system performance if appropriate supplemental integrity activities or risk assessment is used. The rational and supplemental activities associated with the acceptance of degraded data should be documented. The DQA should report at a minimum:

- Odometer beginning and end measurement,
- Sensor coverage as a function of distance and orientation: (e.g., complete, intermittent, or loss),
- Sensor lift-off, as a function of distance and orientation: indicating which sensors and the impact of the lift-off,
- Tool velocity,
- Performance specification related to POD, POI, Detection thresholds and sizing accuracy on a segment-wise of joint-wise basis, and

- Analyst comments regarding data quality or performance such as:
  - influence due to a primary essential variable such as wall thickness
  - signal interference due to pipeline coating system,
- degraded data and modified performance specifications due to speed excursion.

4.3. Data Degradation

There are many contributors to data degradation. However, most factors are related to sensor loss, sensor response due to factors associated with the pipeline characteristics, and inspection outside of the ILI system's essential variables. Examples of data degradation are complete data loss and data lacking sufficient quality to be properly analyzed. Data loss is when signal data is not available to perform data analysis which can be associated with sensor functionality. Data degradation is when the signal data is polluted with artifacts. Reduced data quality may not translate in insufficient quality for analysis. The data may still be valid for analysis with reduced POD and/or modified specifications. Generally, data loss or degradation cannot be determined until the data quality assessment report is delivered. In many cases modified performance specifications on a joint-by-joint basis, or similar approximate segmentation, can be derived and acceptable for use in the integrity assessment.

4.4. Data acceptance

Data acceptance requires the pipeline operator to establish that the inspection results can be used in the integrity engineering analysis to ensure the pipeline's integrity. Data may be accepted for portions of the inspection where sound data quality is achieved. The pipeline operator should agree with specified anomaly detection or take supplemental actions with the ILI service provider on the criteria for data acceptance prior to performing the ILI. As part of developing the acceptance criteria, the following questions should be vetted:

- Does sensor overlap available to reduce the impact of any potential sensor malfunction and/or degraded data?
- Does the sensor loss impact the long seam?
- Can a modification to ILI system and/or re-inspection provide the compromised data?
- Are speed excursions detrimental to the performance specification?
- Can complementary ILI data sufficiently supplement the EMAT data?
- Can a re-inspection provide a better speed profile?
- Can previous or future planned hydrotests supplement the EMAT data?
- What is the risk associated with any blind spots (e.g., downstream girth welds, weld heat affected zone, area of sensor loss, etc.)?
- Is there pipeline related signal interference (e.g., surface roughness due to internal corrosion, pipeline coating system or condition, etc.)?
- Will there be any impact on the location specific risks where data is degraded?

4.5. Quality Gate – Section 4: ILI System Operational Verification

- Project Requirements – confirm that the ILI system and operating conditions are consistent with those required to achieve the performance specification.
- Pre-inspection Requirements – confirm tool preparation activities before launching an ILI tool into a pipeline were completed and acceptable, including but not limited to, tool calibration, tool functionality tests, tool mechanical checks, and above -ground marking.
- Inspection Requirements – confirm that activities associated with ILI tool launching and receiving were completed and acceptable, including but not limited to, tool handling, tool launching, tool tracking, pipeline configuration, and on-stream operations.
- Post-inspection Requirements – confirm activities associated with the tool's operational success, including but not limited to, checking the tool's functionality, mechanical integrity, and data completeness. Note that sound data quality checks do not guarantee that the interpretation performance of the obtained data and the ILI systems ability to deliver results will be within its agreed performance specification.
- Operational Verification and Data Quality Assessment – confirm that the EMAT Field Report and DQA reporting requirements are met and acceptance criteria are achieved.
- Data Degradation – confirm that areas of data degradation have appropriate remedial actions and risk mitigations are in place.
- Comparing to a hydrotest – how do the anomalies reported compare when measured against a postulated hydrotest?
- Discovery – is sufficient information and competency available to perform the necessary verification, data quality review, data integration, and engineering assessment to issue discovery within a prescribed time period of the EMAT ILI?
- Health, Safety and Environment (HSE) - all HSE protocols and procedures were followed. Any near misses, safety issues and incidents were reported, discussed, actioned, and lessons learned captured.

5. Integrity Engineering Analysis

The objective of this section is to provide guidance on performing an integrity engineering analysis using EMAT ILI data. The Integrity Engineering Analysis section is highlighted in **Figure 16**. Integrity engineering analysis is a formal process to determine actionable anomalies, assign responses (immediate, 365-day, scheduled, and monitored), develop a dig program, and establish a reassessment interval. The integrity engineering analysis may become an iterative process of integrating data as new information is obtained, specifically from in situ direct examinations. The goal of the integrity engineering analysis is to ensure the pipeline's integrity through analysis, appropriate level of conservatism, and timely response.

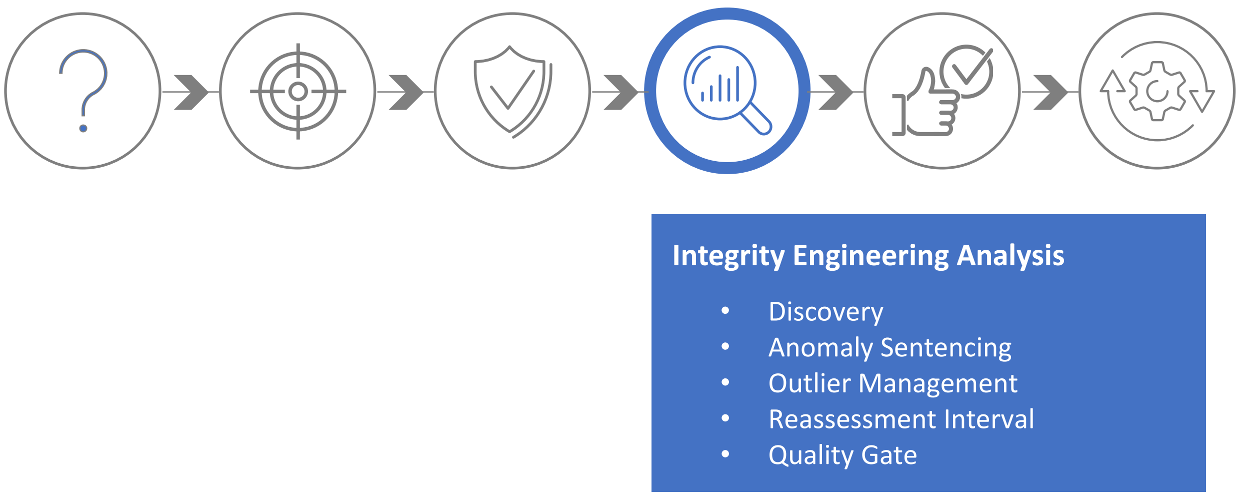


Figure 16: EMAT ILI Assessment Landscape: Integrity Engineering Analysis

Integrity engineering analysis has three main objectives.

- The first objective is prioritizing the actionable anomalies from the EMAT ILI,
- The second objective is to compare the integrity of anomalies when compared to a postulated hydrotest, and,
- The third objective is to establish the re-assessment interval through ILI Assessment Results Validation.

The integrity engineering analysis will establish anomalies' response criteria by using engineering assessment methods and data integration. The re-assessment interval will be established based on a combination of ILI performance, ILI assessment results validation, mitigation activities, and comparison to a postulated or actual hydrotest. The integrity engineering analysis is fundamental to establishing discovery as part of the ILI assessment. This section is founded on guidance from API RP 1176 and should be used alongside it.

5.1. Discovery

Discovery occurs when adequate information is available to determine if the reported anomalous conditions present a potential threat to the integrity of the pipeline. All reported anomalies that are identified as actionable anomalies will be assigned a response. The process map for establishing Discovery is in **Figure 17**. Each sub-process would have appropriate procedural detail to provide instruction. As best practice, discovery should be a product of verified ILI data quality, confidence in the reported anomalies having a propensity to be SCC and having the relevant historical data for the ILI system and pipeline to sentence anomalies. Prior to receiving the EMAT ILI report, the pipeline operator should gather and analyze relevant data for integration with the EMAT ILI reported anomalous conditions. The process of discovery should be completed in a manner based on the requirements of current regulations or internal procedures.

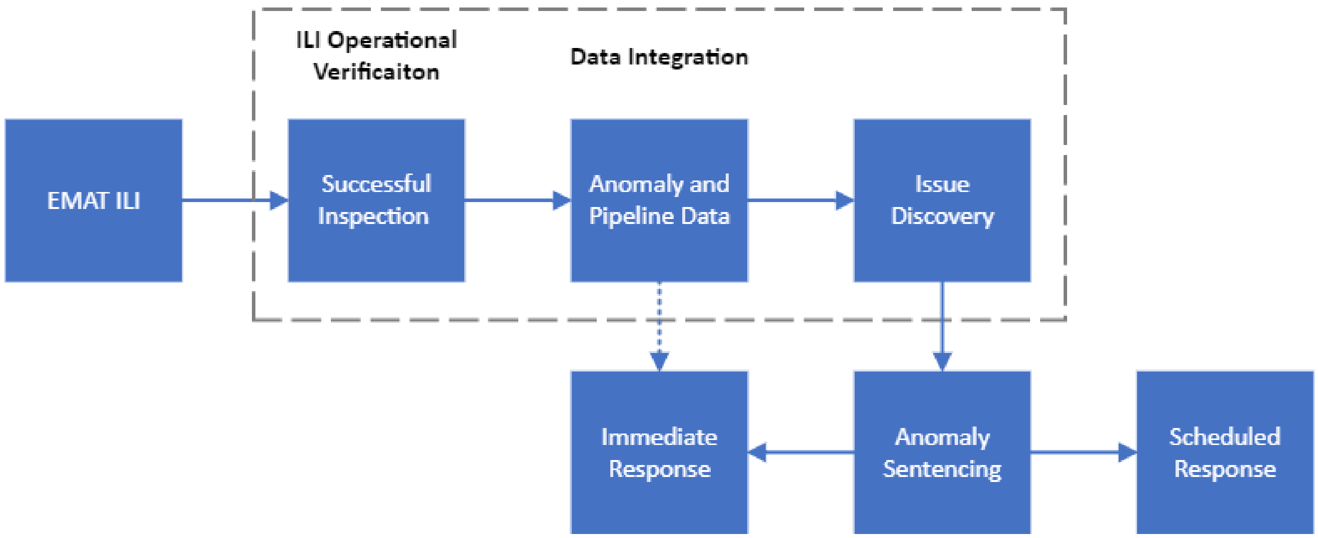


Figure 17: Discovery Process Map

5.2. Anomaly Sentencing

Anomaly sentencing is the process of determining if an ILI reported anomaly is actionable and assigning it an appropriate response. An actionable anomaly is an ILI anomaly that may exceed acceptable limits. The sentencing of ILI reported anomalies, per API RP 1176, is based on a response methodology that includes: engineering analysis, data integration process, likelihood classification, and rupture pressure calculation (using fracture mechanics or semi-empirical methods) to the ILI reported anomalies. This process combines institutional knowledge about the pipeline with the current ILI signals associated with actual pipeline crack-like defects. The institutional knowledge should be documented and evident for operating history, in-service failure history, hydrotest history (including failures), pipeline attributes and material properties, previous integrity assessments and pipeline inspections, and relevant threat specific operating and maintenance activities (see ASME B31.8S Section 4, *Gathering, Reviewing, and Integrating Data*). The process map for engineering analysis is shown in **Figure 18**.

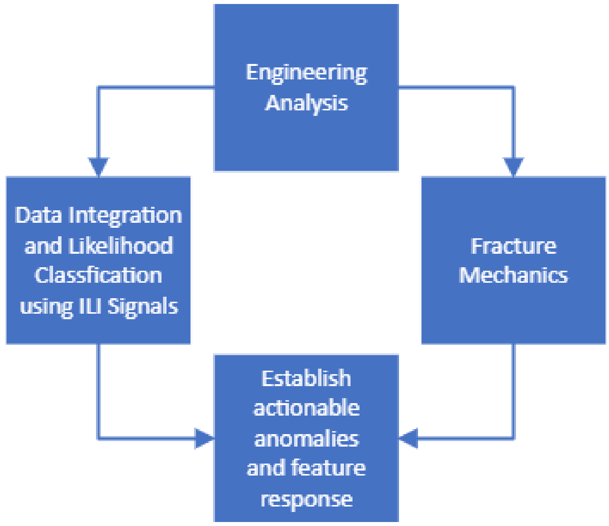
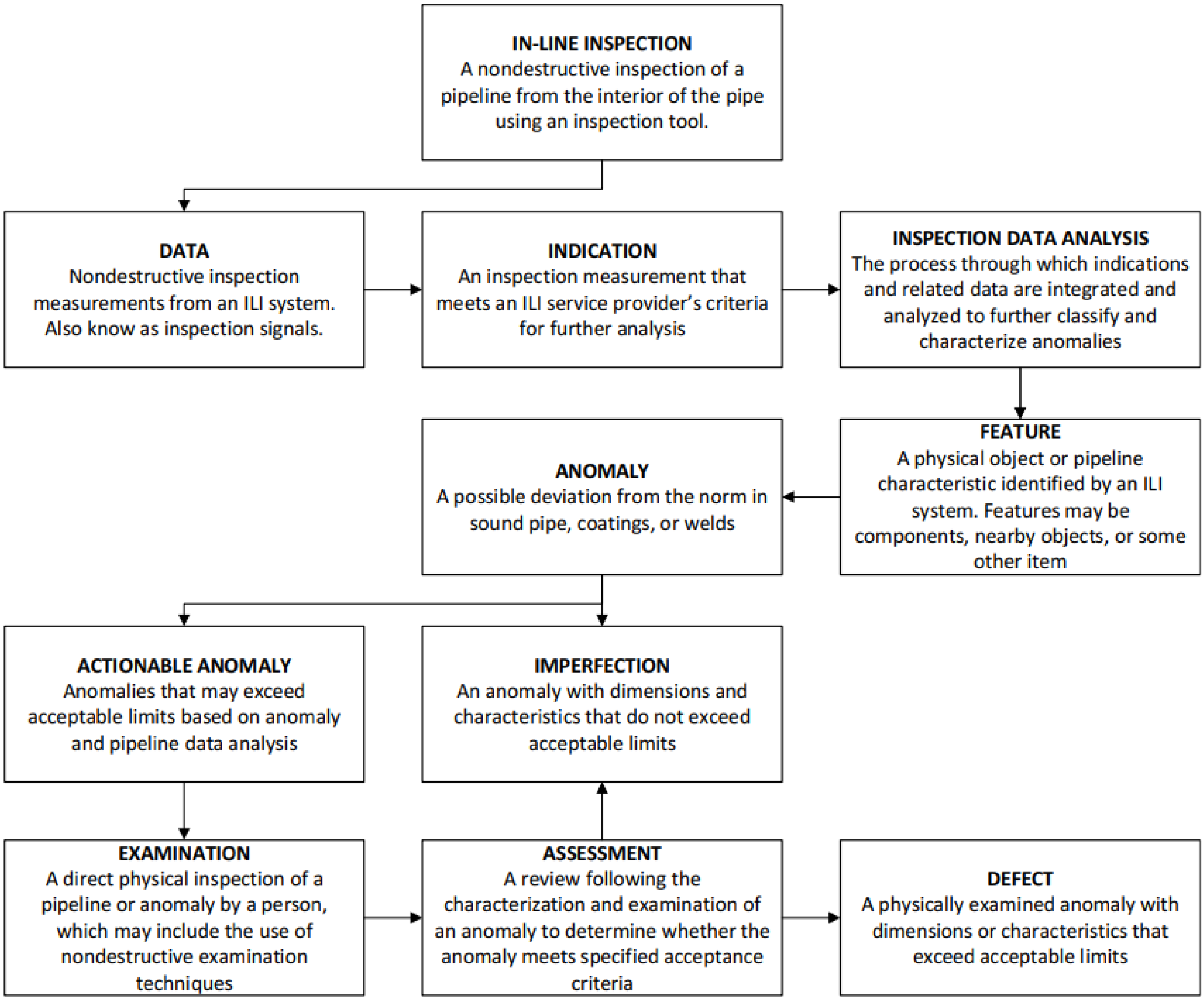


Figure 18: Engineering Analysis Process Map

API STD 1163 states that anomaly and pipeline data analysis is, "*the process through which anomaly and pipeline data are integrated and analyzed to further classify and characterize anomalies*", see **Figure 19** for a flowchart of this process. Additionally, API RP 1176 provides an ILI response methodology that, "*makes the connection between reported anomalies, their propensity to be injurious cracks, and a common set of response protocols*". API STD 1163 and API RP 1176 should be used together to establish actionable anomalies and assign responses. The process map for anomaly sentencing is shown in **Figure 20**. Each sub-process would have appropriate procedural detail to successfully complete the objective of each process.



NOTE Not all steps are required, and the order of steps may differ depending on operator requirements.

Figure 19: Inspection Terminology per API STD 1163 [2]

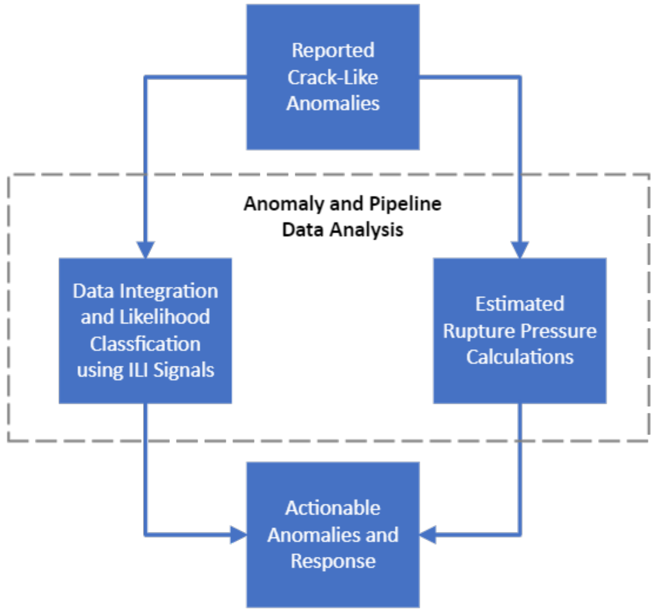


Figure 20: Anomaly Sentencing Process Map

5.2.1. Likelihood Classification

The objective of this section is to determine the likelihood of each EMAT ILI reported anomaly as it correlates to a crack or crack-like defect. The ILI service provider is responsible for translating signals (indications) into anomalies according to the agreed definitions in the Reporting Requirements (see section 3.4). The pipeline operator is responsible for performing the anomaly and pipeline data analysis to identify actionable anomalies. It is best practice for the pipeline operator to have a fundamental understanding of how the EMAT ILI system translates the signals into reported anomalies and their characteristic depth, length, and width.

Likelihood classification, per API RP 1176, is a methodology to translate a set of reported ILI anomalies, in conjunction with additional information (operators experience, susceptibility analysis, etc.), into three categories (Likely Crack, Possible Crack and Unlikely Crack) based on the possibility of the anomalies to correlate to crack and/or crack-like defect. No guidance is provided specifically for correlations with SCC. The determination of likelihood classification requires experience and knowledge in performing integrity assessments for cracking threats using EMAT ILI systems.

If the pipeline operator lacks the necessary competency or additional information, then the initial likelihood classification for reported anomalies should conservatively correlate to a high possibility of them being crack anomalies (e.g., Likely Crack). However, an outside subject matter expert (SME) can also be used to assist in classification. Institutional knowledge should be documented and based on operating history, in-service failure history, hydrotest history (including failures), pipeline attributes and material properties, previous integrity assessments and pipeline inspections, and relevant threat-specific operating and maintenance activities (see ASME B31.8S, Section 4, *Gathering, Reviewing, and Integrating Data*).

Figure 21 illustrates an example of how anomaly and pipeline data analysis may be performed to support the likelihood classification of reported EMAT anomalies in the pipe body. The likelihood classification process may be an iterative application of integrating data and reclassifying remaining anomalies.

However, as in situ direct examinations are conducted, new information is obtained to be incorporated into the classification process. The likelihood classification is described according to API RP 1176. The reader should refer to the latest edition of the recommended practice for additional details.

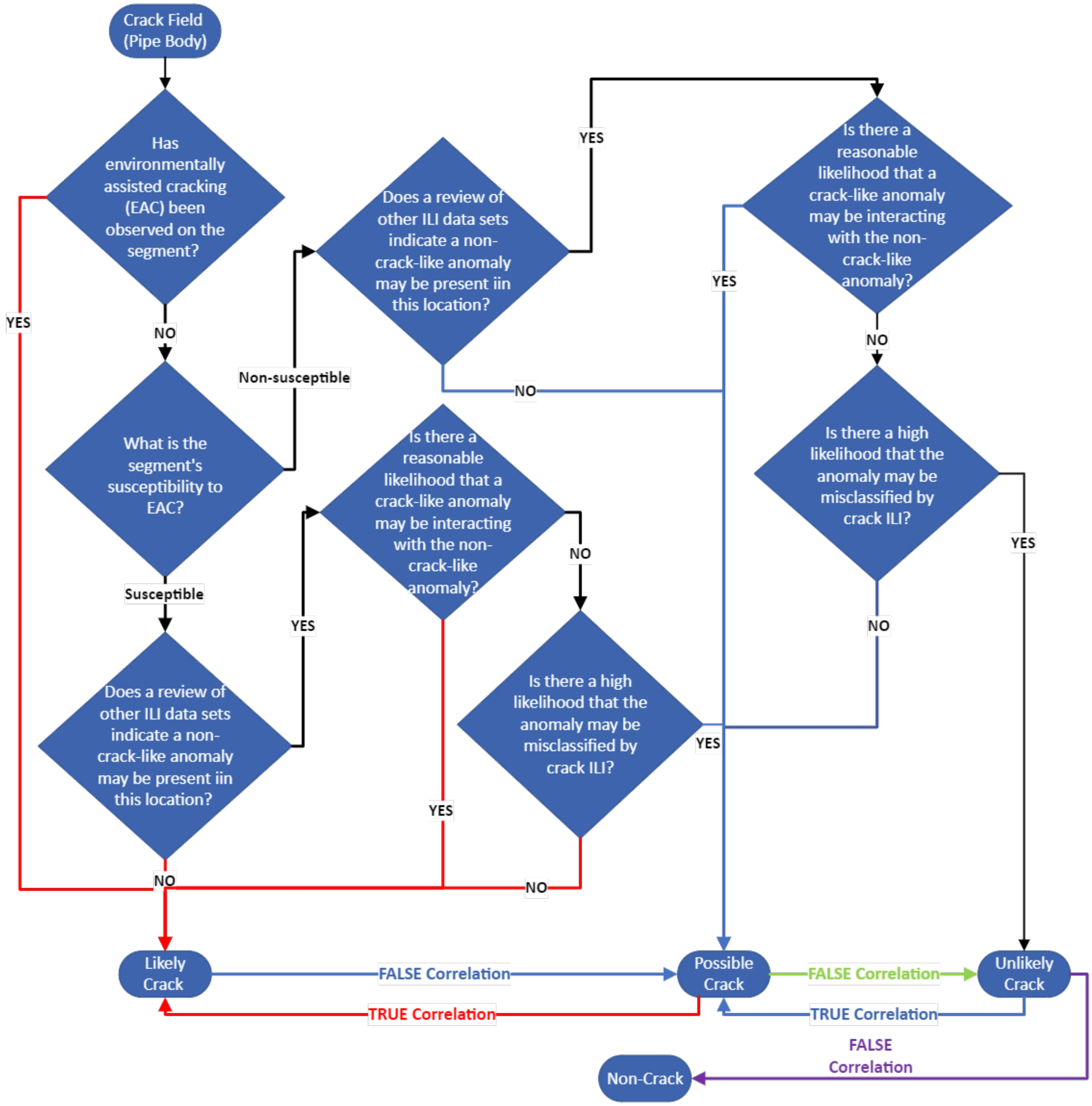


Figure 21: Example Likelihood Classification Workflow for SCC [7]

[7] Figure L.1 – ILI Response Protocol Example, API RP 1176 [4]

5.2.2. Estimated Rupture Pressure Calculations

Calculating an estimated rupture pressure (ERP), also known as burst or failure pressure, requires the use of engineering assessment methods which needs to be vetted by a competent person with experience in performing crack ILI assessments using EMAT ILI systems. The ERP calculations should be reviewed by a subject matter expert (SME). The pipeline operator should follow guidance in Section 7 *Fitness-For-Service of Crack-like Flaws* of API RP 1176 to perform ERP calculations. The pipeline operator should define the input parameters used for the FFS and an appropriate level of conservatism. The material properties used in the ERP calculations should be considered traceable, verifiable, and complete (TVC), appropriately conservative, and consistent with applicable code and pipeline regulation. The pre-defined reporting requirements should be reviewed when calculating ERP to specifically consider how the ILI service provider translates EMAT indications into reported anomaly length and depth values.

5.2.3. Time Dependency and Growth Mechanism

It is essential the pipeline operator performs an analysis as part of data integration and anomaly sentencing to derive the growth mechanism and rate(s). An analysis should also be conducted to calculate the impact of cyclic fatigue and environmentally assisted cracking (EAC) on the remaining un-remediated anomalies to define any time dependency. API RP 1176 suggests four approaches to estimating crack growth with the Uniform Average Growth Rate described as the most probable stage of growth for SCC when observed in the field, which is characterized approximately by a steady growth. The growth rate is derived from the observed depth of the anomalies divided by the elapsed time from the initiation to the present time. An initiation time should be derived, and the most severe SCC anomaly should be used.

5.2.4. Response Criteria Methodology

The pipeline operator should have a written procedure for assigning an appropriate response to actionable anomalies assessed through the discovery and before the next assessment can be maintained. The response methodology (per API RP 1176) considers the likelihood classification, reported anomaly sizing, interaction with other features, time dependency, growth mechanism (time-to-failure), and failure pressure ratio (FPR). The FPR is the ratio of the estimated rupture pressure (ERP) to the considered operating pressure (or MAOP). The ERP is calculated using an appropriate engineering assessment method.

API RP 1176 also provides guidance on assigning response conditions for EMAT ILI results. The anomalies can be categorized into four conditions; Immediate, 365-days, Scheduled, or Monitored. For details on each response condition, refer to the latest version of API RP 1176. Note that the response conditions, as defined by API RP 1176, may not necessarily have any implication in the Code of Federal Regulations (CFR) requirements.

Growth and Time Dependency – As previously discussed, it is essential the pipeline operator performs an analysis as part of data integration and anomaly sentencing to derive the growth rate(s) which will be used to sentence anomaly response. For anomalies which are classified as time dependent an analysis should be conducted to calculate the impact of cyclic fatigue and ECA on the remaining un-remediated anomalies.

Applicability of Response Conditions when also Hydrotesting – When an operator conducts hydrotesting after running an EMAT ILI, FPR-related response criteria listed above need not be followed (i.e., FPR-related excavations are not required, but may be advisable). However, where anomalies with an ERP substantially below the test pressure do not fail, FFS input parameters (e.g., hydrotest process, pressurization levels, elevation changes, etc.) should be reviewed.

5.3. Outlier Management

The response criteria in Section 5.2: Anomaly Sentencing is presented to conservatively, yet realistically, sentence actionable anomalies. However, it is recognized that managing uncertainty is an implicit task in performing an ILI based Integrity assessment. This section creates focus on analyzing the need to schedule anomalies for in situ direct examination to provide confidence in the ILI assessment by investigating anomalies with an emphasis on validating the likelihood classification, verifying any potential stable defects in the pipeline, and mitigating risk. An outlier is a defect which has significantly different physical characteristics than what was reported by the EMAT ILI system and/or a significantly different response than what was calculated. While outliers may not impact the EMAT ILI system's ability to meet its performance specification, the pipeline operator should perform an analysis that mitigates the risk associated with their potential presence. Factors to may include:

- Non-HCA pipe segments may have smaller wall thickness and tolerate shallower absolute crack depths which should be compared to the ILI performance specification.
- Vintage pipeline material may have reduced or poor-quality material properties including lower, but reasonable, material fracture toughness.
- Geo-spatial analysis of reported anomalies near structures intended for human occupancy and the impact on risk assessments.
- ILI data quality may vary from joint-to-joint based on multiple factors. However, the following influences should be directly considered: tool velocity, sensor lift-off, pipeline coating influence, and pipe material geometric homogeneity.
- ILI tool performance may not be uniform in the pipe body, long seam area, or near girth welds.
- Review of ILI anomalies below reporting threshold based on anomaly population density, physical location of the pipe, signal quality independent of anomaly dimensions, and ILI analyst comments.
- Discovery of cracking morphology through in situ direct examination, destructive testing, or failures which indicate:
    - Maximum crack depths deeper than estimated sizing by the EMAT ILI system when the associated lengths are below or near the ILI published performance specification,
    - Cracking inclination and/or orientation to be outside of the radial (α) or axial (β) tolerances of the ILI performance specification, respectively (refer to **Figure 12** in Section 3.3.2), and
    - Additional challenges for inspection where the crack-like anomalies interact with other features such as girth welds, dents, long seams, complex corrosion, etc.

One action, to rule out the tool performance, is to establish possible reasons for outliers and to ask the ILI vendor to look into the raw data and tool behavior at this location.

5.4. ILI Dig Program

The ILI dig program should incorporate the results of the previous sub-sections. A critical concept in the EMAT ILI assessment is the potential iterative application of knowledge gained as SCC are discovered and EMAT anomalies are excavated, evaluated, and compared to remaining EMAT anomalies. The in situ direct examinations should be designed to collect the necessary information to validate the ILI results, likelihood classifications, and comparison to a postulated or information from an actual hydrotest. Once an in situ direct examination performance, anomaly sentencing, and outlier management. Once the ILI assessment validation process is complete, the collected empirical data should be used in the following sub-processes on ILI Results Validation (Section 6.1) and Engineering Analysis Results Validation (Section 6.2).

A well-developed program may include several iterations of the methodology. Ideal results of the ILI assessment's dig program are the prompt and effective repair of SCC and other defects as a result of EMAT ILI and integrity engineering analysis to integrate into an overall integrity management program. The comprehensive methodology involves several steps as follows:

- Data integration and analysis of results according to predefined protocols,
- Determination of growth mechanism and time dependency of SCC,
- Determination of the likelihood that EMAT anomalies are actual SCC,
- ILI assessment validation,
- Determination of response timeline for EMAT ILI reported anomalies,
- In situ direct examination through pipe excavation and investigation of anomalies,
- Analysis of results and iterative re-application of methodology (as applicable), and
- Compare to a postulated or integrate supplementary information from a hydrotest.

5.5. Reassessment Interval

Establishing the reassessment interval should be a result of the comprehensive analysis. The reassessment interval should incorporate results from the ILI assessment results, considering the largest possible remaining anomaly in the pipeline after ILI-based remediation, a conservative and realistic SCC growth rate, and outcomes from the ILI assessment results validation. The objective of the reassessment interval should not be based on an estimated remaining life to the point of a failure condition, but rather to a conservative point before the estimated failure condition. Continual evaluation is essential to ensure that the reassessment interval remains appropriate. If an SCC outlier is discovered after the integrity assessment is concluded, then the growth rate, anomaly sentencing for EMAT reported anomalies, and reassessment interval should be reviewed and reassessed.

5.6. Quality Gate – Section 5: Integrity Engineering Analysis

- Discovery – Was discovery issued in a timely manner to address immediate integrity conditions and based on sound ILI data and sufficient relevant pipeline data to determine actionable anomalies.
- Anomaly Sentencing – Was a written procedure for determining actionable anomalies followed?

- Likelihood Classification – Were likelihood classifications performed by someone with sufficient experience and knowledge performing EMAT post ILI assessments?
- Estimated Rupture Pressure calculations – Were appropriate material properties used in the calculations? Was an appropriate methodology used to perform the calculations? Were ERP performed by a competent person?
- Response Assignment – Are the assigned responses sufficiently conservative to consider uncertainties in the ILI assessment?
- Outlier Management – Has an analysis been performed, or scheduled, to consider the risk of outliers for the ILI assessment?
- Reassessment Interval – Was an appropriately conservative crack growth rate and outcome of ILI assessment results validation used to establish the reassessment interval?

6. ILI Assessment Results Validation

The objective of this section is to provide guidance on how to validate the EMAT-based ILI Assessment results. The ILI Assessment Results Validation section is highlighted in **Figure 22**.

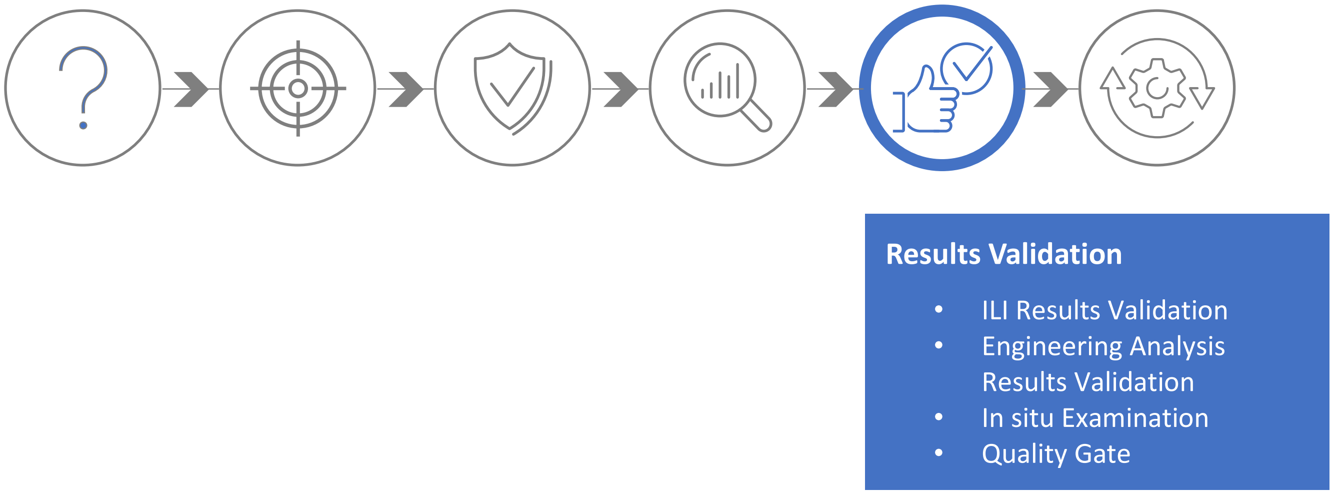


Figure 22: EMAT ILI Assessment Landscape: ILI Assessment Results Validation

The ILI Assessment is the product of the EMAT ILI, integrity engineering analysis, and appropriate pipeline remediation to integrate into an overall integrity management program. The validation program has the following four objectives:

- Validate the ILI performance.
- Validate the anomaly sentencing.
- Validate the ILI assessment achieves is comparable to or uses supplementary information from a hydrotest.
- Outlier management is appropriately addressed.

A process map showing how these three objectives are linked to the overall ILI assessment process is provided in **Figure 23**. Each sub-process would have appropriate procedural detail to successfully complete the objective of each process. The ILI Results Validation process provides confidence in the ILI's ability to reliably meet its performance specification. The Engineering Analysis Results Validation process provides confidence in the ILI assessment's ability to serve as a proxy for a hydrotest.

Each of these are divided into two sub-processes. One focused on the ILI's performance, and one on anomaly sentencing. If the goal of the inspection is not achieved, then an iteration of establishing actional anomalies is required through the engineering assessment process, or the ILI assessment is either rejected or the goal and objectives are modified. If the goal is modified, then the integrity engineering analysis is performed again, and supplemental integrity assessment(s) are considered. It is possible for the EMAT ILI performance specification to be met while outliers are discovered through in situ direct examination that require supplemental integrity-related activities to ensure the pipeline's integrity. If the goals of the inspection are achieved, then the activities proceed with those covered in the section on Continual Evaluation.

The validation program should be documented and provide acceptance criteria for validating the ILI results against the ILI Specifications and the engineering assessment. The extent of the validation program through in situ direct examination begins with the actionable anomalies derived from the section on Integrity Engineering Analysis. The in situ direct examinations should be designed to collect the necessary information to validate the ILI results, and likelihood classifications. Once an in situ direct examination performance, anomaly sentencing, and outlier management.

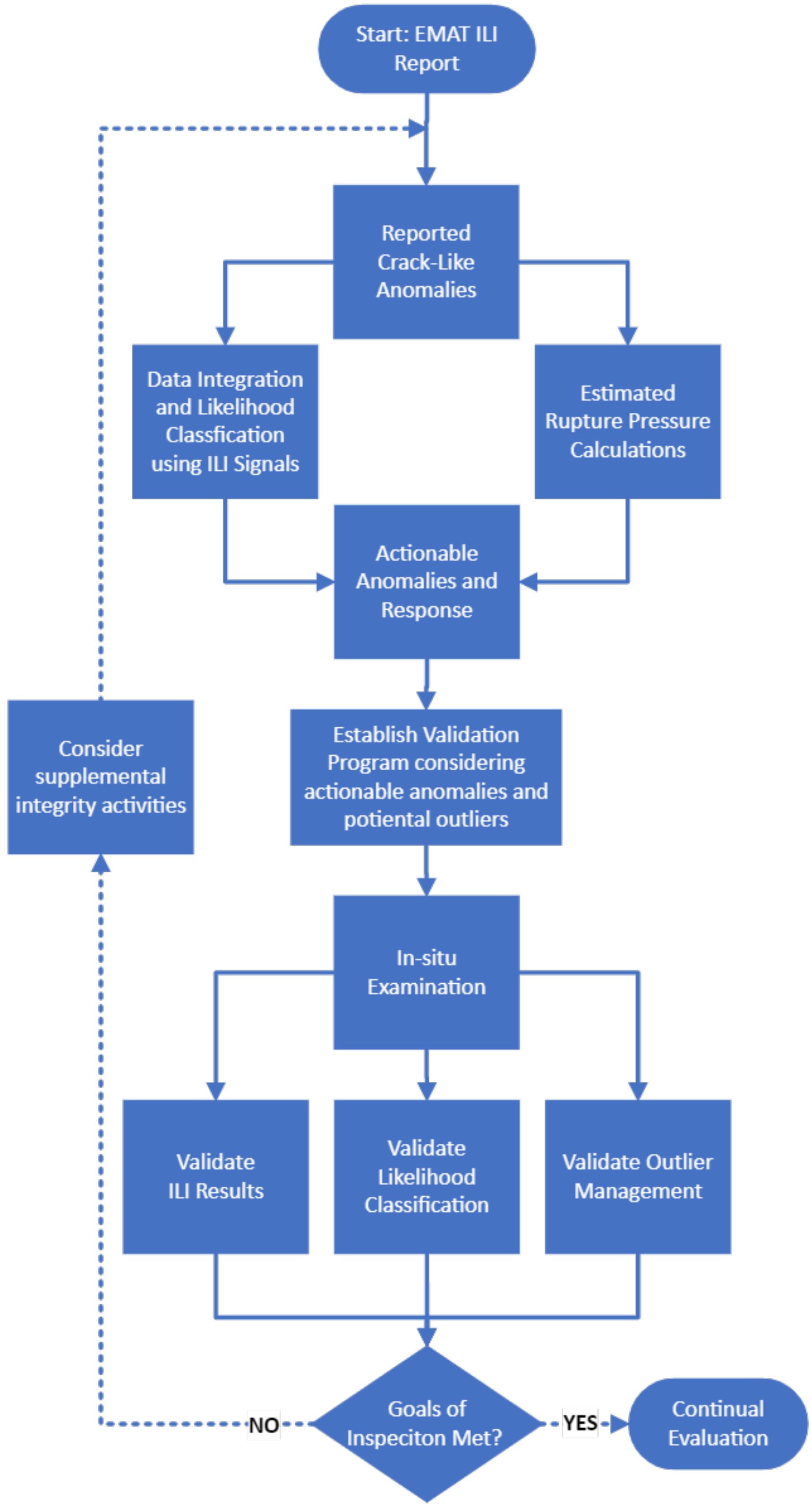


Figure 23: ILI Assessment Results Validation Process Map

The process for *System Results Validation* presented in API STD 1163 should be used as a minimum standard to validate the EMAT ILI system's performance. Objectively, the EMAT ILI results should be within the stated performance specification for the pipeline being inspected, or the actual performance of the EMAT ILI system should be established and used in the integrity engineering analysis. The validation program should define the extent of validation work, such as number of physical examinations required, how direct measurement data is collected, acceptance criteria, and assignment of who will complete the various activities and analysis.

Evaluating the results of the in situ direct examination should result in a practical understanding of the ILI performance. Three factors should be the focus of the ILI Assessment validation: EMAT ILI's ability to report on the location of crack-like defects, provide accurate characteristic data on crack anomalies, and sentence reported anomalies for remediation. **Table 2** is an example of practical outcomes from ILI assessment validation results.

Table 2: Example of Practical Results from ILI Assessment Validation

Validation	Criteria	Response
Successful	EMAT ILI assessment reliably and conservatively identifies critical defects. The EMAT ILI system, through verification, demonstrates reliable characterization of critical and near critical anomalies and is within performance specification. In situ direct examination and empirical testing results are consistent with provide confidence in the ILI assessment to establish the pipeline's integrity.	Update system of record with EMAT ILI assessment results for future use as validation data. Establish reassessment interval as appropriate. Perform continual evaluation and action improvement opportunities. Provide feedback to ILI service provider.
Acceptable	The EMAT ILI assessment reliably and conservatively identifies critical defects. The EMAT ILI system reliably detects and reports critical and near critical anomalies. However, the characterization is not within performance specifications. Additional remediation activities are required to establish confidence in the pipeline's integrity. Identify activities for continual evaluation and improvement.	Continue iterations of ILI assessment results validation through in situ direct examination and empirical testing results until the revised goal and objectives of the ILI are achieved. Perform risk assessment and consider supplemental integrity activities and assessments. Update System of Record with EMAT ILI assessment results. Establish appropriately conservative re-assessment interval. Perform continual evaluation and action improvement opportunities (i.e., opportunistic digs). Provide feedback to ILI service provider.
Un-Acceptable	ILI Assessment is not able to reliably identify critical and near-critical anomalies. The EMAT ILI system is not able to reliably detect and report critical and near-critical anomalies to make ILI Assessment practical.	Reject the ILI. Perform alternate integrity assessment, (e.g., hydrotest, re-run EMAT).

6.1. ILI Results Validation

Motivation and Selection of Validation Method

Level 1 — This level applies only to pipelines with anomaly populations that represent low levels of risk in consideration of either consequence or probability of failure. The service providers stated tool performance is utilized for this run but not proven nor disputed in the context of this run. Therefore, the validity of a run cannot be rejected on the basis of a Level 1 assessment only; escalation to Level 2 or 3 is required before a run can be rejected.

Level 2 — The validity of the ILI run results is established on the basis of comparison against other ILI run results, in either the same or a similar line. Only a very limited number or no validation measurements are performed. No definitive statement is made about the actual tool performance. Although it is possible to state with a high degree of confidence whether the tool performance is worse than the specification (and perhaps reject the inspection as a consequence thereof), the approach does not allow one to state with confidence that the tool performance is within specification. Various approaches have been proposed and some of them are further discussed in API STD 1163

Level 3 — At this level, extensive validation measurements are available that allow stating the as-run tool performance. The advantage over a Level 2 approach is that a direct link can be established between the ILI performance and the impact this has on integrity management decisions. Some broad guidelines for the statistical processing of validation measurements are described in API STD 1163

6.2. Engineering Analysis Results Validation

The level of results validation is derived from the learnings from the sections on Pre-Inspection Evaluation, ILI Operational Verification, ILI Results Validation, and Integrity Engineering Analysis. The pipeline operator should establish if the EMAT ILI can be used as an ILI assessment based on the in situ direct examination results. The initial number of in situ direct examinations and selected anomalies (both actionable and monitored anomalies) should be sufficient to establish confidence in the EMAT to use in the overall pipeline integrity management system.

In accordance with API RP 1176, the initial validation program should include a representative sample of each likelihood classification to establish statistical significance and confidence. A Level 2 validation of engineering assessment results consistent with practices in API STD 1163 is required. The in situ direct examination program should be updated as new data is obtained and integrated. An overview of the three levels of ILI validation, per API STD 1163, should be modeled in the engineering assessment results validation subprocess. Annex C of API STD 1163 provides an informative reference for calculating statistical confidence of the engineering assessment results. A process map that may be used for engineering assessment results validation is in **Figure 24**.

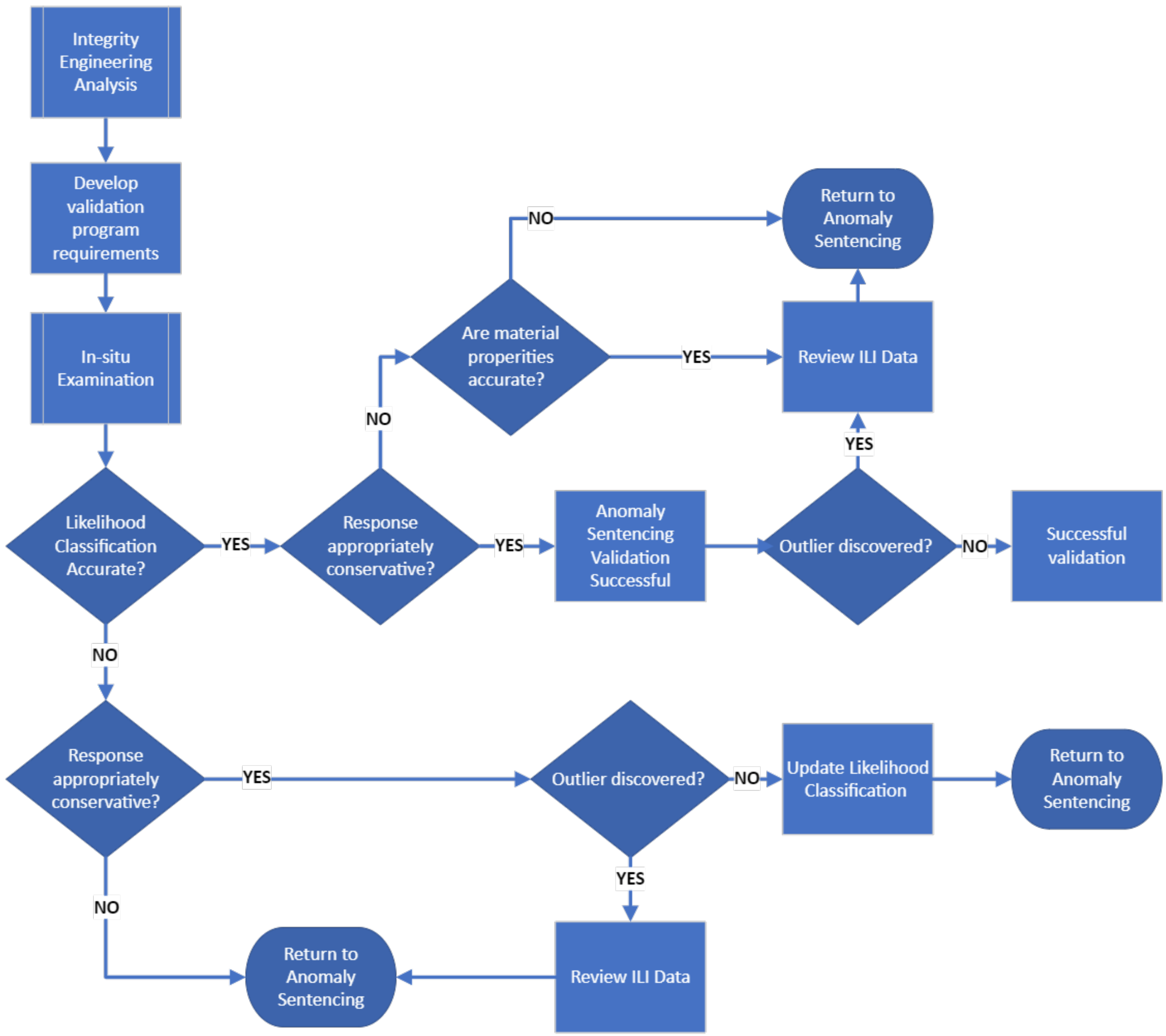


Figure 24: Example Engineering Assessment Validation Process Map

The pipeline operator's validation process and associated procedures should be consistent with API STD 1163 and should be reviewed with the EMAT ILI service provider to confirm validation efforts are appropriate for the EMAT ILI system. API STD 1163 provides three levels of ILI results validation, all of which are preceded by an ILI process verification. The recommended process is provided in this section.

Validating the EMAT ILI systems performance related to POD, POI and sizing accuracy is fundamentally dependent on the quality and accuracy of the excavation-based examination activities. Guidance on in situ direct examination (see Section 6.3) should be followed to ensure the necessary empirical data is available to perform the ILI results validation with confidence. API STD 1163 provides a process map to visualize the associated efforts (**Figure 25**). The pipeline operator should have written procedures for performing ILI results validation in accordance with API STD 1163.

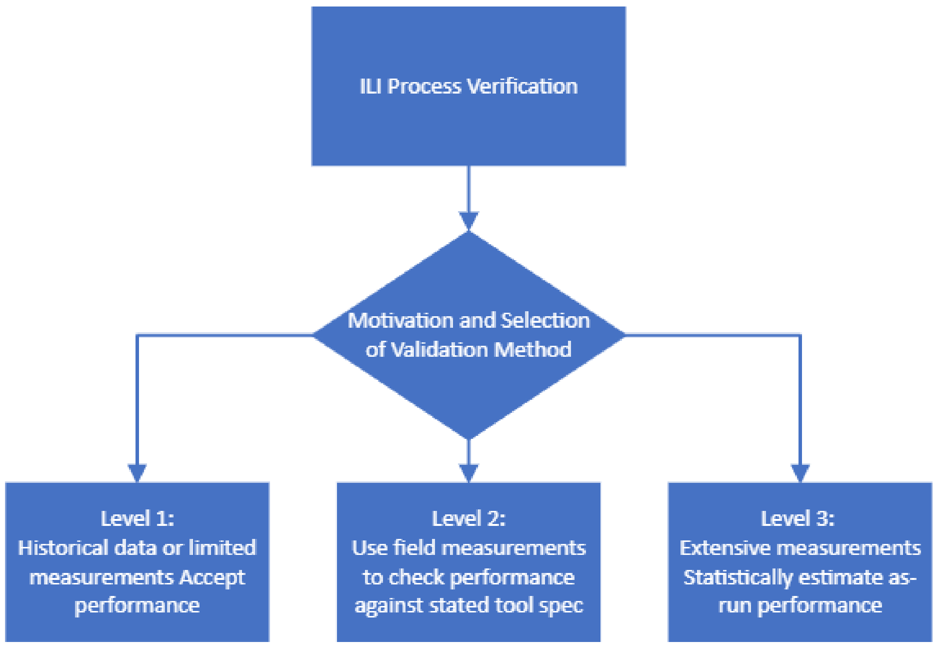


Figure 25: Overview of Three Levels of ILI Validation per API STD 1163

6.2.1. ILI Process Verification

The ILI process verification is intended to verify the ILI system operational verification process was followed. The ILI process verification should include:

- A process verification or QC of completed ILI activities,
- A comparison with historic data (if available) for the pipeline being inspected,
- A comparison with historic data or large-scale test data from the inspection system being used, and
- A comparison with limited field excavations results if warranted by the reporting of significant anomalies.

Three levels of ILI results validation can be performed and selecting the appropriate level ensures optimal allocation of integrity management resources and reduces the overall risk to the maximum extent possible. Drivers for selecting the appropriate level of validation include but are not limited to the following:

- Previous experience in the pipeline segment, or similar pipeline segment, with the EMAT ILI system:
    - Multiple lines in single operating area,

- Based on primary and secondary essential variables, and
- Considering validated EMAT ILI system performance.

- Size and severity of anomaly population.
- Risk assessments associated with the specific threats:
    - Susceptibility to threat and
    - Data integration.

Baseline ILI assessments using EMAT ILI should have the Level 2 ILI results validation requirements satisfied. Level 1 is encouraged for all EMAT ILI assessments, and when not achievable the reasoning is documented and integrated into the Level 2 ILI results validation efforts. See **Figure 26** for the requirements associated with Level 1 and 2 validation requirements according to API STD 1163. All reported significant errors in detection, identification, and sizing should be investigated. Significant errors are those that are outside the performance specification. The root cause(s) of all reported significant errors should be determined and used to modify, as necessary, the ILI assessment procedures and any iterations of the engineering assessment and actionable anomaly response. Physical examinations of all prescribed actionable anomalies provide the data and confidence to employ rigorous data driven methodologies.

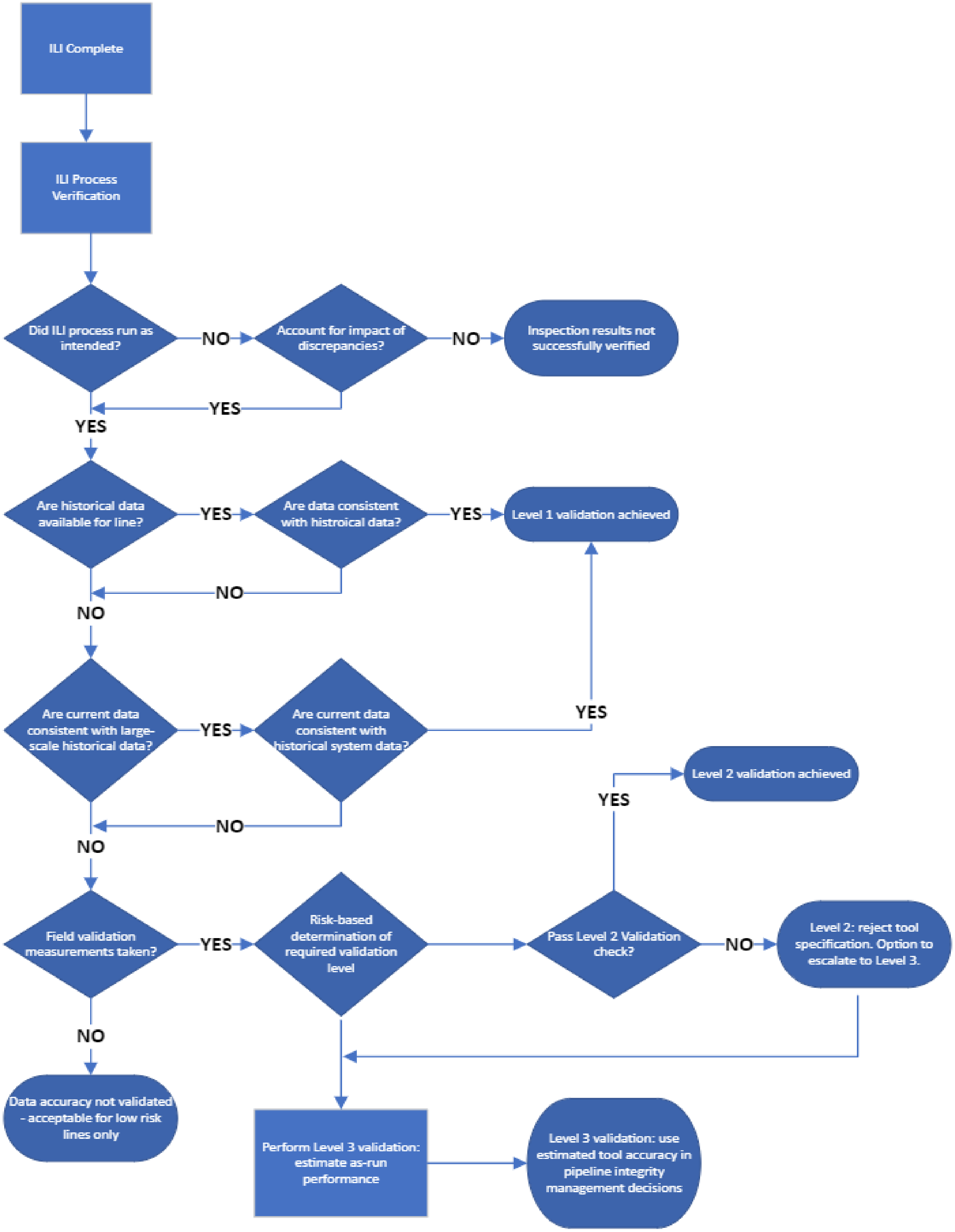


Figure 26: API STD 1163 ILI Results Verification and Validation Process

6.3. In situ direct examination

The principal objectives of in situ direct examinations are to gather data about the pipeline and integrity threat. To accomplish these objectives, a documented procedure should be defined prior to the in situ direct examination activities that uses calibrated instruments and deployed by qualified technicians. The pipeline operator should pre-define how the results of the in situ direct examination will be used as part of the ILI Assessment, considering items in Section 4 and Section 5. The program provided in this section may be used and further developed by the pipeline operator.

The pipeline operator should have written procedures for performing in situ direct examinations and qualified personnel are essential to ensure the safety and accuracy of in situ direct examination activities. These procedures should consider the applicability of pressure reduction and physical examinations.

Opportunistic in situ direct examinations resulting from normal operations and maintenance activities should be leveraged when possible as part of the pipeline operator’s continual evaluation program. The written in situ direct examination procedures should be shared with the ILI service provider to ensure that the activities can be appropriately evaluated against the EMAT ILI data and results. Assignment of examination and review activities may require agreement between the pipeline operator and ILI service provider. These responsibilities should be agreed in advance and incorporated into the written procedure. The results of examinations should be documented and summarized in a manner that facilitates integrating results into the integrity assessment and support continual evaluation (e.g., Guidance in SCC JIP 2 and API RP 1176 should be used as a reference until sufficient experience, institutional knowledge, and procedures are developed for in situ direct examinations). An example process map for in situ direct examination is provided in **Figure 27**.

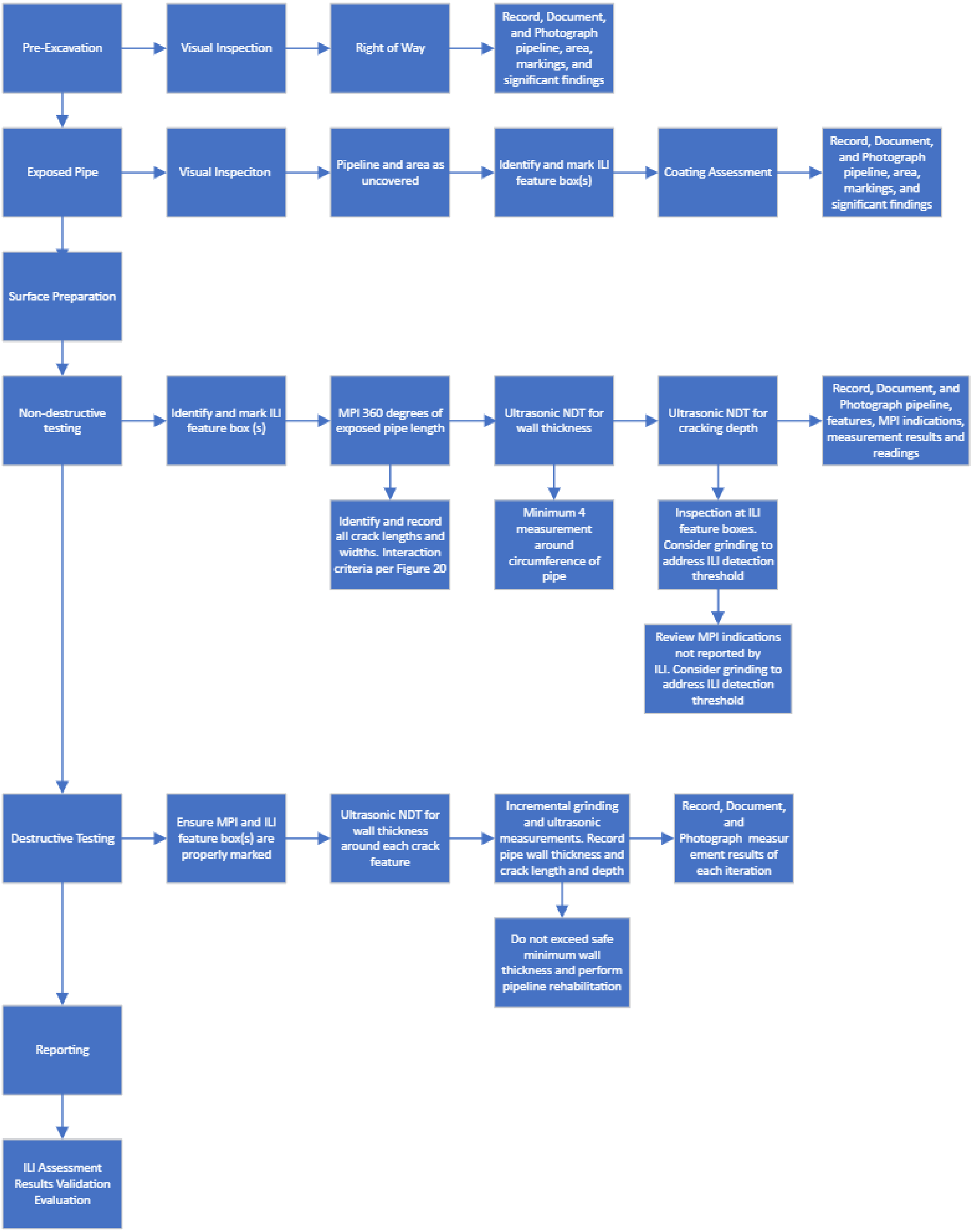


Figure 27: In Situ Direct Examination Process Example

Understanding false-positives and false-negatives are fundamental for successful ILI validation process, and the basis for more accurate integrity engineering analysis. The following lessons learned should be incorporated into the in situ direct examination procedures to gather and assess data to perform the ILI Assessment results validation:

Visual Inspection

Visual inspection of the pipeline pre- and post-surface preparation is fundamental to the in situ direct examination. Photographs are a crucial element of the visual inspection and should be incorporated continuously throughout each stage of the in situ direct examination program.

Coating Assessment

A coating assessment may be required as part of section ILI System Operational Verification and on the objectives of the ILI. The pipeline's coating system and overall coating condition should be documented. NACE SP0204 [31] provides references to describe the coating condition. For anomaly-specific validation, the coating assessment at the location of the target EMAT anomaly should be photographed and documented. The ILI service provider should provide input to the in situ direct examination procedure.

Non-Destructive Examination (NDE)

NDE technologies have an inherent uncertainty associated with the results which present challenges when validating a crack ILI assessment. Only pipeline operator qualified technologies, procedures, and technicians should be used to validate ILI assessments. There are significant advantages when NDE technologies are complemented with buffing activities as described in Appendix A for ILI assessment validation. Each pipeline operator should have an established NDE qualification program.

Magnetic Particle Inspection (MPI)

MPI is the current basis for in situ direct examination for SCC on the external pipe surface, including welds. The inspection can be completed using dry power MPI (DPMIP), wet visual MPI (WVMPI), wet fluorescent MPI (WFMPI), or black on white MPI (BWMPI). Appendix C of NACE SP0204 provides additional informative material. Performing MPI on the full pipe circumference and length will provide data and appropriate confidence in the ILI assessment for SCC. The pipeline operator should invest time in the in situ direct examination to identify and confirm all true-positive, false-positive and false-negative EMAT anomalies. Other technologies capable of evaluating the pipe surface and providing reliable identification, such as MPI, may be used.

Long Seam and Pipe Body Examination

Long seam examination should provide conclusive information about the pipe type, long seam orientation, and manufacturing process. A full circumference inspection of the pipe body should be performed to reveal and record any cracking. Inspection results for cracking should be documented before and after any type of surface buffing. Metallography and hardness testing can be used to establish the long seam attributes. MPI, or qualified NDE, should be used to determine the presence of external cracking and its characteristic length. Iterations of MPI and buffing have proven to be a reliable practice for ILI assessment results validation through in situ direct examination. NDT methods may be used once sufficient data and experience is available to qualify the technology, technicians, and procedures. Pipeline operators should take advantage of EMAT ILI validations that use iterative buffing to validate the NDT methods. NDT results for cracking should document the surface before and after any type of buffing. If no defect or pipe imperfection is not discovered at the EMAT reported anomaly location, then the pipeline operator should pursue identification and understanding of the cause for the response from the EMAT ILI system.

6.3.1. Pipe Body Examination

Examination of the pipe body can include a program of destructive or non-destructive techniques. A full circumference inspection of the pipe body should be performed to reveal and record any cracking. MPI should be the basis for establishing the presence of external cracking and its length, or other qualified NDT.

Iterations of MPI, or qualified NDT, and grinding is the best practice for ILI Assessment Results Validation. **Table 3** provides a summary of the variables and definitions used to determine the crack length and depth.

Table 3: Definitions of Crack Dimensions

Dimension	Description	Procedure
Crack Length		
Lm	Length of a surface breaking crack identified using NDE.	Perform MPI and use NDT such as caliper, tape measure, ruler, or camera system to measure length of crack anomaly.
Li	Length of each surface breaking crack after griding to accommodate EMAT ILI detection threshold. Where "i" is a number assigned to each crack, as shown in **Figure 28**.	Record the wall thickness removed to account for EMAT ILI detection threshold using NDT. Perform MPI and used NDT such as caliper, tape measure, ruler, or camera system to measure length of crack anomaly.
La	Length of surface breaking crack after grinding to accommodate EMAT ILI detection threshold and interlinking criteria applied.	Record the wall thickness removed to account for EMAT ILI detection threshold using NDT. Perform MPI and used NDT such as caliper, tape measure, ruler, or camera system to measure length of crack anomaly.
Crack Depth		
Di	Depth of surface breaking crack where "i" is a number assigned to each crack, as shown in **Figure 29**.	Record the wall thickness removed to account for EMAT ILI detection threshold using NDT. Perform MPI and use NDT such as ultrasonics, eddy current, x-ray, or CT scan.
Davg	Average depth of crack or interacting crack anomalies in a defined area.	Best practice is to perform iterative grinding followed by ultrasonic wall thickness measurements until cracks are removed from the pipe wall, or destructive testing. A qualified in situ NDT can also be used.

In situ direct examination using grinding is preferred if operating conditions and pipeline conditions are safe to do so. The iterative process of measuring the remaining wall thickness, performing MPI, and exercising sanding can deliver the accuracy and empirical data to validate the ILI Assessment Results. Secondly, if the appropriate criteria are met, grinding can serve as the pipeline repair. Each pipeline operator should develop their own procedure which considers the specific details for their pipeline, operations, competency, and target defect. While this topic is outside of the scope of this JIP, Appendix A provides an example procedure for grinding which was gathered during the interview stage of the project. There are other alternatives and operators may have their own procedures that should be followed.

Crack Length

The crack length can have several interpretations. The pipeline operator should align with the ILI service provider and NDT technician on the various length interpretations to ensure appropriate data collection and comparison. Targeted crack lengths are illustrated in **Figure 28** for reference. The length interpretations from the in situ direct examination may be compared to the reported crack length.

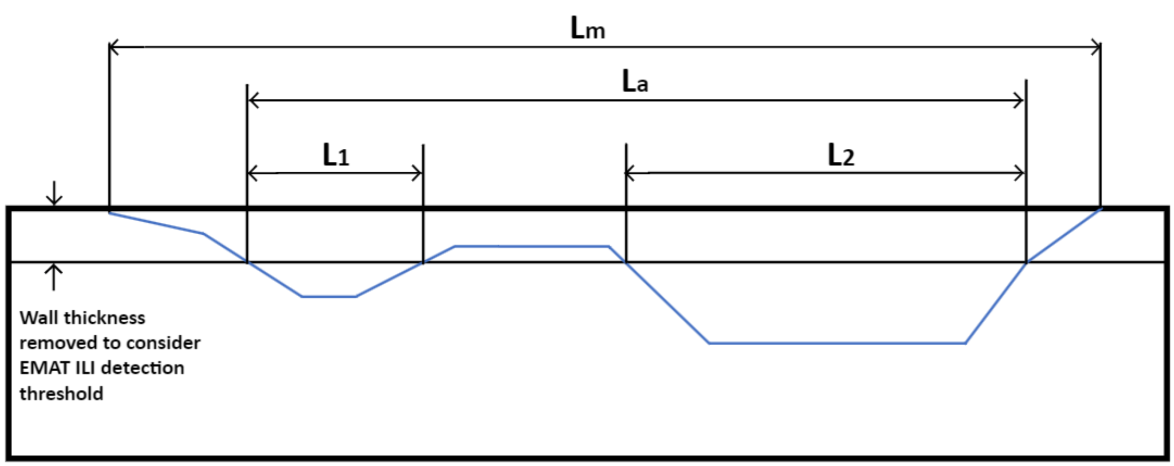


Figure 28: Relevant Crack Length for ILI Comparison

To establish the length profile, an iterative process of performing MPI and grinding can be used. Key steps include:

- Perform minor incremental grinding to remove the metal associated with the EMAT crack-detection threshold, to a depth communicated by the ILI service provider,
- Perform MPI, or qualified NDT, to the inspected area and any reveal any cracking,
- Measure the maximum interlinked individual crack length, "Lm", using appropriate interaction rules, (e.g., CEPA, API 579, and BS 7910) to determine whether to aggregate closely spaced cracks.
- Then compare the interlinked crack length, "Lm", with the EMAT reported crack length. The comparison should also consider the EMAT sizing tolerance given in the ILI performance specification.
- If "Lm" is within the tolerance of the EMAT reported crack length, then the crack length measurement is satisfactory. If "Lm" is outside the tolerance of the EMAT reported crack length, then the crack length measurement is unsatisfactory.

Note: There may be difficulty in aligning NDE defect depth to the EMAT determined anomaly depth. NDE often overstates the length due to the difficulty of determining the start and end points of a defect as it returns to the base material due to wall thickness variations, uneven surfaces, or operator techniques.

Crack Depth

The physical crack depth can be measured using destructive or non-destructive testing. The pipeline operator should align with the ILI service provider and field technician(s) on how to perform in situ direct examination for crack depths that will be compared to the reported EMAT anomaly depths. This will ensure the quality of the validation activities. The inspection window of an EMAT ILI system can vary between ILI systems (i.e., each ILI service provider may have a different implementation of the EMAT technology) and is directly related to the EMAT sensor's physical dimensions, sensor configuration, and sensor technologies. Therefore, the inspection window has a direct influence on reported dimensions. For example, the average crack depth measured across the length of the EMAT inspection window may be the best comparison of in situ direct examination depth measurements to the reported EMAT anomaly depth. This example is shown in **Figure 29**.

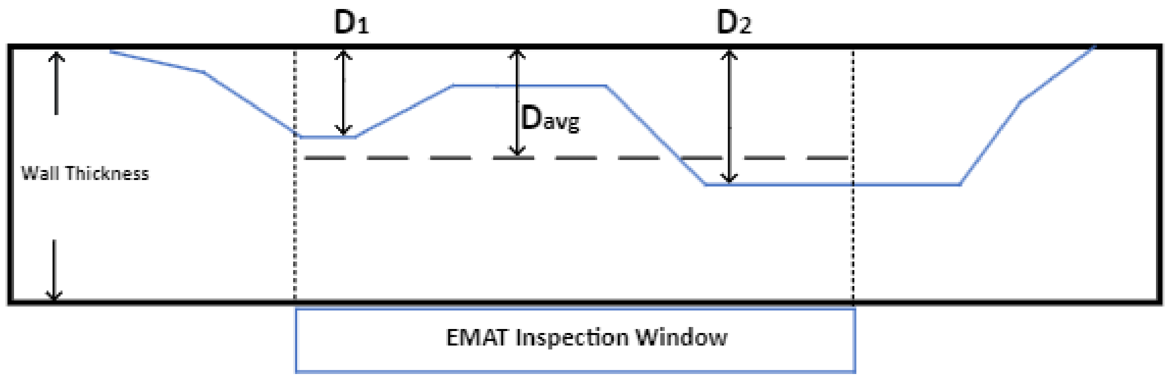
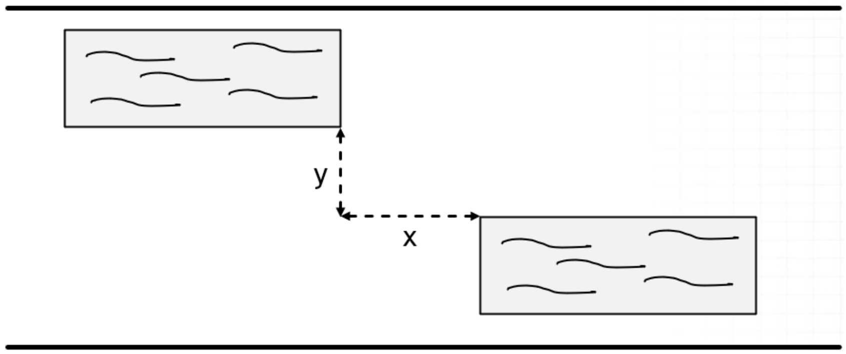


Figure 29: Relevant Crack Depth for ILI Comparison

After aligning with the ILI service provider on how to collect the in situ based crack depth, compare it with the corresponding anomaly depth in the EMAT ILI report. A unity plot of verified measurements should be used to determine ILI performance in accordance with the in situ interlinking depth is within the tolerance of the EMAT reported depth, then the EMAT reported crack depth measurement is satisfactory. If in situ interlinking depth is outside the tolerance of the EMAT reported depth, additional techniques (destructive testing to expose the crack faces) can be used to determine if the EMAT report depths are satisfactory.

Crack interaction

Crack interaction is when two neighboring crack defects on the pipeline, as seen below, with circumferential distance, **"Y"** yield a true statement in **Equation 1** and the axial distance, **"X"** yields a true statement in **Equation 2**. The variables **"L_1"**and **"L_2"** are the individual crack lengths being considered for interaction.



Equation 1: Circumferential Interaction Criteria

$$Y \leq 0.14\ \frac{(L_1 + L_2)}{2}$$

Equation 2: Axial Interaction Criteria

$$X < 0.25\ \frac{(L_1 + L_2)}{2}$$

This is one example [5], there are other methods that can be used (e.g., API 579 [13], BS 7910 [32]).

6.3.2. Reporting

A comprehensive in situ report should provide documented data and information to verify that the agreed procedure for collecting field data was followed. Insufficient documentation of in situ activities may limit the data's usefulness to validation processes or in future assessments.

- ILI dig sheet
- Pre-work ECA and defect assessment
- Results from coating assessment, including ILI call
- Results from NDT, including ILI call
- Results from each of the grinding iterations document with measurement and photographs
- Rehabilitation method used as primary validation method (i.e., grinding repair or destructive testing)?
- How were non-destructive testing technicians qualified to perform in situ assessments? a different classification?
- Are growth rates applied for scheduled anomaly response conservative and based on empirical data?
- Do the validation efforts provide confidence that the EMAT ILI system is successfully reporting crack and crack-like anomalies (such as SCC) and characteristic data to complete the integrity assessment?

- Was a comparable acceptable level of a postulated hydrotest achieved?

6.4. Quality Gate – Section 6: ILI Assessment Results Validation

- Is a written process and associated procedures established for ILI results validation?
- Has the EMAT ILI service provider provided input and agreement to the written validation processes and procedures?
- Can empirical data be gathered and used as primary validation method (e.g., grinding repair or destructive testing)?
- How were non-destructive testing technicians qualified to perform in situ assessments?
- Have the validation results been shared with the EMAT ILI service provider for feedback and continuous improvement?
- Are conservative likelihood classifications assigned until sufficient empirical data is available to integrate and substantiate a potential re-classification?

7. Continual Evaluation & Improvement

The crack management program should leverage the activities and lessons learned associated with the ILI assessment to identify opportunities for continuous evaluation and improvement for both the pipeline segment and the EMAT ILI system. As shown in **Figure 30** the continual evaluation and improvement efforts are located at the end of the ILI assessment process map.

Figure 30: EMAT ILI Process Landscape: Continual Evaluation and Improvement

Continuous evaluation and improvement activities should be sufficiently frequent, and documented, to address new and relevant information prior to the next integrity assessment. This will ensure that the time dependency of the SCC threat was properly addressed, and that the accuracy of the integrity assessment is sound. The pipeline operator should document the details of the continual evaluation that considers at minimum the results from the processes mapped in **Figure 31**.

Sharing lessons learned and continuous improvement with the ILI service providers is essential for EMAT technology development. The ILI service providers should recognize their responsibilities in supporting pipeline operators with their continuous evaluation efforts. For example, if opportunistic digs have revealed critical information about EMAT callouts or discovery of defects not detected by the ILI, then additional EMAT data analyst support may be required.

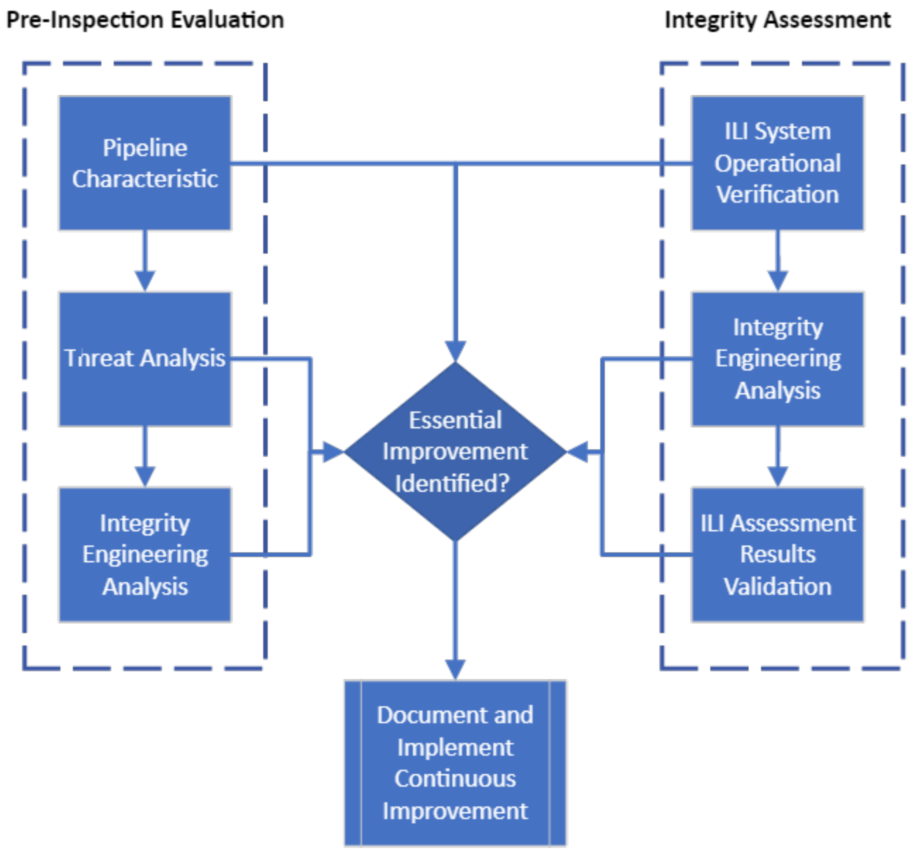


Figure 31: Continuous Evaluation and Improvement Identification Process

7.1. Quality Gate – Section 7: Continual Evaluation & Improvement

- Are material properties traceable, verifiable, and complete (TVC)?
- How will TVC activities be incorporated into the integrity assessment results and planning?
- How will opportunistic excavations be leveraged to support the integrity assessment results?
- How will continuous evaluation be managed to ensure new data is integrated and necessary response taken?
- Are the requirements continuous evaluation and improvement activities documented?
- Does a framework exist between the pipeline operator and ILI service provider for continual evaluation and improvement?
- Is risk appropriately evaluated to determine appropriate response to continuous improvement and evaluation findings?

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Appendix A: Commentary on Examination and Repair by Grinding

In situ direct examination using grinding is preferred if operating conditions and pipeline conditions are safe to do so. The iterative process of measuring the remaining wall thickness, performing MPI, and exercising grinding may deliver the accuracy and empirical data needed to validate the ILI assessment results. Secondly, if the appropriate criteria are met, grinding may serve as a pipeline repair. Each pipeline operator should develop their own procedure which considers the specific details for their pipeline, operations, competency, and target defect.

The following is an example of performing direct examination and repair using grinding. Other approaches can be used, and useful guidance can be found in the PRCI Repair Manual [33]. Often operators will have their own procedure that needs to be followed.

Example:

<u>Safe working pressure</u>

A safe working pressure should be determined by a competent person and the appropriate pressure reduction should be in place prior to work activities.

<u>Grinding Profile</u>

The grinded area should have a minimum slope of 4:1 (length and width-to-depth ratio). If the crack defects were removed by grinding no deeper than 0.060 inch in a 0.312 inch nominally thick pipe (see **Figure A1**), then the grinded area is transitionally ground smooth in all directions such that the nominal wall thickness exists no closer than 0.240 inch to the deepest part of the sanded area (see **Figure A2**). Transitioning the grinded area over a wider surface area of pipe is acceptable and may reduce stress concentration. This approach is consistent with industry best practices.

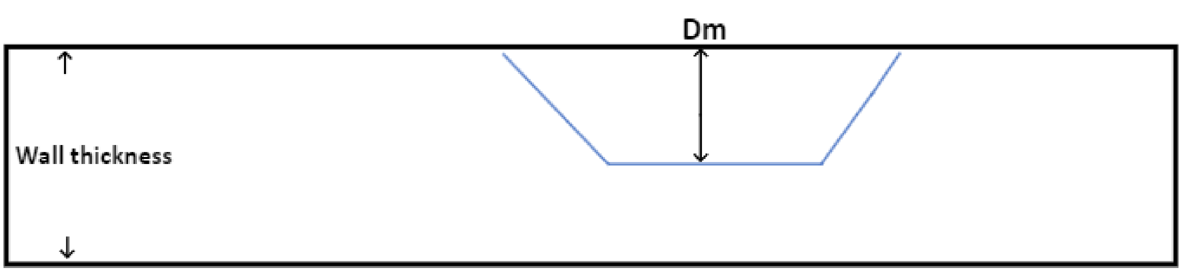

Figure A1: Example Crack Profile of depth D_m

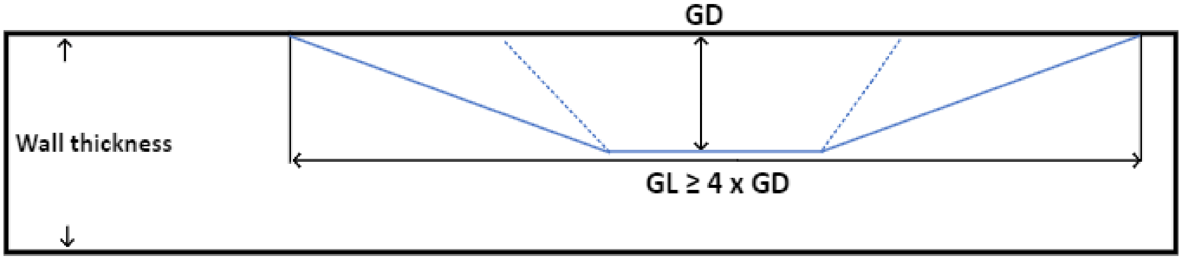

Figure A2: Example Grind Profile of depth G_D and length G_L

Grinding Technique

Generating excessive heat should be avoided and appropriate mitigation practices should be in place. A light to moderate pressure technique should prevent generating excessive heat in the pipe. Surface oxidation or bluing of the grinded area is an indication of excessive heat. Angle the flexible sanding disc approximately parallel to the pipe surface, and do not exceed an angle of 45° from the pipe surface. Remove metal in a circumferential direction or perpendicular to an axial oriented crack defect.

Grinding for Crack Removal

Prior to performing any grinding activities on the pipeline, an engineering critical assessment (ECA) for the discovered crack defects should be performed to ensure the pipe is safe for work. Additionally, in anticipation of the resultant metal removal by grinding, a metal loss defect assessment considering the expected remaining wall thickness should be performed to determine if the pipe is expected to be repaired by grinding or require rehabilitation. A competent person should perform the ECA and defect assessment prior to working on the pipeline. Grinding is exercised with caution at increments less than 5% of actual wall thickness, to not introduce excessive heat or stress risers into the pipe wall, and not using rigid grinding discs or rotary grinding tool.

The following activities are performed between grinding iterations:

- Measure the remaining wall thickness using ultrasonic wall measurement non-destructive testing.
- Perform MPI.
- Measure and document the crack or crack-like defects length.
- Calculate the safe working pressure.

NDT to measure cracking depth may be used to support the decision-making process to continue grinding activities and justify safe working pressures.

Grinding to remove crack defects up to a depth of 10% of the nominal wall thickness is allowed and is not limited to crack length being removed.

Grinding to remove crack defects up to 40% of the nominal wall thickness may be allowed if an engineering critical assessment of the failure pressure for the crack or crack colony is acceptable.

A remaining strength calculation using B31G for metal loss should be documented before grinding repairs begin to establish the maximum allowable removal of pipe wall metal. The estimated length of area to be grinded and 40% depth of actual wall thickness should be used in the B31G calculations, considering the grinded area profile requirement.

If B31G calculations fail, RSTRENG may be used. If RSTRENG fails using the estimated dimension of metal loss, then no grinding should be permitted.

If, during grinding, the direction of the crack defect changes and both length/opening increases, or the field personnel have questions, then the grinding should be stopped, and activities re-evaluated.

After crack defects are removed by grinding, the pipe may be considered repaired if a competent person confirms the remaining wall thickness material is sound to operate at the maximum allowable operating pressure (MAOP), including appropriate safety factors. A comprehensive engineering analysis should be conducted that considers factors that may potentially impact the accuracy of the calculations, including interacting defects, secondary loading, proximity to longitudinal seams or girth welds, manufacturing or construction related imperfections, and/or any other potential interactions within the pipeline material.

Grinding to remove cracks greater than 80% depth may be permitted on a case-by-case basis if pipeline pressure is lowered to a pressure near zero or an engineering assessment by a competent person provides evidence it is safe to grinding up to 80% of pipe wall thickness.