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Engineering Critical Assessment to Reconfirm Maximum Allowable Operating Pressure of a Pipeline System

API RP 1194

First Edition, XXXX 2027

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Special Notes

This document contains guidance for use when completing an Engineering Critical Assessment (ECA) for reconfirmation of the maximum allowable operating pressure (MAOP) of a pipeline. The guidance herein is based on the contributions of Subject Matter Experts (SMEs) and is intended for use in evaluation of pipeline features and integrity conditions within a comprehensive engineering analysis process designed to be an alternative for internal pressure testing (i.e., pressure testing at a pressure higher than the intended operating pressure) to establish fitness-for-service at a desired MAOP. This guidance was developed in alignment with the U.S. regulatory code Title 49 CFR 192.632 that allows such an analysis for reconfirmation of MAOP of gas transmission pipelines; however, it can be used when assessing other non-gas steel pipelines or in other jurisdictions. The following is intended to provide technical guidance and options for consideration in data gathering, quality assessment, and choice of appropriate fitness-for-service models for relevant threats. Operators should evaluate applicability and alignment of this RP within their organization including compliance with procedures, practices, and appropriate system conditions. It should also be noted that operators may require additional technical interpretation for compatibility with regulatory requirements of applicable jurisdictions. The information presented herein does not constitute a guaranty of the quality, capacity, safety, or fitness-for-service of any pipeline.

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Foreword

[will be populated with latest boilerplate language prior to publication]

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Introduction

This Recommended Practice (RP) provides guidance to the pipeline industry on the use of fitness-for-service (FFS) approaches for reconfirming maximum allowable operating pressure (MAOP) for pipelines and pipeline facilities, including line pipe, non-line pipe, and other pressure-containing components integral to the pipeline (e.g., flanges, valves, fittings, bends). Note pressure vessels, tanks and non-pipe assemblies are not within scope of this document. The purpose of this RP is to provide a structured process for demonstrating that a pipeline or pipeline facility is free from injurious anomalies or features that could compromise integrity, and to confirm that remaining features have a failure pressure ratio (FPR) that supports safe operation at the intended MAOP with a margin of safety appropriate for its location. Where conditions or anomalies are present that could reduce this safety margin, the operator is expected to apply appropriate mitigation, repair, or replacement measures to restore integrity of the asset.

This RP is designed to guide operators in planning and executing an Engineering Critical Assessment (ECA) for MAOP reconfirmation (MAOP-R), providing an outline for the process while relying on and referencing existing industry guidance on the more detailed elements of the process (e.g., ASME B31.8S, API 1160 for threat susceptibility; API 579, ASME B31G for FFS models). When properly applied, this method can offer an effective means to evaluate the potential for flaws to exist on an asset at a target pressure, providing an equivalent level of assurance to that achieved through the completion of a pressure test.

This approach was developed through the collective efforts of pipeline operators, service providers, and SMEs using technical principles and definitions established within U.S. Department of Transportation (DOT) Title 49 Code of Federal Regulations (CFR) Part 192, specifically regarding the use of Engineering Critical Assessment (ECA) as defined in 49 CFR § 192.632 for reconfirming MAOP. It serves as a framework for consistent application of engineering principles, broadly applicable across a range of pipeline and facility assets. The methods described in this document are not prescriptive and are intended to complement, not replace, applicable regulatory requirements, operator procedures, or engineering judgment. Instead, this RP serves as a framework for consistent application of engineering principles in support of MAOP-R activities and provides references to relevant existing industry standards and practices, including ASME B31.8S, API 1160, API 579-1/ASME FFS-1, and ASME B31G. Although aligned with the requirements of 49 CFR § 192.632, the guidance is written for broader applicability to both natural gas and hazardous liquid pipelines, to expand upon ECA principles to extend the method as an alternative to pressure testing.

Recognizing that this RP emphasizes the use of certain FFS methodologies, it is important to distinguish between FFS, engineering assessments (EAs), and ECAs as each represents a different level of analytical rigor and application. FFS assessment, as defined in API 579-1/ASME FFS-1, *Fitness-for-Service* [1], is:

> *"quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage, or that may be operating under a specific condition that might cause a failure."*

EA, as defined in ASME B31.8 [2], is:

> *"a documented assessment using engineering principles of the effect of relevant variables upon service or integrity of a pipeline system and conducted by or under supervision of a competent person with demonstrated understanding of and experience in the application of engineering and risk management principles related to the issue being assessed."*

ECA has several accepted definitions in various codes and standards focusing on establishing the maximum allowable flaw size in a component or material. The definition adopted by the U.S. regulatory code 49 CFR

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Part 192 [3], includes the evaluation of specific flaws and material properties and expands it by including consideration of operating history, potential for in service degradation, and future operational activities:

> *"a documented analytical procedure based on fracture mechanics principles, relevant material properties (mechanical and fracture resistance properties), operating history, operational environment, in-service degradation, possible failure mechanisms, initial and final defect sizes, and usage of future operating and maintenance procedures to determine the maximum tolerable sizes for imperfections based upon the pipeline segment maximum allowable operating pressure."*

For the purpose of this RP, ECA for MAOP-R is defined in alignment with the U.S. regulatory code definition. It should also be noted that while the process described integrates concepts from FFS, EA, and ECA approaches, and certain threat and integrity assessment approaches are relied upon, it distinctly excludes the risk management aspects included in EAs.

Integrity Management Program (IMP) vs. ECA Objectives

Many of the assessments, flaw characterization methods, and data relied upon for the MAOP-R ECA are shared with Integrity Management Program (IMP) requirements. While there is overlap in certain elements, the objectives of an IMP are fundamentally preventive, risk-based, and targeted at the complete life-cycle management of an asset. IMPs focus on the continual identification, assessment, and mitigation of threats to pipeline integrity through data integration, risk assessment, and application of preventive and mitigative measures. Their intent is to manage overall system risk by prioritizing segments , ensuring that inspection, maintenance, and monitoring activities are performed proactively to prevent incidents .

In contrast, the objective of an MAOP-R ECA is demonstrative and feature specific. It is not a risk management framework, but an engineering analysis used to prove the current FFS of an asset to a specific operating pressure level and safety margin, and is a one-time event. The ECA applies certain engineering and fracture mechanics principles to quantify flaw tolerance (or demonstrate absence of such conditions), validate material properties, and demonstrate that known or postulated flaws would not fail at the intended operating pressure. While the IMP establishes a broad, programmatic approach to integrity assurance, the ECA provides a quantitative, engineering-based justification of structural integrity for pipeline segments or conditions as of the date of the assessment. A comparison of IMP and ECA aspects is presented below.

Aspect	Integrity Management Program (IMP) **(49 CFR Part 192, Subpart O)**	Engineering Critical Assessment (ECA) **(49 CFR § 192.632)**
Objective	Continuous, risk-based program to monitor and manage risk over the life of the asset.	One-time reconfirmation of MAOP where traceable, verifiable, and complete (TVC) pressure test records are absent or insufficient.
Baseline Assumption	MAOP has been previously established, i.e., construction, material, and weld flaws are stable at MAOP.	Records to establish MAOP are missing or deficient, the ECA provides a pressure test-equivalent demonstration using engineering and fracture mechanics with validated inspection data.
Material Properties	TVC records strictly required for certain activities such as defect assessment and repair. In the absence of anomalous features, IMP activities such as risk assessments typically use expected properties without further verification until needed. Unknowns, if used, are understood and managed.	If TVC records are absent, material verification is required (§ 192.607) to establish grade, wall thickness, seam type, and toughness. Material verification can be performed opportunistically with appropriate assumptions applied but is ultimately required for all segments even if defects are not present. Unknowns must be resolved.

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Threat Coverage	All 192.917 and ASME B31.8S threats including monitoring for potential emergence of newly identified threats over time.	Focus on current presence of conditions that could impair the serviceability of the pipe. Consideration for future threat emergence is not included in ECA.
Timing	Ongoing, continuous process with periodic reassessment intervals.	One-time, segment-specific process performed when MAOP must be reconfirmed.
Outcome	A management system approach including threat identification, risk prioritization, assessment, repair, mitigation, monitoring and continuous improvement using performance indicators.	Establishes a failure pressure ratio demonstrating the line is qualified to operate at MAOP with the required margin for class location, thereby enabling continuation of IMP processes.

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1 Scope

This r RP provides guidance on conducting an ECA for the purpose of reconfirming MAOP on pipeline and facility assets. While this RP is written for reconfirming MAOP of steel pipelines transporting natural gas, it is recognized that some components may have applicability to pipelines transporting liquids for MOP reconfirmation. The ECA integrates fitness-for-service (FFS) methodologies with verified (or appropriately assumed) material properties, as well as uncertainty and flaw growth considerations to provide an assessment demonstrating equivalence to a qualification pressure test. While this guidance is primarily intended for application to reconfirm MAOP for gas transmission line pipe in accordance with 49 CFR 192.632, it is recognized that the concepts are applicable to pipelines transporting liquids and non-line pipe and components associated with pipeline facilities (e.g., valve sites, and compressor, pump, meter, and pressure-limiting stations). Broader liquid/facility applications are informative unless separately required by jurisdiction.

2 Normative References

The following reference documents are required for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Standard 1163, *In-line Inspection Systems Qualification*

API Recommended Practice 1183, *Measuring and Assessing Dents in Pipelines*

API Recommended Practice 1188, *Hazardous Liquid Pipeline Facilities Integrity Management*

3 Terms, Definitions, Acronyms, and Abbreviations

For the purposes of this document, the following definitions, acronyms, and abbreviations apply.

3.1 Terms and Definitions

anomaly
An unexamined deviation from the norm in pipe material, coatings, or welds, which may or may not be a defect.

axial strain
Longitudinal deformation of the pipe wall resulting from uniform tensile or compressive stress along the pipe axis.

bending strain
Non-uniform longitudinal deformation caused by unplanned curvature in the pipe, where one side experiences tension (extrados – outside of the curvature) and the opposite side compression (intrados – inside of the curvature).

Charpy v-notch energy

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result of a standardized high strain-rate test which determines the amount of impact energy absorbed by a material during fracture. This absorbed energy is a measure of the notch toughness of a given material.

component
Any physical part of the pipeline, other than line pipe, including but not limited to valves, welds, tees, flanges, fittings, taps, branch connections, outlets, supports, and anchors.

corrosion
Deterioration of metal resulting from chemical or electrochemical interaction with its operating environment, encompassing both uniform and localized material loss mechanisms.

crack
A sharp-tipped, localized material discontinuity.

crack-like flaw/features
An anomaly with a small root radius that could behave structurally like a crack

defect
A physically examined anomaly with dimensions or characteristics that exceed acceptable limits.

examination
The direct physical inspection of a pipeline, which may include the use of non-destructive examination (NDE) techniques or methods.

failure pressure ratio (FPR)
Ratio of the estimated rupture pressure (ERP) from a limit state analysis to the maximum allowable operating pressure (MAOP), i.e., FPR=ERP/MAOP. Also sometimes referred to as Limit State Pressure Ratio (LSPR).

fitness-for-service assessment (FFS)
A methodology whereby flaws or a damage state in a component is evaluated in order to determine the adequacy of the component for continued operation.

flaw
A discontinuity, irregularity, or defect that is detected by inspection.

fracture mechanics
An engineering discipline concerned with the behavior of cracks in materials. These models provide mathematical relationships for critical combinations of stress, crack size and fracture toughness that led to crack propagation.

hard spot

An area on steel pipe material with a minimum dimension greater than 2 inches (50.8 mm) in any direction and hardness greater than or equal to Rockwell 35 HRC (Brinell 327 HB or Vickers 345 HV)

hydrogen embrittlement
A broad term often used generically to describe the way atomic hydrogen affects the properties of steels.

Note: For the purposes of this document, this is a general term that could be used for HAC, HIC, and HSC. For more information on these topics or hydrogen embrittlement please see ASME B31.8S

in situ direct examination
See Examination.

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integrity assessment
The process of inspection and subsequent engineering analysis of a pipeline or pipeline related asset to identify certain conditions that could affect the integrity of the pipeline.

interacting threats
Two or more threats acting on a segment that increases the probability of failure to a level greater than the effects of the individual threats acting alone.

limit state
A condition beyond which the pipeline no longer fulfills its intended design, safety, or functional criteria.

maximum allowable operating pressure (MAOP)
The maximum pressure at which a pipeline or segment of a gas pipeline may be operated based on regulatory limits (49 CFR § 192).

maximum operating pressure (MOP)
The maximum pressure at which a pipeline or segment of a liquids pipeline may be normally operated based on regulatory limits (49 CFR § 195).

mechanical damage
A generic term used to describe dents, gouges, ovality, buckles, and/or cold work caused by the application of external forces.

metal loss
Types of anomalies in pipe in which metal has been removed from the pipe surface, usually due to corrosion or gouging.

non-destructive examination (NDE)
Testing method, such as radiography, ultrasonic, magnetic testing, liquid penetrant, visual, leak testing, eddy current, and acoustic emission, or testing technique, such as magnetic-flux leakage, magnetic-particle inspection, shear-wave ultrasonic, and contact compression-wave ultrasonic.

plain dent
A dent without interacting features.

Note: For more information on dents in general, please refer to API RP 1183.

pipeline facility
Supporting installations within a pipeline system such as valve sites, compressor, pump, metering, or regulator stations.

pressure test
Means by which the integrity of a piping system (inclusive of piping and components) is assessed, in which the system is filled with a fluid, sealed, and subjected to pressure to demonstrate the pressure containment ability of the system.

probability of detection (POD)
The probability of a feature being detected by an inspection method.

probability of identification (POI)
The probability that the type of an anomaly or other feature, once detected, will be correctly classified (e.g., as metal loss, dent).

probability of sizing (POS)

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The probability that a particular inspection method will accurately quantify the dimensions or attributes of an anomaly or other feature.

resident threat
a manufacturing-, welding/fabrication-, or equipment-related imperfection that if not acted upon by a time-dependent or time-independent threat, remains dormant and does not deteriorate with time.

risk
Measure of potential loss in terms of both the incident probability (likelihood) of occurrence and the magnitude of the consequence.

segment
Length of pipeline or part of the system or facility that has unique characteristics in a specific geographic location.

specified minimum yield strength (SMYS)
Minimum yield strength prescribed by the specification under which pipe is purchased from the manufacturer.

stress corrosion cracking (SCC)

Form of cracking produced by the combined application of tensile stress (residual or applied), a corrosive environment, and a steel that is susceptible to SCC.

technical competency
Having the knowledge, skills and abilities needed to perform specific tasks within a particular field or job role.

threat assessment
Process of identifying potential threats to the integrity of a pipe or segment, including data integration and risk assessment; in line with the integrity management process outlined in ASME B31.8S.

traceable, verifiable, and complete (TVC)
Traceable records are those that can be linked to a specific location in a pipeline or facility, verifiable records are those containing information that may be confirmed by other records or data, complete records are those that are finalized by a signature or other marking.

ultimate tensile strength (UTS)
The maximum load per unit of original cross-sectional area that a tensile test specimen of a material sustains prior to fracture.

wrinkle bend
Installed circumferential pipe deformations introduced during legacy construction practices, resulting in wrinkles on the inner radius of the bend that act as stress concentrators.

3.2 Acronyms and Abbreviations

ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
CFR	Code of Federal Regulations
CP	Cathodic Protection
CSCC	Circumferential Stress Corrosion Cracking

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CTOD	Crack-tip Opening Displacement
DC-ERW	Direct Current Electric Resistance Welding
DOT	Department of Transportation
EA	Engineering Assessment
EAC	Environmentally Assisted Cracking
EC	External Corrosion
ECA	Engineering Critical Assessment
EFW	Electric Flash Welding
EMAT	Electromagnetic Acoustic Transducer
FAD	Failure Assessment Diagram
FBE	Fusion-bonded Epoxy
FEA	Finite Element Analysis
FFS	Fitness-for-Service
FPR	Failure Pressure Ratio
GA	General Arrangement Drawings
GIS	Geographical Information System
GWA	Girth weld anomaly
HAC	Hydrogen-assisted Cracking
HAZ	Heat Affected Zone
HF-ERW	High-frequency Electric Resistance Welding
HCA	High Consequence Area
HIC	Hydrogen-induced Cracking
HSC	Hydrogen Stress Cracking
IC	Internal Corrosion
ILI	In-line Inspection
IM	Integrity Management
IMP	Integrity Management Program
IMU	Inertial Measurement Unit
JMF	Just-missed Flaw
JSF	Just-surviving Flaw
LF-ERW	Low-frequency Electric Resistance Welding
LFM	Low-Field MFL
LiDAR	Light Detection and Ranging
LOF	Lack of Fusion
MAOP	Maximum Allowable Operating Pressure
MAOP-R	Maximum Allowable Operating Pressure Reconfirmation
MFL	Magnetic Flux Leakage
MFL-A	Axial MFL
MFL-C	Circumferential MFL
MOP	Maximum Operating Pressure
MTR	Material Test Report
NDE	Non-destructive Examination

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PDAM	Pipeline Defect Assessment Manual
PHMSA	Pipeline and Hazardous Materials Safety Administration
POD	Probability of Detection
POI	Probability of Identification
POS	Probability of Sizing
PRCI	Pipeline Research Council International, Inc.
QA/QC	Quality Assurance / Quality Control
RES	Residual MFL
RP	Recommended Practice
SCC	Stress Corrosion Cracking
SME	Subject Matter Expert
SMYS	Specified Minimum Yield Strength
SSAW	Single Submerged Arc Welding
SSC	Sulfide Stress Cracking
SSI	Spectrum Severity Indicator
SSWC	Selective Seam Weld Corrosion
TSC	Tensile Strain Capacity
TVC	Traceable, Verifiable, and Complete
UT	Ultrasonic Testing
UTCD	Ultrasonic Crack Detection
UTS	Ultimate Tensile Strength
UTWM	Ultrasonic Wall Measurement
WROF	Weather-related and Outside Forces

4 MAOP Reconfirmation

When MAOP-R of existing pipelines is required, several methods are recognized, including Engineering Critical Assessment (ECA).

This document focuses on ECA for MAOP-R. However, performing an MAOP-R ECA may not be feasible for all pipelines or under all circumstances. Application of this method is dependent on the availability, or ability to obtain, records necessary to establish material properties and attributes, as well as data relevant to each identified threat and condition across the full boundary extents of the asset under evaluation.

4.1 General Requirements

Information feeding into an MAOP-R ECA may include:

- Historical records review for pressure test, materials, and past excavation information;

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- Data gathering that meets sufficient quality and completeness standards[1] for material properties, pipeline condition assessment, operational/loading conditions, environmental conditions, and failure history;
- Evaluation of threat susceptibility for applicable threat categories and conditions relevant to those threats;
- Assessment of in-service degradation and feature growth rate, if applicable; and
- Quantification of the interacting effects of threats

4.2 ECA Process Steps

The MAOP-R ECA process for a pipeline segment or pressure-containing components at pipeline facilities involves the following steps:

1. Conduct records research and gather data related to material attributes, prior pressure tests[2], operational history and available integrity management information; Perform quality assurance and quality control (QA/QC) on gathered data. Address any QA/QC concerns through data augmentation as needed.
2. Conduct threat susceptibility and interaction analysis; identify any outstanding data needs.
3. Select and conduct integrity assessment to supplement datarequired the FFS evaluation; Perform QA/QC on gathered data.
4. Choose appropriate FFS model(s) for the threat(s) being assessed;
5. Conduct the FFS assessment(s) using the appropriate model(s); and
6. Document completed FFS for the pipe segment and pipeline system components in alignment with record keeping requirements.

Figure 1 illustrates the detailed process flow.

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[1] The operator will have guidelines that define the data quality, completeness, and validation standards required for MAOP-R ECA data. These may align with TVC standards outlined in this RP or with other criteria established by industry or SMEs.

[2] Material attribute and pressure test records may or may not meet TVC criteria. Non-TVC records should be considered in the analysis with suitable appropriate assumptions applied.

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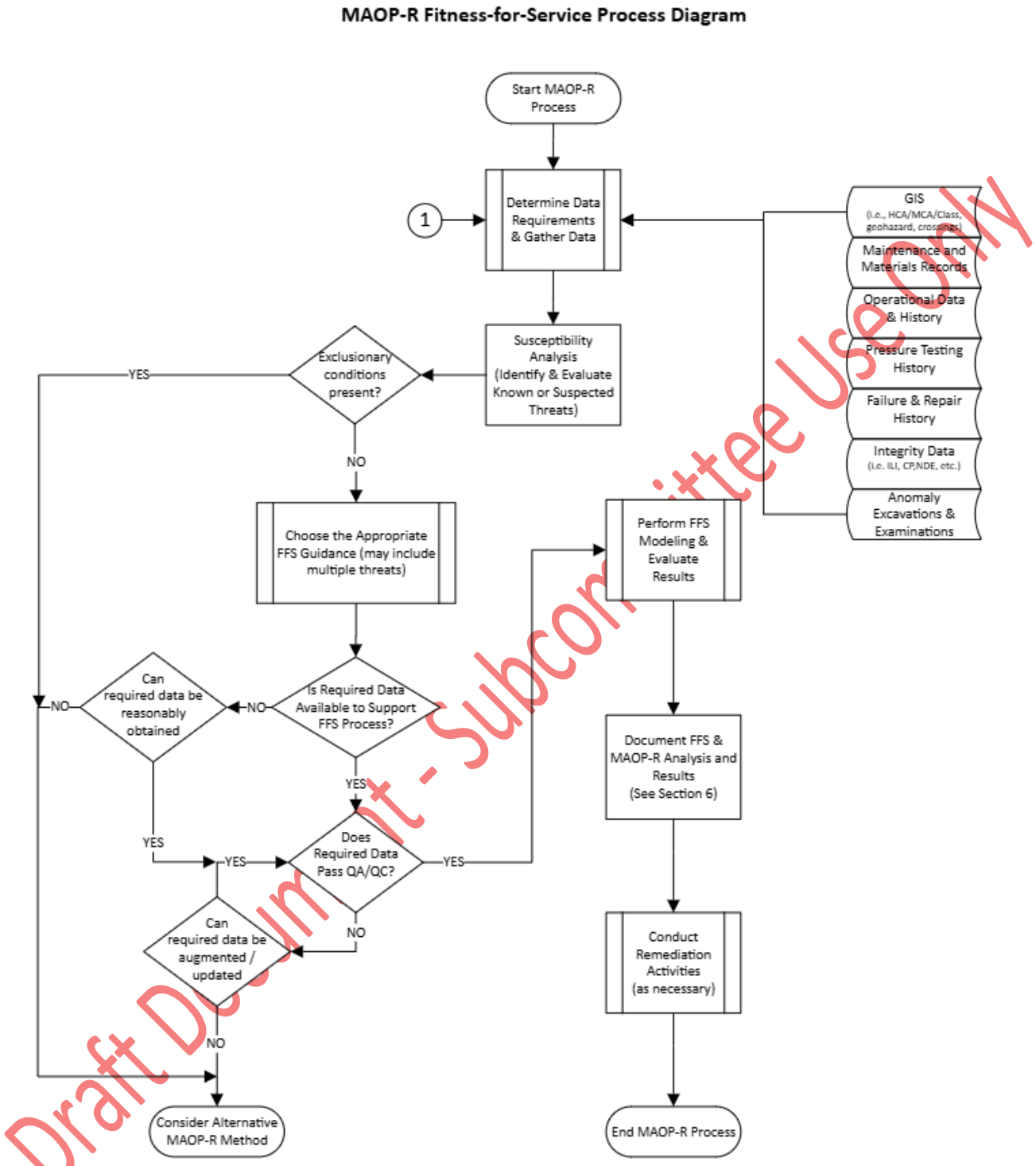


Figure 1: MAOP-R Process Overview

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4.2.1 Determination of Scope Boundaries

The scope of the MAOP-Reconfirmation project is based on material properties, records, prior hydrostatic test records status, and HCA status. Research is required to establish the appropriate applicability of the criteria to piping within the scope of the project. Consideration should be given to

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spatial accuracy of records and HCA/Class Location status to ensure appropriate scope definition, and a buffer may be required to account for inaccuracies. In many cases, regulatory requirements will drive the determination of scope; for instance, when the pipeline is managed or falls under a separate regulation as compared to facility assets. An understanding of the design and operating characteristics of the facility assets is critical in establishing the boundaries. Consultation with stakeholders to determine flow direction and valve configuration is key to the establishment of the boundary limits.

Annex D – 49 CFR Part 192 MAOP Reconfirmation Boundaries contains guidance related to boundary identification for natural gas pipelines requiring MAOP-R in alignment with PHMSA regulations. Guidance provided therein may also be considered for application to other jurisdictions.

4.2.2 Data Sources

Evaluation and determination of the scope boundaries can be completed utilizing data sources such as information utilized in assignments of HCA[3] and class location designations, as-built drawings or Piping and Instrumentation Diagrams (P&IDs) and General Arrangement (GA) drawings, site photographs / aerial imagery, prior integrity inspection and assessment records, and an understanding of the facility's operating parameters and emergency response plans.

4.3 Data Requirements

This MAOP-R process requires comprehensive data coverage applicable to material attributes and integrity threats, including environmental and operational loading conditions, for all pipe and components within the scope of the assessment. Data covering the MAOP-R scope may include, but is not necessarily limited to:

- Operating pressures and temperatures;
- Product conversions;
- HCA/MCA designation

The data coverage and resolution shall be appropriate to identify features that are critical at target MAOP safety margins through the application of limit state equations (where applicable) or to establish that a threat or condition does not exist or is resident and expected to remain stable. If required data is not available, it shall be gathered utilizing an appropriate technology or process, see Section 4.5.10.

Annex B – Data Threat Mapping provides a detailed mapping of threat, operational, and loading condition data relevant to the evaluation of FFS for each threat category.

4.3.1 Configuration and Operating Parameters

Asset configuration and operating parameters shall include:

- Site description (e.g., line designation, mile-post and/or chainage range, site name, state, county). A map or engineering drawing(s) of the site will assist in communicating the nature and configuration of the site and surroundings.
- In the case of pipeline outside of facilities, routing information including but not limited to: crossings, landforms and proximity to geotechnical threats;

[3] As designated in 49 CFR 192.903 and 49 CFR 195.450

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  - Crossings include, buried or aerial, cased or uncased, roads, railways, waterways, other pipelines, other infrastructure;
  - Relevant information from adjacent pipelines or loop lines.
- In the case of pipeline assets inside or immediately adjacent to facilities, information including but not limited to: piping and component configuration, flow configuration and valve settings under normal operating conditions;
- Year of installation and/or commissioning;
- Classification of pipeline locations. Example – for pipelines regulated under 49 CFR Part 192:
  - Class location
  - HCAs
  - Moderate Consequence Areas
- Current MAOP; and
- Product type and flow direction.
- Operating temperature. Where operating temperature may materially affect threat susceptibility or degradation rate, material behavior, the ECA should identify and document the governing temperature basis and any resulting assumptions, limitations, or adjustments used in the evaluation.

4.3.2 Pipe Properties and Attributes

The following material properties are required to support the assessment:

- Nominal wall thickness;
- Nominal diameter;
- Seam type (manufacturing process);
- Grade;
- Toughness (i.e., from Charpy energy values)[4].

Insert paragraph here – example sources for these properties

  - Material Test Reports (MTR) related to pipe or components are a source of minimum yield and/or ultimate tensile strength values.
  - Other types of records such as project completion reports or work orders may, either individually or through combinations of complementary records, contain specified minimum yield and/or ultimate tensile strength values.
  - Where MTRs or other records containing specified minimum yield and/or ultimate tensile strength values are not available and where pipe is manufactured under API 5L or API 5LX, specified minimum yield and ultimate tensile strength values for the established grade

[4] Toughness values are necessary when analyzing conditions that could fail in a brittle manner such as cracks or crack-like anomalies.

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from the edition of the specification in effect on the date of manufacture may be considered for use. In such cases operators should develop and document rationale for chosen strength values .

- Destructive or non-destructive test reports or alternative technologies

In addition to the material properties listed above, the name of the pipe manufacturer and the date of manufacture offer insight into the pipe's susceptibility to certain threats and provide useful information when assessing the level of confidence in material records.

In the case of pipelines regulated under 49 CFR Part 192, material attribute records and data meeting TVC criteria can be relied on when calculating MAOP. Pipelines under other regulatory jurisdictions may consider the definitions for TVC[5] when establishing their criteria for a sufficient level of confidence in material attributes.

Where material property records do not meet TVC criteria, or are considered insufficient to support MAOP calculations on their own, operators may consider one or more of the following options:

- Conservative assumptions; pipelines regulated under 49 CFR Part 192 may use conservative assumptions for certain material attributes as defined in the regulations. Operators not regulated by 49 CFR Part 192 may develop and use appropriate assumptions[6] for certain material attributes based on regulatory language, material specifications in effect at the time the pipe or components were manufactured, and/or SME input.
- Inferences based on engineering judgment and published references; consideration of records (presumably non-TVC), data and information that are available. Operators may form inferences based on engineering judgment for the expected value or range of expected values. For example, if an operator has records, data or other information establishing the name of the pipe manufacturer and the year or era of manufacture, trusted sources can be used to determine the expected manufacturing process or a specified range of manufacturing processes (long seam weld) and minimum grade.[6]
- Use data or information to augment available material records.. In cases where such data and information are congruent with values stated in records, confidence in the records is increased. Where inconsistencies are found, additional effort should be exerted to determine the appropriate value. Useful material attribute data and information sources include but are not limited to: NDE or ILI survey results (certain ILI technologies can characterize some material attributes or identify ranges of values which when combined with complementary information can be used to identify appropriate values), prior direct examination results, testing combinations of material attribute values against engineering specifications for possible and impossible combinations, manufacturing standards, business rules, or other trusted sources[7].
- Additional records research; while many operators have expended considerable effort in researching and processing material records, in areas where records are incomplete or

[5] For definitions of TVC see; Department of Transportation, Pipeline and Hazardous Materials Safety Administration, [Docket No. PHMSA-2012-0068] A Notice by the Pipeline and Hazardous Materials Safety Administration on 05/07/2012 Federal Register: Pipeline Safety: Verification of Records

[6] For further information regarding conservative regulatory assumptions, refer to 49CFR 192.632

[7] A common trusted source for use when evaluating combinations of material attributes is "History of Line Pipe Manufacturing in North America" J. Kiefner and E. Clark [54].

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missing consideration should be given to engaging SMEs with knowledge of the asset. The goal of such efforts is to identify previously unknown or unprocessed material records.

- Field verification for augmenting material records. The results of the program shall provide a sufficient level of confidence that material attributes are representative of the pipeline[8].

4.3.3 Component Properties and Attributes

Material attributes and pressure rating for components such as valves and flanges must also be established for the assessment through either records review or inspection and data collection. For rated components the values can be based on stamps or markings on the component indicating the American National Standards Institute (ANSI) rating. In many cases purchase orders or other records indicate the specification for either individual components or groups of components. Where the number of installed components at a location or within a project extent correlates with the number of components on a record and at least one component is confirmed, the ANSI ratings are suitable for use in MAOP-R.

Where components are not tagged or marked, or where tags or marks are illegible, and where records indicating specifications for components are not available, multiple similar components may be assessed as a group. The following should be considered when establishing properties and attributes for undocumented and/or unmarked components:

- Components may be grouped based on common size, function, manufacturer and indications that they were installed as part of the same construction project or during a defined time period. SME input will assist in establishing groups of components based on these and other relevant criteria;
- Measuring or determining flange thickness, bolt circles, number of bolts, or other attributes may offer insight into the ANSI rating;
- A review of relevant information, data and records for components of the same type installed in the same era at other locations on the same pipeline system may identify complementary information;
- Review relevant purchasing practices and/or engineering specifications for components of the same type installed in the same era on the same pipeline system.

In many cases material attributes for components within a pipeline system are detailed in engineering specifications and/or purchasing practices applicable to the era of construction. Changes to specifications and practices were usually marked by revisions to standard operating procedures or other documentation. Such specifications and practices cannot, on their own, be used to document component attributes and pressure ratings; however, such information can assist in identifying ranges of attribute values and/or possible or impossible combinations of such values.

SME analysis of gathered records, data and information can quantify a level of confidence in the component properties. Where the SME analysis results in a level of confidence considered sufficient to support MAOP-R ECA calculations, the records, data, information and rationale for the conclusion shall be documented and maintained for the life of the pipeline.

4.3.4 Verifying Material Properties Through a Sampling Program

[8] For pipelines regulated by 49 CFR Part 192, sampling programs are outlined under § 192.607. § 192.607(e)(4) and (e)(5) indicate the required confidence level is "at least a 95% confidence level that material properties used in the operation and maintenance of the pipeline are valid."

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Where records, data and information do not establish and/or verify material attributes for pipe or components to a sufficient level of confidence, a sampling program may be developed and implemented by conducting nondestructive or destructive tests, examinations, and assessments. Opportunities to perform in-situ material verification include excavations associated with direct examinations, in situ evaluations, repairs, maintenance, and excavations that are associated with replacements or relocations of pipeline segments that are removed from service. Results from these opportunistic excavations may be applied to other similar[9] pipe or components.

The number of samples required for material verification should be determined using an attribute-specific sampling approach rather than a single prescribed sample count, but may be dictated by regulation.

For pipelines regulated under 49 CFR Part 192 the timeframe associated with verifying material properties through a sampling program is not specified. Operators should therefore define and document their approach to a sampling program along with the associated timeframes. An MAOP-R ECA cannot be considered complete if unverified material properties govern threat susceptibility, predicted failure pressure, or MAOP, unless documented conservative bounds are used and the ECA explicitly documents why the outstanding verification cannot change the governing conclusion. Where the unverified property is not required for the governing assessment result, the ECA may be finalized with the basis and any follow-up verification actions documented.

4.3.5 Historical Pressure Test Results

In cases where historical pressure test records are not commensurate with current MAOP or regulatory requirements, the recorded test pressure may be used to support anomaly postulation, material bounding, and threat evaluation, but do not by themselves constitute a qualifying pressure test for MAOP establishment unless the applicable requirements for that use are fully satisfied. Where an MAOP-R assessment is being performed and pressure test information is available from prior tests, one or both of the following scenarios are likely:

- Pressure test records are incomplete or do not fully address regulatory documentation criteria; and/or,
- Test pressures are non-commensurate with current MAOP or regulatory requirements for the pipeline location.

Critical information required for a pressure test to be used include: test pressure magnitude, physical location and boundaries of the pressure test, and pressure test date. Other required information related to the pressure test can be derived or obtained through analysis (e.g., elevation based on location, assumed pressure logging location, test medium)[10].

Where material attribute records are incomplete, the historical pressure test may assist in identifying a material attribute value or range of possible values. As an example, where nominal wall thickness and diameter are known (or where there is high confidence in these values), solve Barlow's equation a for the unknown attribute.

4.3.6 Integrity Assessment and Maintenance History

[9] For pipelines regulated under 49 CFR Part 192, § 192.607(e) provides direction for identifying similar segments of pipe and determining material properties.

[10] Example: maximum test pressure can be conservatively assumed as being recorded at the lowest point on the test section if the dead-weight location is not identified.

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Operators shall compile comprehensive integrity assessment and maintenance history data for the asset under review. This includes prior and current integrity assessment results (e.g., ILIs, pressure testing, direct assessments), records of excavations and direct examinations, and documentation of any failures/leaks, causal analysis records, and subsequent repairs. Additionally, maintenance and survey data should be included, encompassing corrosion monitoring, cathodic protection and interference testing, coating evaluations, and right-of-way or environmental surveys.

In some cases, data and information from adjacent pipelines or loop lines may be relevant and considered. As an example, geotechnical data and environmental surveys related to an adjacent pipeline may provide relevant information on the environmental loading conditions of the MAOP-R target asset. If such sources do not provide relevant information they should be acknowledged to demonstrate all potential sources of information were considered.

4.3.7 Data Quality Assessment and Data Integration

An MAOP-R ECA is highly data dependent. As such, it is important that QA/QC are performed on all gathered data and that data integration processes are applied. These could include specific data quality requirements, QA verification protocols, and checklists to assure the validity of the data. QA/QC and data integration processes shall evaluate baseline data from all sources along with newly generated data gathered through assessments associated with the MAOP-R.

An MAOP-R ECA for line pipe will most likely require the utilization of data gathered during an ILI or NDE assessment. ILI data shall be validated, either by the operator or the technology vendor, through a QA/QC process conforming to API 1163 Section 8.2 – Evaluation of System Results.

Other inspection technologies used in place of, or in addition to, ILI shall undergo a comparable QA/QC and validation process to confirm that the data generated meets published performance specifications. In addition, operators shall maintain a documented procedure for addressing indications that fall outside the stated tool performance envelope, which includes working with the technology vendor to determine whether additional field examinations, supplemental NDE, or re-analysis of the inspection data is warranted.

Once individual data and information sources have been validated through the applicable QA/QC process, data and information sources shall be integrated into a common reference system. Integrating data sources with one another is essential to identify inconsistencies, impossible combinations of material properties, or inconsistencies with engineering specifications, manufacturing standards, business rules, or other trusted sources.

When data and information meet validation thresholds, it may be considered suitable for use in an MAOP-R ECA and other integrity assessments. In such cases, the MAOP-R assessment shall explicitly reference data and information sources and describe or reference the validation procedures applied.

Data that does not meet validation thresholds may provide value in the MAOP-R assessment; however, a follow-up with the ILI, NDE vendor or other data source to conduct additional in-field examinations, re-analysis of data, or both may be required.

4.4 Accounting for Uncertainties

Uncertainties considered when assessing the failure pressure of a pipeline flaw include those related to pipe dimensions and physical properties, operating conditions, flaw dimensions, growth rates (when applicable), and burst pressure model error.

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Deterministic, safety factor-based approaches have been widely used in structural engineering to account for these uncertainties through application of explicit safety factors and conservative assumptions. These approaches provide an established and practical basis for engineering decision making in support of safety, reliability and regulatory compliance.

In contrast, reliability-based approaches have been increasingly adopted by pipeline operators to quantify reliability levels and support integrity management actions. These methods apply probability theory and engineering principles to explicitly account for uncertainties in the input parameters. A key advantage of reliability-based methods is that they enable quantification of residual risk, providing an additional basis for decision making beyond deterministic evaluation.

4.4.1 Inspection Data Uncertainties

Any ILI data utilized shall conservatively account for uncertainties in the reported assessment results. These uncertainties include tool tolerance, detection thresholds, probability of detection, probability of identification, sizing accuracy, , location accuracy, anomaly findings, and unity chart plots or equivalent for determining uncertainties. Data gaps or reduced ILI performance (e.g., due to speed excursions or debris), if identified, must be addressed in the analysis as parameters such as POD and POI can be reduced in such areas.

When reported dimensions from ILI or direct examination are used in flaw assessment or predicted failure pressure calculations, the analysis should use a conservatively bounded sizing basis consistent with the applicable validated tool tolerance or performance specification.

4.4.1.1. ILI Tool Performance Verification and Validation in Support of an ECA

ILI tool performance verification and validation programs such as those for axial magnetic flux leakage (MFL-A) technologies for metal loss are generally well established and can typically be managed on a survey-by-survey basis where there are sufficient dig validation opportunities and/or previous recoated features to validate tool performance through application of unity plots. However, other inspection technologies for certain threats such as for cracking, selective seam weld corrosion or hard spots may require a combination of ILI technologies and it is not unusual to have zero or very few feature calls from an inspection. This can create a challenge for quantitative survey-specific Level 2 performance validation under API 1163, in support of an MAOP-R ECA. For these scenarios where validation data may be limited, several options still exist to support confidence in the inspection including excavation of all identified features (if feasible), using conservative bound tolerance limits (including depth and interaction rules) to establish feature acceptance criteria for MAOP-R decision making, or a programmatic approach that combines multiple inspections, effectively increasing the sample size. In a programmatic approach, broader tool survey validation results in combination with the survey-specific results are used to establish confidence in the collective data in a process consistent with API 1163 validation objectives without quantification of survey-specific performance estimates. If programmatic validation is used, the ECA shall define the essential variables, the minimum validation dataset or representative validation basis, treatment of false negatives / positives, and performance acceptance criteria.

4.4.1.2. In-ditch measurement tools

In the ditch examination tools and procedures used to characterize crack-like anomalies shall have established performance and evaluation standards for determining crack length and depth. The accuracy of these tools and procedures shall be demonstrated through confirmation testing

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representative of the defect types and pipe material vintages being evaluated, consistent with the requirements of 49 CFR § 192.632.

4.4.2 Uncertainties Associated with Material Attribute Values

Uncertainties impacting all material attribute values, both those meeting and those not meeting the required level of confidence based on records, data and information, originate from two key sources:

- Unknown pipe or components; The potential for pipe or components being resident in the pipeline system that are not documented in records, data or information should be considered and addressed. While records meeting the required level of confidence may cover the entire scope of the MAOP segment, it is possible that undocumented changes to the pipe or components have occurred. The likelihood of undocumented changes increases with the age of the pipeline system and the number of changes in ownership since the system was originally constructed.
- Errors in interpreting material records or errors in spatially linking records to actual locations. For many material records chainage is the only element of a record that links it to a geographic location. For pipeline systems that have been converted from one product type to another, experienced flow reversals or other changes in configuration or use since original construction, care should be taken to ensure material records are accurately referenced to the correct geographic location.

In both cases, comparing attribute values based on records to a recent independent source of material attribute data such as excavation or ILI results will assist in characterizing uncertainty associated with material attribute values. While it is optimal to compare all material attributes to an independent source, the availability of such data sources and/or the practicality of obtaining such data may preclude this level of analysis.

ILI survey data is often a valuable and readily available source of recent information for assessing material uncertainty. Certain ILI technologies can directly measure material attributes; for example, ultrasonic wall measurement (UTWM) technology can measure wall thickness, and some technologies can also identify material properties such as strength to help identify API 5L grade. Where an ILI technology cannot directly measure a material attribute, it may detect variations in that attribute that, through analysis, processing, or validation via in-situ testing, can be used to determine the attribute value or a reasonable range of values. For example, MFL can identify changes in wall thickness. In other cases, signatures associated with pipe manufacturing processes can be used to identify similar material populations for validation through direct measurement or corroboration with historical records.

Recent direct examination (i.e., excavation) data provides another independent source of material data. As with ILI, not all attributes may have been gathered, however, comparing any measured material attributes against values from records will provide useful input.

Carefully assessing at least some material attributes based on records against recent independent data sources will provide input into assessing material attribute uncertainty. In cases where records and independent material attribute information are not congruent, additional records research should be performed. Incongruencies between material attributes based on records and attributes from recent independent data sources will be referred to the operator's material verification process.

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Where material attribute values are based on a combination of records, data, and information that meet the required level of confidence, the rationale for the conclusion shall be documented in the ECA report.

4.4.3 Model Inaccuracies

For deterministic assessments using established burst pressure models, such as ASME B31G and related industry recognized limit state equations, explicit quantification of model error is generally not required. These models have been developed and validated against extensive experimental burst test data and incorporate inherent conservatism intended to provide reliable predictive performance for deterministic evaluations. As a result, the uncertainty associated with model prediction is implicitly addressed within the model formulation and validation basis.

In contrast, when these same limit state models are applied within a probabilistic assessment framework, model error should be explicitly considered and quantified. Probabilistic analyses require a representation of all significant sources of uncertainty to accurately estimate reliability and probability of failure. Accordingly, model error becomes an essential input for probabilistic assessments, even when the underlying limit state model is accepted for deterministic use.

4.4.4 Probabilistic Assessment

Regulatory requirements for reconfirmed MAOP are based on the lowest predicted failure pressure for any known, postulated, or interacting defect, divided by the greater of 1.25 or the applicable location-based factor. Probabilistic or reliability-based analyses may be used to supplement the assessment; however, they do not supersede this minimum compliance basis unless incorporated within a separately justified and accepted alternative approach. Acceptance criteria must be established and documented.

Failure pressure assessments performed as part of a FFS evaluation rely on input data that are inherently subject to uncertainty. In deterministic analyses, the use of conservative or bounding values for these inputs can result in overly conservative predictions of failure pressure. Reliability-based, or probabilistic, assessment methods provide an alternative means of addressing uncertainty by explicitly representing uncertain parameters as probability distributions. These methods employ the same underlying limit state[11] models used in deterministic analysesbut directly account for the variability and uncertainty of the input parameters. Rather than producing a single deterministic failure pressure, the analysis estimates the probability that the limit state will be exceeded. Figure 2 provides an overview of the distinctions between deterministic and probabilistic assessment approaches.

When probabilistic methods are used as the basis for assessment acceptance, the ECA should clearly document the applicable limit state(s), the probabilistic methodology and probability basis employed, the evaluation interval, the target acceptance criterion, and the treatment of model uncertainty. The ECA should also provide the technical justification demonstrating that the selected acceptance criterion achieves a level of safety equivalent to or greater than that provided by the applicable deterministic acceptance approach. Established reliability-based pipeline guidance, such as CSA Z662 Annex O, may be used as a benchmark framework for the development, documentation, and justification of reliability-based acceptance criteria.

[11] A limit state is a state beyond which a pipeline no longer satisfies a design requirement.

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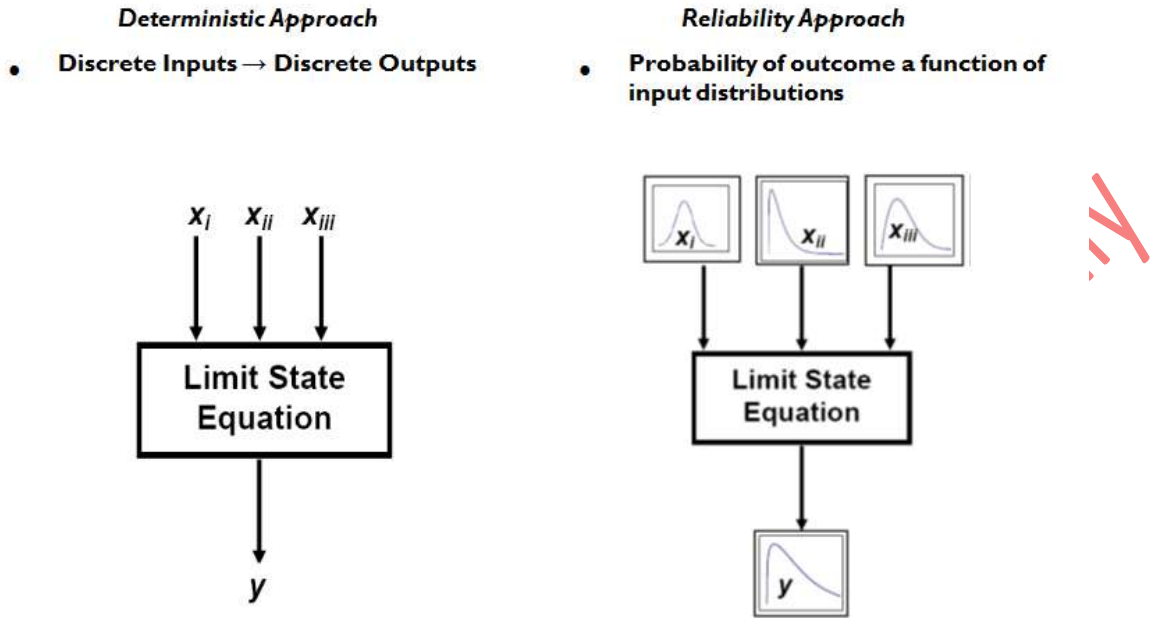
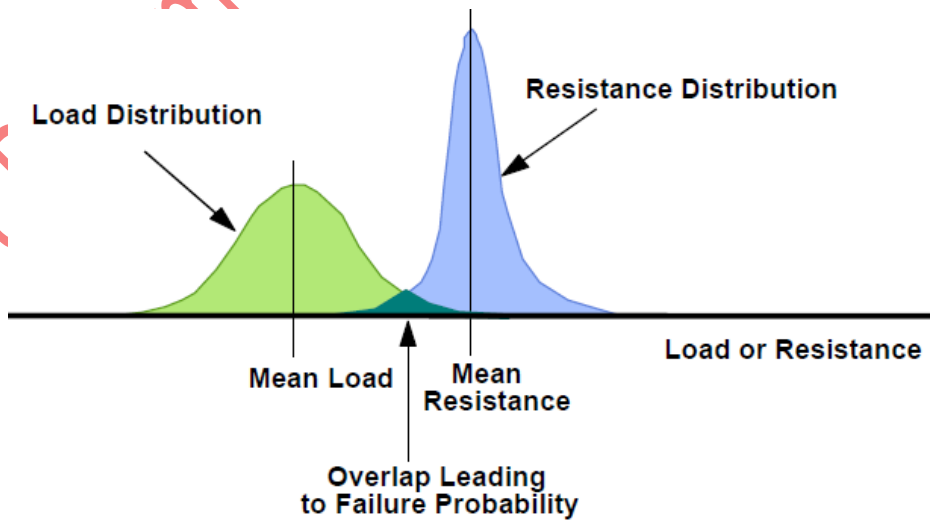


Figure 2: Deterministic vs. Reliability Approaches

The reliability/probabilistic assessment is well suited to application with ILI data where the feature information and sizing uncertainties are well understood and a Monte Carlo simulation[12] can be applied to determine the probability of failure as depicted in Figure 3. In this figure, the probability that the load exceeds the resistance is determined. Where there is overlap, this represents the probability of exceeding the limit state. With respect to failure pressure calculations of pipeline features, the load would represent the pipeline operating pressure and the resistance would represent the estimated failure pressure of the feature from the limit state equation. However, both are represented by distributions due to the uncertainties associated with each.



[12] Monte Carlo simulation is a computational method that uses repeated random sampling to produce numerical results, helping to understand the probability of various outcomes for complex or uncertain systems.

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Figure 3: Monte Carlo Simulation to Develop Probability of Failure

The acceptability of reliability levels or failure probabilities is typically measured against established acceptance limits from industry precedent or guidance, jurisdictional requirements, setting one's own criteria (i.e., defensible company acceptance criteria), or adopting appropriate acceptance criteria applied in other high consequence industries or international pipeline jurisdictions.

4.5 Threat Susceptibility Assessment

To assess threat susceptibility for use in an MAOP-R ECA, operators should utilize established susceptibility criteria, methodologies, and guidance available within industry standards such as ASME B31.8S [4], API 1160 [5], and API 1188 [6], as well as the broader body of industry guidance and references incorporated within these standards and PHMSA's advisory bulletin on threat deactivation, ADB-2017-01. However, some specific considerations are necessary on the use of these standards as they were developed for the purpose of implementation within the context of an IMP, and as noted previously, IMPs have uniquely different objectives from that of an MAOP-R ECA.

To reconfirm MAOP on a pipe segment using FFS approaches, the susceptibility of the target asset to both *Primary*, (i.e., pressure sensitive) and *Secondary* (i.e., non-or not directly) pressure sensitive or resident) threats, and to any environmental and operational loading conditions acting on the asset shall be evaluated. This includes assessing the potential interaction of *Secondary Threats* and loading conditions on any known or postulated *Primary* threat-related anomalies on or within the asset.

For the purposes of an MAOP-R assessment, traditional threats categories defined in industry standards and commonly used in operator integrity programs are broken into three categories:

- **Primary, pressure sensitive threats:** those threats that are primarily influenced by circumferential stress (i.e., hoop stress) imparted by the operational pressure of the system. These include metal loss[13] and axially oriented crack-like features[14].
- **Secondary, non-pressure sensitive and resident threats:** those threats that are either **non-pressure sensitive** and primarily influenced by axial stressors[15,16] imparted by environmental and installation factors, such as girth welds or circumferentially oriented SCC (CSCC), or **resident** construction and manufacturing features such as dents, hard spots, wrinkle bends or mitered connections. Within traditional integrity programs these threats are often treated as time-independent or resident threats. For the purposes of reconfirming MAOP through a

[13] Metal loss includes both time-dependent metal loss in the form of external and internal corrosion, and resident metal loss caused by mechanical damage in the form of gouges and scrapes.

[14] Axially oriented crack-like features include both time dependent environmentally assisted cracking in the form of stress corrosion cracking (SCC), selective seam weld corrosion (SSWC), and hydrogen-induced cracking (HIC); manufacturing seam weld features, and cracking associated with mechanical damage. Cracks may exhibit time dependent behavior due to fatigue or environmental crack growth.

[15] Internal pressure induces axial stress in a pipeline component through the Poisson effect. However, this pressure-induced axial stress is typically approximately one-third the magnitude of the hoop stress in restrained pipe. While it can contribute to the growth of circumferentially oriented features, it is generally not the primary driving force. Instead, such features are more significantly influenced by other axial stressors, such as pipe bending, ground movement, or thermal expansion. The pressure-induced axial stress adds to the total axial stress but is usually secondary to these primary loading mechanisms.

[16] The Poisson Effect as it applies to cylindrical pipes is the contraction in the axial direction of a pipe due to the expansion of the pipe in the hoop direction. This contraction in the axial direction results in an axial stress equal to 1/3 of the hoop stress for a constrained (buried) pipe or up to 1/2 of the hoop stress for unconstrained (above-ground) pipe [11].

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FFS assessment, these *Secondary Threats* shall be considered for their potential existence and evaluated for their interaction with *Primary Threats* and destabilizing loading conditions.

– **Interacting environmental and operational loading conditions**: those conditions that interact with *Primary* and *Secondary Threats*, imparting the circumferential and axial stresses required to grow existing features through abnormal conditions or fatigue, or destabilize resident features. These include land movement, cyclic fatigue, and internal overpressure events. These threats are often considered within integrity programs as time independent threats.

Table 1 presents a mapping of these MAOP-R assessment threat and condition categories to each of the traditional 10 threat categories defined under API 1160, with consideration also given to the categorization of threats presented in ASME B31.8S.

Table 1: MAOP-R ECA to Integrity Management Threat Mapping [5]

		Integrity Management Threat Categories									
		External Corrosion	Internal Corrosion	Selective Seam Weld Corrosion	Environmentally Assisted Cracking	Manufacturing	Construction	Mechanical Damage	Weather and Outside Forces	Equipment	Incorrect Operations
MAOP-R ECA Threat & Loading Condition Categories	Primary, Pressure Sensitive Threats	X	X	X	X[3]	X[2]		X[1]			
	Secondary, Non-Pressure Sensitive/Resident Threats				X[4]	X[5]	X[6]	X[6,7,9]			
	Environmental & Operational Loading Conditions								X	X	X[8]

1. Metal loss in the form of gouges or scrapes or cracking associated with mechanical damage.
2. Axially oriented cracking in the form of seam weld features (e.g., hook cracks, lack of fusion), including as subject to fatigue.
3. Axially oriented, time-dependent cracking with growth potential (e.g., SCC, HIC/HAC).
4. Circumferentially oriented SCC.
5. Pipe body features (e.g., hard spots, laminations).
6. Girth weld anomalies, original construction dents, wrinkle bends, mechanical couplings, mandrel marks/ripples.
7. Plain dents, with depths up to 10 % do not pose an integrity threat alone but shall be considered for threat interaction.
8. Operational conditions leading to overpressure events or pressure-induced cyclic fatigue.
9. No method exists to calculate the failure pressure of a smooth dent. It is recognized; however, that internal pressure and pressure cycling play roles in the stability of existing dent features.

Established threat susceptibility criteria and integrity assessment data are used to confirm the presence or absence of specific threats at the time of the FFS evaluation. Threats determined to be inactive at the time of the FFS evaluation, but which may later emerge or reactivate due to deterioration, environmental conditions, or operational changes, are outside the scope of the FFS analysis and are managed through an operator's IMP. A new threat or loss of containment occurring after the FFS assessment does not invalidate the analysis unless the source data used at the time was incorrect, unavailable, or interpreted incorrectly.

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In some cases, the analysis may identify threats or conditions that render available FFS methods impracticable. This typically occurs when interacting threats are present for which no reliable failure pressure prediction models exist, or where available models are too complex or impractical to apply. Additional guidance on evaluating susceptibility to these threats within the context of an MAOP-R ECA process is provided in Section 4.7. This guidance is not intended to be exhaustive; rather, it highlights scenarios where integrity management (IM) considerations, such as assessment prioritization, may be insufficient to support reconfirmation of MAOP.

4.5.1 External & Internal Corrosion (Primary)

All carbon steel pipelines and components are inherently susceptible to external corrosion (EC) when exposed to a corrosive electrolyte, such as soil, atmospheric conditions, or marine environments. This susceptibility exists regardless of historical integrity performance or the presence of protective measures. As such, EC should be considered a credible threat in all MAOP-R assessments..

Internal corrosion (IC) susceptibility is variable and depends on operational conditions, gas or liquid quality, and system configuration. Operators may determine a pipeline segment as not susceptible to IC if this conclusion is supported by operational and integrity records, including product characteristics, flow regime, and historical inspection data. If evidence confirms that IC is not active (stabilized), this conclusion can be documented without further requirement for assessment.

For gas systems, IC susceptibility is governed primarily by the potential for water or hydrocarbon condensation (dew point control). Pipelines transporting "normally dry gas" (e.g., < 7 lb/MMscf water vapor) above the dew point and that are routinely pigged are generally considered lower risk. However, conditions that permit condensation, evidence of black powder, or liquids in drips indicate increased susceptibility and require further evaluation. When water is present, acid gases and contaminants such as CO_2, H_2S, oxygen, and organic acids can increase the risk and rate of internal corrosion [7].

For liquid systems, IC is typically associated with water bottoms or sludge accumulation in low-flow or stagnant areas such as drain lines, dead legs, and stub lines. These locations require particular attention, as do systems with operational upsets that can carry water or solids into the mainline [6].

4.5.2 Selective Seam Weld Corrosion (Primary)

Selective Seam Weld Corrosion (SSWC) is a type of corrosion that affects the bond line region and heat-affected zone (HAZ) of the longitudinal seam of a pipeline resulting in a groove-like appearance in the seam. The term "selective" refers to the preferential attack of the weld zone rather than the adjacent base metal. SSWC can be internal or external and has been observed in both gas and liquid pipelines.

Historically, SSWC has been observed on piping manufactured using both low and vintage high-frequency electric resistance welding (LF-ERW / HF-ERW), direct current ERW (DC-ERW), and electric flash welding (ERW) [5], [8], [9]. With the introduction of API 5L and 5LX requirements for post-weld heat treatment in 1967 and the reduction of sulfur content in steel produced from mid-1980 and onward, the overall likelihood of pipe seams susceptible to SSWC has been reduced for modern HF-ERW.

API 1160, Annex A.4 provides guidance regarding SSWC susceptibility. As a supplement to this guidance, recent research on SSWC susceptibility criteria has been performed, most notably through

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a 2024 report published by the Pipeline Research Council International, Inc. (PRCI) [9]. This PRCI report provided an update to the current industry understanding of and experience with SSWC and concluded that the most important parameters in determining susceptibility are seam weld type, vintage, and manufacturer in that order of importance. The pipe manufacturer is an important factor but not the most critical since the PRCI report indicated SSWC has been observed on pipes manufactured by at least ten different manufacturers.

The PRCI publication provided susceptibility guidelines based on four prioritization categories:

- **"High-High Priority":** for pipelines with past in-service failures attributed to SSWC.
- **"High Priority":** for pipelines with pressure test failures attributed to SSWC or those having all the characteristics of line pipe in which SSWC is typically found (including confirmed SSWC from in-the-ditch or cut-out metallurgical analysis).
- **"Medium Priority":** for pipelines exhibiting limited susceptibility factors and no confirmed history of SSWC features or related failures.
- **"Low Priority":** for pipelines with low susceptibility (e.g., post-1995 manufacture year, no external and internal corrosion anomalies reported by a recent ILI tool that are adjacent to, on, or cross the longitudinal seam weld).

Those assets categorized as "High-High Priority" or "High Priority" following the PRCI susceptibility guidance should be further evaluated to evaluate the potential for SSWC features and assess the FFS of any identified features for the purposes of MAOP-R. Those assets categorized as "Medium Priority" or "Low Priority" do not require further evaluation for the purposes of MAOP-R and should continue to be managed through an operator's IMP.

4.5.3 Environmentally Assisted Cracking

Environmentally assisted cracking (EAC) encompasses threats driven by corrosive attacks on the pipe metal caused by exposure to specific environmental conditions, either internal or external to pipe, and resulting in any of several forms of metal cracking. If identified the potential for these threats shall be considered, including but not limited to:

- axially and circumferentially oriented stress corrosion cracking (SCC),
- hydrogen-induced cracking (HIC),
- hydrogen-assisted cracking (HAC),
- hydrogen stress cracking (HSC),
- and sulfide stress cracking (SSC).

NOTE: For additional information on these and other EAC sub-threats (e.g., HSC, SSC), refer to the susceptibility guidance provided in ASME B31.8S, Appendix A-4 [4], API 1176, Section 6.2 [10], API 1188, Section 6.2.3 [6], and the additional industry guidance referenced therein.

4.5.3.1. Axial Stress Corrosion Cracking (Primary)

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Axial SCC in a soil environment is a form of EAC of line pipe that can form when an aqueous environment exists in combination with a cathodic protection system that is insufficiently designed or where cathodic protection (CP) is shielded from the pipe body. Shielding may occur as a result of disbonded coatings or high resistivity of the soil. Two forms of SCC may occur on a pipe segment, intergranular (high-pH) and transgranular (near-neutral pH). Both forms result in the development of longitudinal surface crack colonies that can link up to form long shallow cracking features [11], [12].

Three conditions are required for SCC to occur. These include susceptible material, a conducive environment, and the presence of tensile stressors, primarily driven by the circumferential stress (i.e., hoop stress) imparted from the operational pressure of the pipe. Industry knowledge on the driving factors of SCC and commonly accepted susceptibility criteria are outlined in ASME B31.8S and the Canadian Standards Association standard CSA SPE-225.7. A summary of the susceptibility criteria established within these two standards is presented in Table 2.

Table 2: Axial SCC Susceptibility Factors [4], [11]

Near Neutral pH SCC	High pH SCC
Below Ground and Onshore	
Pipe Age > 10 Years[1]	
Operating Stress > 60% SMYS	
Corrosion coating systems[2] other than plant- or field-applied Fusion-Bonded Epoxy (FBE) or Liquid Epoxy (when abrasive surface preparation was used during field coating application).	
Independent of distance from a compressor station.	Distance from compressor station discharge 20 < miles (32 km)[3]
Independent of Operating Temperature	Operating Temperature >100°F (38°C)

1. Age of pipe coating may be used if the pipeline segment has been assessed for SCC.
2. A stress level of 60% of SMYS is generally regarded as the threshold for susceptibility to SCC. However, SCC has been observed in pipelines operating below this threshold, typically in association with localized stress concentrators such as dents, gouges, weld toes, and mechanical damage. Residual stresses from pipe forming or welding may also contribute to susceptibility [10].
3. Coating system should include field joint coatings.
4. Distance downstream of a compressor discharge station should consider the reverse flow history of the line.

Susceptibility should be reviewed for the pipe body, seam weld and girth weld deposits, weld HAZ, and in-line pipe fittings within the MAOP-R extents. In addition to the factors listed above, any asset that has experienced a service incident or pressure test failure caused by SCC shall be considered susceptible unless the conditions that caused the SCC have been remediated.

If the pipeline does not meet established SCC susceptibility criteria, there is no history of SCC on the target asset or similar assets[17] within the operator's system, and the operator has a sufficient level of confidence in the records establishing pipe material attributes and coating details, a non-susceptible conclusion may be documented in the MAOP-R ECA without further inspection. In all other scenarios, further evaluation shall be performed using an integrity assessment method capable of fully characterizing axial-oriented SCC features and any identified features assessed for MAOP-R ECA.

4.5.3.2. Circumferential Stress Corrosion Cracking

[17] Similar assets, in the context of SCC susceptibility, may include assets with like coatings/coating performance (e.g., tape coat, coal tar enamel) and who's operational history aligns with the target asset (i.e., operating stress level, pipe/coating age, operating temperature, CP performance, upstream compressor distance).

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Susceptibility conditions for CSCC follow similar factors as those for axially oriented SCC with the major difference represented in the stress driving the crack growth. As discussed, axial SCC is driven by the hoop stress on the pipe. However, for CSCC the driving stresses are those related to locally high axial stressors. Due to axial stresses driving this threat, CSCC has been observed on pipelines operating at very low hoop stress levels, well below the axially oriented SCC stress threshold of 60% of SMYS [10].

Additional principal and secondary susceptibility factors have been identified within industry research on CSCC [11], [13]; however, use of these secondary susceptibility factors does little to narrow the pipe segments that may contain CSCC, with these factors indicating the majority of natural gas pipelines to be susceptible to CSCC. Instead, a more targeted approach to CSCC susceptibility should be utilized, wherein pipelines with a history of CSCC and those exhibiting the three major components required for CSCC should be reviewed for further assessment [13], [10].

- Susceptible Material:
  - CSCC has been seen on steel pipelines with a large range of wall thicknesses, diameters, grades, and ages; and
  - All steel pipelines should be considered as potentially susceptible to CSCC.
- Corrosive Environment:
  - Areas of disbonded / damaged coating;
  - Areas of inadequate cathodic protection (as defined in NACE SP0169) [14]; and
  - Areas of water collection or corrosive soil types.
- Locally High Axial Stress [13]:
  - Geological / hydrotechnical-based movement (e.g., landslides, erosion, insufficient pipe support);
  - Thermal expansion / contraction of the pipe;
  - Bottom-side dents caused by rocks in the trench; and
  - Other bending stressors (i.e., construction activities).

The threat of CSCC should be considered in the MAOP-R ECA by evaluating for potential interaction with other conditions that could apply locally high axial stress. This includes external loading conditions due to weather and outside forces threat like settlement or land movement. If it is confirmed that no potential for external axial loading exists for the pipe and there is no history of CSCC, then a non-susceptible conclusion may be documented for the MAOP-R ECA without further inspection. If potential interaction is determined, further evaluation shall be performed using an integrity assessment method capable of fully characterizing CSCC features and any identified features assessed for MAOP-R ECA.

4.5.3.3. Hydrogen Induced Cracking / Hydrogen Stress Cracking (including as related to Hard Spots) (Primary)

Hard spots are localized areas within the pipe wall exhibiting higher hardness than the surrounding base metal and have historically been introduced during vintage pipe manufacturing processes, often due to poor control of cooling rates that caused localized quenching of the steel plate. API 5L identifies

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a defective hard spot as "hardness exceeds 35 HRC, 345 HV10, or 327 HBW, based on individual indentations."

Hard spots are considered resident threats that do not affect a pipe segment's pressure-containing capacity unless cracking in the form of hydrogen-induced cracking (HIC) / Hydrogen Stress Cracking (HSC) becomes a concern, which can occur due to changes in service conditions such as coating degradation, soil chemistry, or cathodic protection effects [15].

Although hard spots are not inherently pressure-sensitive, they are included in the MAOP-R ECA evaluation due to their potential for initiation of hydrogen cracking and interaction with other threat features.

Hard spot susceptibility guidelines are provided in a recently published research report provided by PRCI, *PR727-22605-R01 Hard Spot Susceptibility Review* [16]. The PRCI report establishes a susceptibility scoring process that can be utilized by an operator to determine a pipe segment's susceptibility to hard spot defects. The scoring methodology is based on factors such as vintage, prior occurrence of hard spots, manufacturer, grade, cathodic protection history, operating stress, and toughness (if known). The results provide a numeric score for use within an IMP for prioritization for hard spots ranging from "Not a threat" to "Meaningful threat", with monitoring or ILI within certain time periods for scores of 35 or greater (Table 22 from the PRCI report).

Table 3: PRCI Table 22 – Suggested Threat Levels, Susceptibility Scores, and Response Times [16]

Threat Level	Threat Score	Recommended Baseline ILI
Not a threat	< 35	None
Low threat	35 – 47	Reevaluate threat in 10 years
Moderate threat	48 – 60	Plan ILI within 7 years
Meaningful threat	> 60	Plan ILI within 2 years

The threat susceptibility assessment should explicitly consider the potential presence of hard spots, including pipe body hard spots and long-seam associated hard spots, where indicated by pipe manufacturing process, vintage, operating history, prior leaks or failures, or other relevant information. The basis for determining susceptibility to hard spots and any limitations of the available data should be documented as part of the threat susceptibility evaluation. It should be noted that certain criteria can exempt a pipe segment from the hard spot susceptibility (such as newer vintages or seamless).

Hard spots may be treated as a non-limiting resident condition for the current ECA when the documented basis supports low susceptibility and no evidence of active or interacting hard spot-related damage, while baseline hard spot assessment and long-term follow-up remain part of the integrity management program.

4.5.4 Manufacturing-related Flaws

4.5.4.1. Seam Weld Cracking (Primary)

Problematic seam welds are manufacturing-related anomalies located within the bond line and/or HAZ of the pipe's longitudinal weld. These anomalies are typically associated with vintage manufacturing practices characterized by inadequate welding techniques, engineering specifications, and quality control procedures. The 2005 INGAA report *Integrity Characteristics of Vintage Pipelines* provides a detailed overview of historical seam weld processes [17].

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Vintage welding processes have been shown to produce crack-like anomalies[18] in the longitudinal weld, including cold weld, hook crack, plate misalignment, and lack of fusion (LOF). These anomalies are the result of manufacturing variability and limitations inherent in early welding techniques, such as poor alignment, inadequate / over trimming, or insufficient fusion during fabrication. Weld types with elevated risk for such anomalies include:

- Welds produced using autogenous welding processes, including:
  - LF-ERW;
  - DC-ERW; and
  - EFW.
- Processes resulting in pipe joint factors less than 1.0, including:
  - Lap-welding;
  - Hammer-welding; and
  - Furnace butt-welding
- Single submerged arc welding (SSAW).

While these processes were used widely across the industry, historical data and incident reviews have identified specific manufacturers and time periods with higher incidence rates of problematic seam welds. These are summarized in the INGAA report.

Seam weld anomalies from these legacy processes are typically treated as "resident threats" under ASME B31.8S and API 1160, provided the segment has passed a pressure test to at least 1.25 times the MAOP and are not subject to enlargement by pressure-cycle induced fatigue or interacting with other threats [4], [5]. Seam weld anomalies shall be evaluated for these potential growth mechanisms (e.g., pressure cycle-induced fatigue) and the presence of interacting threats [18].

If a pipeline segment cannot be confirmed to have undergone a qualification pressure test to 1.25 times MAOP and the seam weld threat remains unassessed, further evaluation shall be performed using an integrity assessment method capable of characterizing seam weld anomalies and any identified features assessed for MAOP-R.

4.5.5 Construction-related threats

Construction-related threats, as defined in ASME B31.8S, API 1160, and API 1188, include a range of features introduced during pipeline fabrication and installation[19]. These may include girth weld anomalies, original construction dents and mechanical damage from handling or backfilling, fabrication weld anomalies, wrinkle bends, ripples, buckles, and mechanical couplings.

These threats are generally considered resident unless subjected to elevated longitudinal strain or cyclic stresses. As such they are categorized as *Secondary Threats* within the context of MAOP-R and are not inherently limiting to the FFS conclusion for reconfirming MAOP. However, their potential to interact with *Primary, Pressure-sensitive Threats* (e.g., metal loss, axial cracking) or become

[18] Definitions and descriptions of these types of anomalies are provided within API 5T1.

[19] For the purposes of MAOP-R evaluations, rock dents and mechanical damage produced during installation activities are covered under the threat of Mechanical Damage.

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destabilized from operational and environmental loading conditions shall be assessed as part of the MAOP-R assessment.

To establish susceptibility to construction-related threats, operators can review available construction records and integrity assessment data for evidence of such threats either on the target asset or on other assets constructed concurrently or using similar construction practices. The influence of operational and environmental loading on the stress state at identified or postulated threat locations shall also be evaluated.

In the absence of information (e.g., ILI results, radiography records) that definitively rule out the presence of construction-related threats, their existence shall be assumed. In such cases, an assessment of potential interaction with destabilizing loads or other coincident threats will be conducted.

If the assessment demonstrates that no interactions exist which could compromise the pipeline at the designated MAOP, the MAOP-R evaluation may conclude that these postulated features do not pose a limiting condition, and no further action shall be taken for the purposes of MAOP-R.

If the assessment demonstrates interaction for postulated construction-related threats, then further evaluation shall be conducted to confirm the existence of the construction-related threat, the extent of that interaction, and the impact it has on the FFS of the segment.

NOTE For additional information on construction-related threats and their treatment in integrity evaluations, refer to ASME B31.8S, Appendix A-6 [4]; API 1160, Annex A.7 [5]; API 1188, Section 6.3.4 [6]; and related guidance cited within those standards.

4.5.5.1. Girth Weld Anomalies (Secondary)

Girth weld anomaly (GWA) prevalence has decreased over time due to improved welding practices and the introduction and broader application of radiographic and ultrasonic inspection methods. Where construction records confirm radiographic inspection of field welds, GWAs may be considered addressed for the purposes of MAOP-R. However, in most older pipelines, such records are unavailable or have deteriorated since the time of construction. In the absence of definitive documentation, GWAs shall be assumed to exist as resident features.

GWAs are circumferentially oriented features present within the weld and/or HAZ that are considered stable, resident features in the absence of critical longitudinal strain, either through geological / hydrotechnical-based movement, temperature effects, or surface loading cycles; and any interacting threats that may reduce the tensile strain capacity (TSC) of the girth weld [19], [4].

Failure mechanisms for GWAs are primarily driven by longitudinal strain demands that exceed the TSC of the girth weld. Under normal system operating and environmental conditions, strain demand typically remains below the TSC of the girth weld and any GWAs present will not present an FFS concern. The GWAs will have increased potential for failure if the strain demand increases, or TSC of the weld decreases, to a point where strain demand is greater than or equal to the TSC.

The primary consideration for MAOP-R is the demonstration that no such interactions exist. Segments identified as susceptible to GWAs should be evaluated for their interaction with each of these destabilizing threats. Factors to consider in the evaluation of interacting threats for GWAs are provided in Section 4.5.10.

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To collect strain and interacting threat data, an inertial measurement unit (IMU) ILI may be utilized in combination with other threat specific ILI technologies. When this data is combined with the pipeline's as-constructed / GIS-based coordinates, the strain along the length of the pipeline can be calculated. This strain data can then be analyzed to determine areas where external forces are causing pipe movement, increased bending / axial strain, or other high-strain events that may destabilize resident GWAs. If data from prior IMU ILI is available, run comparisons may be valuable to more accurately characterize these pipe movement areas and bending strain levels.

Where weld-specific conditions such as low toughness, transitional weld geometry, misalignment, undermatching, or other known deficiencies may reduce tensile strain capacity, and if these locations could interact with any destabilizing conditions, direct assessment or weld-specific analysis is required. [19], [4].

4.5.5.2. Wrinkle Bends (Secondary)

Wrinkle bends are circumferential pipe deformations introduced during legacy construction practices, typically through controlled field-applied bending. These field bending techniques were employed from early 1930s to mid-1950s and were largely eliminated with the adoption of modern design and construction codes such as ASME B31.4 and ASME B31.8 [17]. For susceptibility purposes, any pipeline constructed prior to mid-1950s with a diameter greater than 12 inches should be assumed to contain wrinkle bends unless construction records or ILI data confirm their absence.

Wrinkle bends are considered stable, resident pipeline features in the absence of interacting conditions, dynamic external loading conditions, or fatigue mechanisms [4].

If interacting conditions such as elevated longitudinal stress from external loading or coincident threats like metal loss, cracking, or seam weld anomalies are present, the behavior of the wrinkle bend may become unstable and may therefore require further assessment. In such cases, the assessment of the feature is not addressed within the scope of this document. In the absence of interacting threats, historical evidence supports the long-term stability of wrinkle bends [4].

4.5.6 Mechanical Damage

Mechanical damage, including dents, gouges, scrapes, and ovality, is a time-independent threat that can occur at any point during the lifecycle of a pipeline. Mechanical damage may result from ground disturbance activities such as excavation, equipment impact, improper backfilling, transportation, or handling during installation. Mechanical damage can be introduced by third-party activities or by operator personnel and contractors, whether during initial construction or routine inspection and maintenance activities. Because these threats may have occurred at any time in the asset's history and may be produced from both third-, second-, and first-party personnel, their potential presence shall be considered in all MAOP-R assessments.

When evaluating susceptibility to mechanical damage threats, operators should not assume these features are absent without confirmation from full coverage inspection methods or, for operator-controlled properties (e.g., compressor stations, pump stations, meter stations) the operator has sufficient historic records showing the assets has no history of activities having occurred that could have introduced mechanical damage.

The primary method of identifying the presence of deformation features is through metal loss and geometry ILI technologies. However, some metal loss tools may not result in reliable sizing of

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deformation features when using standard performance specifications. Due to this limitation, additional scrutiny and the use of appropriate assessment approaches shall be employed to ensure accurate characterization.

In the context of MAOP-R, mechanical damage threats shall be evaluated based on their classification and interaction with other features or loading conditions.

- *Primary, Pressure-sensitive Threats* such as gouges and scrapes shall receive full FFS assessment due to their potential to compromise pressure containment and interact with other threats.
- Mechanical damage categorized as *Secondary Threat*s in the context of MAOP-R, including dents and ovality, shall not require further evaluation if:
  - they do not exceed depth or dimensional thresholds,
  - do not interact with other coincident threats or loading conditions,
  - and these features also fall within acceptable limits defined by applicable industry standards and regulatory criteria.
- If *Secondary Threats* exhibit interactions with other threats, further evaluation shall be conducted to determine their impact on the asset's FFS and their acceptability for MAOP-R.

Mechanical damage in the form of buckles should be considered defects and remediated in accordance with applicable regulatory requirements.

If the piping under review is within the fence of operator-controlled property (such as a compressor station, pump station, or meter station) and there is no history of activity that could have introduced mechanical damage then the threat can be documented as assessed for the purposes of the MAOP-R. The primary requirement is to determine whether any threat interaction exists such as cracking, corrosion, or external loading that could compromise the feature's stability.

4.5.6.1. Dents (Secondary)

The failure of a dent can occur at two stages in its life cycle, with or without interacting features. These failure stages are "formation-induced failure" and "service-induced failure".

- formation-induced failure: involves the pipe wall deformation and damage associated with indentation (and removal of the indenter for unrestrained dents). It is possible that the contact with the indenter promotes immediate or short-term failure that can be identified as a formation-associated event.
- service-induced failure: involves the response of the dented pipe to internal pressure. The modes of failure can be associated with fatigue damage accumulation related to cyclic loading and/or reaching the dent failure pressure.

For the purposes of an MAOP-R assessment, only service-induced failures are relevant as it is understood that previous formation-induced failures would have already occurred.

Operators should perform assessments capable of identifying pipe wall deformation features and characterizing features coincident with identified dents. The presence of dents shall be determined along the entire length of the target MAOP-R segment. Dents may be screened as non-injurious only where coincident features and relevant interacting loading conditions have been evaluated and

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shown not to affect acceptability. Screening techniques to determine the injurious nature of identified dents are provided in API 1183.

Dents that are deemed non-injurious based on the screening approaches shall not require further assessment. Dent features that cannot be confirmed as non-injurious through this process will require further evaluation using available FFS assessment techniques.

Plain dents, regardless of shape, with depths up to 10 % of the pipe diameter and without coincident features, have been shown through testing to have similar failure pressure as plain line pipe [20], [21], [22]. The failure pressure of a dent interacting with corrosion should be evaluated to consider the interaction and be evaluated as isolated corrosion. Consistent with ASME B31.8, corrosion features interacting with dents up to a depth of 6 % OD may be evaluated independently. Further guidance may be drawn from available industry and regulatory requirements on dent interaction and remediation criteria.

The potential for cracking as a result of indentation should be evaluated in characterizing a plain dent. A dent with a crack or suspected crack is not considered a plain dent.

Operators should follow guidance provided in API RP 1183 for dent FFS assessment. Additional guidance on estimating the strain on dents identified through ILI or direct examination is available in ASME B31.8, Annex R [2].

4.5.6.2. Gouges and Scrapes (Primary)

Gouges and scrapes are forms of non-time dependent metal loss and, like external/internal corrosion metal loss, is a *Primary, Pressure Sensitive Threat*. As with other mechanical damage threat types, the susceptibility of a pipe segment to gouges and scrapes cannot be discounted and should be assessed for their presence on a target segment using appropriate integrity assessment methods (see Section 4.5.10), and interaction with other coincident features and loading conditions, including interaction with other mechanical damage features (i.e., dent-gouge features).

FFS assessments approaches for gouges and scrapes follow those of general corrosion-based metal loss. Where available, run comparison of metal loss features identified through ILI can be performed to identify growth and distinguish non-time dependent metal loss (i.e., gouges/scrapes) from corrosion-based metal loss.

4.5.6.3. Ovality (Secondary)

For the purposes of reconfirming MAOP through an FFS assessment, ovality of a pipe segment does not pose a threat to the safe operation of the segment unless out-of-roundness exceeds fabrication tolerances provided in the original construction code [1]. Measurements of an asset's maximum, minimum, and mean diameter should be gathered through appropriate integrity assessment methods. If a segment exceeds fabrication tolerances, further evaluations should be conducted using available FFS assessment techniques, such as API 579-1.

Interaction of ovality and the stresses imparted through it on coincident features should be considered when evaluating those interacting threats.

4.5.7 Weather-Related and Outside Forces / Geohazards

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To determine the structural integrity of assets at a target MAOP using FFS methodologies, operators shall consider the susceptibility of weather-related and outside forces (WROF) (i.e. geohazards) across the full extent of the target pipeline segment. For the purposes of MAOP-R, WROF is an interacting threat that includes external and environmental forces which may impart axial or bending strain on a pipe or component and includes environmentally driven cyclic-induced fatigue strain from thermal and surface loads. WROF that should be considered during an MAOP-R assessment include but not limited to:

- Geological-based movement (e.g., landslides, seismic activity);
- Hydrotechnical-based movement (e.g., flooding, scouring);
- Loss of supporting backfill (e.g., erosion, excavations);
- Surface loading (i.e., vehicle crossings);
- Thermal loading; and
- Frost heave.

WROF threats are primary failure mechanisms for features where structural stability is governed by strain capacity rather than pressure containment capacity. These forces have the potential to introduce stress conditions that result strain demands, which can impact the FFS of *Secondary, Non-Pressure Sensitive and Resident Threats*, such as CSCC, GWAs, and wrinkle bends. These features (excluding CSCC) are generally considered stable under normal loading conditions [4]. However, when subjected to axial or bending strain, the resulting strain may exceed the TSC of the feature, leading to failure [4], [23], [24], [19], [25].

Additionally, CSCC is influenced by axial and bending stress, which imparts strain on the feature such as in areas of ground movement or pipe bending [13], [10], [26]. *Primary, Pressure Sensitive Threats*, such as metal loss, seam weld anomalies, and axial-oriented body cracking (e.g., SCC, HIC), are primarily driven by hoop stress but can be exacerbated by axial stress and the associated strain introduced by WROF threats [25].

WROF threat susceptibility analysis requires the evaluation of various data sets, including qualitative data from monitoring reports and quantitative data from available sources such as IMU ILIs, light detection and ranging (LiDAR), or strain gauges. Operators should also consider the influence of casings and other pipe constraining elements (e.g., anchor weights, suspension brackets), which can introduce localized stress concentrations and restrict pipe movement. These constraints may elevate axial and bending stresses, increasing strain demand on resident features such as wrinkle bends and girth weld anomalys. These constraining elements should be evaluated as potential amplifiers, or in some cases mitigators, of WROF loading during MAOP-R assessments.

Additional guidance on the identification and evaluation of WROF can be found in:

- API 1187 – Pipeline Integrity Management of Landslide Hazards [27]
- API 1117 – Recommended Practice for Movement of In-Service Pipelines [28]
- API 1102 – Steel Pipelines Crossing Railroads and Highways [29]

4.5.8 Incorrect Operations

Incorrect operations are defined as incorrect operating procedures or failure to follow a procedure [4]. Incorrect operations can involve process upsets due to, but not limited to over pressurization, slug flow,

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cavitation, changes in fluid dynamics, upstream or downstream process changes, tank overfills [5]. PHMSA Advisory Bulletin (ADB-017-01) indicates this threat should always be considered active [30].

The primary consideration with respect to incorrect operations affecting an asset for the reconfirmation of MAOP would be through over-pressurization or cyclic operations that could destabilize an existing threat [5]. MAOP-R evaluations should include the review of abnormal operations and maintenance data, and historical failures caused by incorrect operations and the impact these events have on susceptible threats.

Pressure-cycle Induced Fatigue

Pressure fluctuations on a pipeline result in strain reversals. This can lead to fatigue failure if there is a pipeline feature such as axial crack-like features, GWAs, or wrinkle bend causing a localized increase in pipe stress and subsequent features growth [24], [31], [4]. Pressure fluctuation may result from operational activities or conditions, including:

- Pipeline start-up and shutdown – Particularly important for intermittent pipeline operations;
- Bi-Directional Pipelines – Flow reversal causing large pressure fluctuations;
- Pipeline Pigging – Regular maintenance pigging may result in pressure / flow reductions during runs; and
- Planned Pressure Reductions – Reductions in operating pressure resulting from planned excavations or integrity management activities.

Natural gas pipelines in normal operation typically do not see “aggressive” pressure cycling as is common within liquid operating lines. However, a review of pressure history records should be conducted to determine a system’s pressure cycle severity for the purposes of an MAOP-R assessment regardless of the product type. One of the methods used to evaluate pressure cycle severity is the Spectrum Severity Indicator (SSI). Gas transmission pipelines with calculated SSIs less than 50 are generally considered to be benign from a fatigue damage accumulation standpoint [32], while values greater than 50 may require additional assessment.

NOTE: It should be noted that the SSI threshold (i.e. below 50) was developed for application to gas transmission pipelines and may not be applicable to liquid pipelines.

Other methods used to characterize a system’s pressure cycle severity include, but are not limited to:

- PRCI’s MAT-8 categorization [33]; and,
- Baker TTO 5 categorization [34].

A detailed fatigue analysis should be considered to assess the impact to the pipeline’s fatigue life for both *Primary* and *Secondary* identified or postulated anomalies if the target asset has been identified to operate with aggressive pressure cycling.

GRI Report GRI-04/0178 may also provide additional information regarding fatigue due to pressure cycling [4].

4.5.9 Equipment

Equipment is defined as components other than pipe and pipe components, such as pressure control equipment, relief equipment, gaskets, O-rings, or seal/pump packing. All equipment impacting the operational conditions of an MAOP-R target pipeline shall be evaluated to determine if its continued use is commensurate with the target MAOP, including a review of the original ANSI ratings of in-scope

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equipment to the target MAOP. Additionally, the failure history of the equipment shall be reviewed to identify any impact such failures may have had on the historical operating conditions and the interacting influence of these operating conditions on susceptible threats.

The equipment devices, however, are not subject to FFS evaluations beyond their commensurate status to the target MAOP as pressure containment of this equipment is verified through the equipment's adherence to design codes and standards (e.g., ASME B16.34, API 520/521, ASTM A105) and their continued service conditions are monitored through an operator's Operations and Maintenance program.

4.5.10 Considerations for Interacting Threats

In the context of MAOP-R evaluations, the primary objective of assessing threat interactions is to determine whether a known or postulated anomaly can be reliably analyzed in isolation or whether the presence of additional interacting threats introduces complexities that shall be considered and could influence the predicted failure pressure of the feature. This evaluation serves two critical purposes:

(1) to confirm the absence of interacting threats, thereby validating the applicability of FFS models to the identified feature and conditions or the confirmed stabilized state of a resident feature; or

(2) to identify combinations of threats and loading conditions that could result in elevated or changed threat behavior or result in such a high degree of interaction or uncertainty that the established FFS approaches become technically invalid or operationally impractical.

Common threat interaction categories identified from the review of regulatory incident data and industry standards have been compiled and published within the PHMSA Report DTPH56-14-H-00004, *Improving Models to Consider Complex Loadings, Operational Considerations and Interactive Threats* [35]. The interactions established within that report have been expanded upon aligning with the threat and loading conditions described in industry integrity management standards (ASME B31.8S, API 1160, API 1188) and are utilized within this RP.

Table 4 – Interacting Threats

		Time Dependent			Stable (Resident)								Time-Independent							
		EC	IC	SCC	MFR		CONST			EQUIPMENT				IO	TPD			WROF			
		External Corrosion (EC)	Internal Corrosion (IC)	Stress Corrosion Cracking (SCC)	Defective Pipe (DP)	Defective Pipe Seam (DPS)	Defective Fabrication Weld (DFW)	Defective Girth Weld (DGW)	Construction Damage (CD)	Malfunction of Control or Relief Equipment (MCRE)	Stripped Threads, Broken Pipe, or Coupling Failure (TSBPC)	Gasket Failure (GF)	Seal or Pump Packing Failure (SPPF)	Incorrect Operations (IO)	Third Party Damage (TP)	Previously Damaged Pipe (PDP)	Vandalism (V)	Earth Movement (EM)	Heavy Rains and Floods (HRF)	Lightning (LT)	Cold Weather (CW)
EC	EC			X	X	X		X	X[1]	X	X[3]	X		X	X	X		X	X		X
IC	IC				X	X		X		X		X		X							
SCC	SCC				X	X	X	X	X[4]	X				X				X	X		
MFR	DP					X	X	X	X	X[2]					X[7]	X[7]	X[7]				
	DPS								X[5]	X[2]				X[6]	X[7]	X[7]	X[7]	X			
CONST	DFW										X			X	X			X	X		X
	DGW								X	X					X	X		X	X		X[8]
	CD									X[2]	X							X	X		

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EQUIP	MCRE										X	X	X	X	X	X			X	X	X
	TSBPC													X	X			X	X		X
	GF													X	X		X	X	X	X	
	SPPF													X							
IO	IO														X		X	X	X		X
TPD	TP																	X	X		
	PDP																	X	X		
	V																				
WROF	EM																		X		X
	HRF																				X
	LT																				
	CW																				

Source: Adapted from DTPH56-14-H-00004, Final Report No. 16-228 to US DOT PHMSA

Table 4 Footnotes:

1. Interaction applies unless the history of the segment indicates the construction damage has not contributed significantly to corrosion.
2. Interaction applies if the segment has not been subject to a pressure test to at least 1.25 times MAOP
3. Interaction applies if the Dresser-coupled segment has no CP or has CP but no bonds to the Dresser couplings
4. Interaction applies unless it can be shown either that little or no coating damage exists or that the segment is not susceptible to SCC
5. Interaction applies if the pipe is seam-welded and was installed with wrinkle bends
6. Interaction applies if the pipe was manufactured with low-frequency welded ERW seam or flash welded seam
7. Interaction applies unless it is known that the pipe material exhibits ductile fracture behavior under all operating circumstances
8. Interaction applies only to pipe joined by acetylene girth welds or girth welds of known poor quality

When evaluating threat interactions for use in MAOP-R assessments, threat features and operational/environmental loading conditions should be overlaid geospatially along the pipeline. This interaction assessment can be performed by overlaying, comparing, and integrating relevant data sets for the scoped asset, including pipeline attributes, construction factors, operating parameters and history, integrity assessment history, maintenance and repair history, and incident data.

4.6 Inspection Methods to Support FFS of Susceptible Threats

The completion of an MAOP-R ECA requires the gathering, integration, and / or generation of data. Asset data needed to perform MAOP-R assessments is outlined in Annex B – Data Threat Mapping.

When required data is unavailable, additional data may be obtained or generated through several approaches. The most cost-effective method, when feasible, is to conduct further records research. This involves leveraging combinations of existing records, information, engineering principles, and procurement and construction practices to validate or establish a sufficient level of confidence in material attributes (see Section 4.3).

If records research does not yield sufficient data, required information may be generated using validated technologies and assessment processes capable of characterizing anomalies associated with susceptible threats. These include:

- ILI surveys; and
- Full coverage NDE.

When selecting integrity assessment methods to support an MAOP-R assessment, it is important to consider the potential for interacting threats. Assessment methods should be selected considering the

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methods capabilities to detect and size interacting features and any limitations such interactions may impose on a particular method's accuracy to detect and size features.

Spatially aligning and correlating ILI survey data with other ILI surveys and/or other data sets (e.g. GIS) can improve the probability of identification.

Guidance on available ILI technologies, and limited NDE technologies are available within the following industry standards:

- ILI Technology Guidance:
  - NACE SP0102, In-Line Inspection of Pipelines [36]
  - API Standard 1163, In-line Inspection Systems Qualification [37]
  - API RP 1176, Assessment and Management of Cracking in Pipelines [10]
  - ASNT ILI-PQ, In-Line Inspection Personnel Qualification and Certification [38]
  - Pipeline Operators Forum, Specifications and requirements for in-line inspection of pipelines
- NDE Technology Guidance
  - API 1188, Hazardous Liquid Pipeline Facilities Integrity Management, Table 3[20] [6]

Table 5 – Inspection Technologies supporting ECA

	ILI Technologies[1]				NDE Technologies					Screening Approaches		
	MFL-A	MFL-C	Geometry ILI	EMAT/UT	IMU[3]	Radiography	GWUT	Visual Inspection	Magnetic Particle Inspection	ECDA	ICDA	SCCDA
External Metal Loss	Yes	Yes	—	Yes	—	Yes	Yes	Yes	Yes	Yes	Yes	—
Internal Metal Loss	Yes	Yes	—	Yes	—	Yes	Yes	—	—	—	Yes	—
Seam weld anomalies	—	Limited[2]	—	Yes	—	Yes	—	Limited	Limited	—	—	—
Axial body cracks (SCC, HIC, HSC)	—	Limited[2]	—	Yes	—	Yes	—	Yes	Yes	—	—	Yes
Circumferential cracks (CSCC, GWA)	Limited[2]	—	—	Yes	Limited[3]	Yes	—	Yes	Yes	—	—	—
Hard Spots[5,6]	Yes	Yes	—	—	—	—	—	—	—	—	—	—
Dents[8] / Deformations / Ovality	Limited	Limited	Yes[9]	Limited	—	—	—	Yes	—	—	—	—
Wrinkle Bends[7]	Yes	Yes	Yes	Limited	Yes	—	—	Yes	—	—	—	—

Table 5 notes:

1. All ILI technologies require consideration of probability of detection (POD), probability of identification (POI), and probability of sizing (POS).

[20] NDE technologies presented for facilities may be applied to any above ground or excavated assets, provided the limitations of the technology does not exclude it for use on the target asset.

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2. MFL technologies are not well suited for detection and sizing of all crack types; however, they may still provide benefit in crack inspection when paired with EMAT as they are commonly used as a screening tool for identifying the long seam and also aid in discriminating crack-like anomalies from seam variations such as excess trim.
3. The analysis of bending strain utilizing an IMU can identify pipe-effects in areas where there is potential for land movement. IMU cannot measure cracking directly however is useful for determining susceptibility to circumferentially oriented features or land movement interaction.
4. Any detection method utilized should be able to identify the location (i.e., bond line, HAZ, both) of the crack-like flaw and its dimensions
5. Hard spots require assessment as part of an ECA when the documented susceptibility evaluation or available inspection/data indicate the hard-spot threat is credible and potentially interacting at the time of assessment. A low or not-a-threat susceptibility together with no crack-like indications and no evidence of interacting corrosion or other activating conditions supports treating hard spots as a non-limiting resident condition for the one-time ECA, with any baseline hard-spot assessment and longer-term follow-up addressed through the operator's integrity management program.
6. To detect hard spots on susceptible pipeline segments, an ILI survey capable of detecting and reporting hard spots is typically relied upon. Technologies for identifying hard spots primarily rely on MFL to detect and size hard spots by measuring changes in the residual magnetic field or the magnetic permeability. It's likely that multiple inspection technologies will be required to assess hard spots and any potential interacting threats. Inspection methods such as magnetic particle testing, eddy current, acid etching and hardness testing can be deployed to further understand the extent of a hard spot, confirm hardness measured by an ILI tool, and/or identify cracks or other interacting conditions within the hard spot. It should be noted that current direct examination methods rely on measurements at the outer surface and the ILI relies on measurement from inside the pipe. As a result, hardness assessments may represent conditions at the internal surface or through the wall thickness, depending on the inspection technologies used.
7. Sizing tolerances of the tools at the location of the wrinkle should be considered when assessing the potential for threat interaction and the need for further assessment via excavation and NDE testing.
8. For assessment of dents with coincident features or interacting flaws, operators should consider applicable guidance in API RP 1183, API RP 1160 (including interacting threat guidance), API RP 1176 for dent-associated cracking and threat interaction, and API 579-1/ASME FFS-1 Part 12 for dent-gouge combinations. Where multiple threat types coexist and cannot be assessed independently, the operator should document the basis for the interaction treatment and any limitations of the selected assessment method. Dents may be screened as non-injurious only where coincident features and relevant interacting loading conditions have been evaluated and shown not to affect acceptability.
9. Plain dents can be identified using geometry ILI tools equipped with mechanical calipers, eddy current, or ultrasonic sensors.

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4.7 Choose Appropriate Fitness-for-Service Models for Analysis

The selection of appropriate FFS models is a critical step in the evaluation of flaws identified through integrity assessments, as the chosen model directly influences the accuracy and conservatism of the overall MAOP-R assessment.

Multiple models have been developed to calculate failure pressure or remaining life for various flaw types, including corrosion, cracks, and mechanical damage. Most commonly used FFS models are empirically derived or calibrated against specific full-scale test datasets. Consequently, applicability may be limited to certain ranges of material properties and flaw geometries, and use outside those ranges may produce non-conservative results.

Personnel responsible for selecting and applying FFS models should understand underlying assumptions, applicability, and limitations. Model selection should consider the characteristics of the known or assumed feature population, available data, pipe material and geometry, associated uncertainties, and the intended use of the results. In practice, model selection balances technical rigor, regulatory requirements, and operational practicality [42].

This document is not intended to provide a comprehensive list of available FFS models or prescribe their use in all circumstances. Additional models may be appropriate, including those not specifically addressed in this document or applicable regulations. The technical basis for selecting and applying a model should be documented, with consideration given to the following:

- Model applicability, assumptions, and limitations,
- Validation or benchmark evidence supporting its use,
- Software verification and configuration, where applicable,
- Minimum input data quality requirements and associated uncertainties, and,
- Documented technical review or SME involvement, as appropriate

Applicable regulatory requirements should be reviewed prior to selecting a model, as they may prescribe specific methodologies or establish approval requirements for alternative approaches. When a non-standard model is selected, its technical suitability and compliance with applicable regulatory requirements must be demonstrated and documented.

The applicability of a given FFS model depends heavily on the nature of the flaw being evaluated. For corrosion-related metal loss, models such as ASME B31G, Modified B31G, RSTRENG, Psqr [43] [44] and API RP 579 Level 1 are commonly used, each offering varying degrees of conservatism and complexity. These models have been validated through full-scale burst testing and are suitable for use with both ILI and NDE gathered data.

For mechanical damage such as dents, specialized models exist but are often limited by a lack of broad validation and the challenges of accurately characterizing such flaws non-destructively. Consequently, selecting a FFS model (if applied) shall be flaw-specific and informed by the available data, the limitations of the model, and the intended outcome of the assessment [42].

It may be determined during the threat susceptibility analysis that certain threats or conditions exist which, if remaining in the pipeline, disqualify an asset from being a viable candidate for MAOP-R using the ECA method. These scenarios are referred to as exclusionary conditions, and they represent combinations of threats, conditions, or data limitations that prevent the effective application of FFS methodologies. Exclusionary conditions typically arise in cases where failure pressure prediction models are either unavailable or unsuitable for assessing the remaining strength of the pipeline, or where the complexity of

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the threat interactions make modeling impractical. Examples include deformations with coincident cracking, wrinkle bends subjected to dynamic loading, or other conditions where reliable characterization cannot be achieved with current inspection or modeling capabilities.

Exclusionary condition scenarios generally fall into one or more of the following categories:

- **Technically Unsupported**: These are conditions where the assumptions or boundary conditions required by available FFS models, such as flaw isolation, uniform stress fields, or material properties are not met or cannot be validated. In such cases, applying standard FFS models may not yield technically sound results.
- **Operationally Impractical**: These scenarios involve complex interactions among threats, loading conditions, or material behaviors that can be modeled with advanced analysis such as FEA but the effort required to collect, validate, and analyze the necessary data may exceed the practicality or value of the assessment outcome.

When conducting MAOP-R evaluations, operators shall consider whether any threats present on the asset fall into these exclusionary categories. If so, the use of FFS methodologies may not be appropriate, and alternative MAOP-R approaches should be pursued. Technological advancements in inspection and modeling capabilities may eventually enable the assessment of some current exclusionary conditions through FFS methodologies that utilize complex or risk-based solutions.

An overview of commonly utilized FFS approaches is provided below. These approaches are categorized based on the specific feature types they are designed to assess and include:

- Metal Loss Model Approaches
- Fracture Mechanics Model Approaches
- Wrinkle Bends Assessment Approaches
- Dents and Dent Gouge Assessment Approaches

4.7.1 Metal Loss Models

Failure pressure prediction models available for metal loss evaluation vary in complexity and conservatism, ranging from simple screening tools to advanced analytical techniques. The selection of an appropriate model should be guided by the quality of available data, the severity and morphology of the metal loss feature, and the intended use of the assessment – in the case of an MAOP-R assessment this is the determination of predicted failure pressures for identified and postulated metal loss anomalies with a confidence level equal to or greater than that provided by a pressure test.

Full discussion on the data, equations, and process for implementation of each approach described herein does not appear in this RP. Evaluations should be carried out in accordance with the procedures described in the referenced sources. Individuals conducting evaluations should have appropriate training in the use of any approach selected for the MAOP-R assessment. When evaluating the FFS of identified and postulated metal loss features based on ILI data, appropriate established growth rates must be applied from the date of the inspection to the ECA date. Guidance on metal loss growth rates is provided in Section 5.3 of this RP.

Metal loss FFS models can be categorized into three levels of assessment, each offering a different balance between complexity and conservatism.

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4.7.1.1. *Level 1*

Level 1 assessments provide a simplified and conservative estimate of failure or burst pressure which can then be used to establish a Failure Pressure Ratio (FPR). These methods typically rely on a small number of input parameters, such as the maximum depth and axial length of the metal loss feature and are suitable for rapid screening and prioritization of anomalies identified through ILI assessments.

Common Level 1 models include:

- ASME B31G
- Modified B31G
- API 579 Level 1

These models are widely used due to their simplicity and regulatory familiarity, but they tend to be conservative and may overestimate the severity of certain flaws.

4.7.1.2. *Level 2*

Level 2 assessments improve upon Level 1 by incorporating more detailed flaw geometry. These models reduce conservatism by accounting for the cross-sectional corrosion profile and extent of the metal loss feature, making them suitable for integrity validation and operational decision-making.

Examples of Level 2 models include:

- Effective Area Method (RSTRENG)
- Psqr Model
- API 579 Level 2

4.7.1.3. *Level 3*

Level 3 assessments offer the highest fidelity of feature analysis and are typically reserved for critical defects or high-consequence areas. These methods may use similar principles as Level 2 but require integration of extensive data and advanced computational tools such as finite element analysis (FEA).

Level 3 assessments are capable of modeling complex geometries, material behavior, and loading conditions, and are often used to simulate burst tests or validate pipeline performance under unique conditions.

Common Level 3 approaches include:

- API 579 Level 3
- Custom FEA-based models

4.7.2 Fracture Mechanics Models

The assessment of crack-like flaws in pipelines requires the selection of fracture mechanics models that align with the specific flaw type, pipe materials, and operating conditions identified on the target asset. API 1176 thoroughly addresses crack management, providing guidance on some of the more common

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fracture mechanics models for use in addressing pipe body, seam, and circumferential cracking flaws – including:

- NG-18 Ln-Secant
- CORLAS™
- PRCI MAT-8
- API 579-1/ASME FFS-1, Part 9

As with metal loss and other flaw type models, crack-like features models have been empirically derived and calibrated against industry datasets, accounting for a large range of material toughness values and flaw geometries; however, not all models are validated for all possible combinations of inputs. For example, the NG-18 Ln-Secant and modified Ln-Secant models are only appropriate for ductile failure modes. Analysts selecting and performing FFS evaluations should fully understand the capabilities and limitations of any model chosen for use when conducting an MAOP-R ECA.

Identified and postulated crack or crack-like features that meet the acceptance criteria outlined in that Standard, including assessments for interaction with other threats, may be considered acceptable for MAOP-R ECA. Additionally, those crack-like features with growth potential, either through environmental (i.e., corrosion) or fatigue-induced growth, shall be evaluated for the remaining life of the feature using appropriate crack growth rates. Guidance on remaining life is provided in Section 5.3 of this RP.

4.7.2.1. *Selective Seam Weld Corrosion Models*

SSWC is observed as axially oriented, groove-like features that can have failure modes that behave more like cracks than corrosion. As such, conventional corrosion models (e.g., B31G, RSTRENG) are not considered appropriate; fracture-mechanics or seam-specific models should be used to establish failure pressure ratio and remaining life.

Various models have been used within the industry to estimate failure stress for crack-like features associated with SSWC. API 1160 identifies the following models as appropriate for estimating rupture pressure for these features [5]:

- NG-18 Ln-Secant
- CORLAS™
- API 579, Part 9

Additional models such as Raju/Newman, MAT-8, and BS 7910, and others have also been applied [9], [8], [45]. Studies evaluating fracture mechanics models applied to SSWC have shown that these models can exhibit increased uncertainty because they vary in how effectively they account for key factors influencing burst pressure such as residual stress, toughness, bond strength, crack-tip bluntness, and interactions with adjacent features. [45]. Model selection for SSWC should be based on the characterized anomaly morphology, available toughness / residual-stress / bond-line data, and the ability of the inspection or NDE method to support the chosen model. Where available evidence indicates seam-adjacent or preferential corrosion rather than true crack-like SSWC, the operator should document the basis for the classification and select the assessment accordingly.

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4.7.2.2. *Girth Weld Anomalys*

Any GWAs in a system that are identified as subject to pressure-induced cyclic fatigue, or external axial forces (e.g., geological / hydrotechnical-based movement) should be evaluated either through excavation and direct examination or weld-specific analysis.

Tensile Strain-based Models

Multiple tensile strain-based models have been developed over the years for use in determining FFS of pipelines regarding the behavior of girth welds.

Many of these models function under the same principles, provide similar results, and exhibit common limitations; with the applicable upper strain range of the models between 2-3%.

When utilizing tensile strain-based modeling for the assessment of GWAs, operators shall consider the presence of transitional welds (joining two pipes of un-equal wall thicknesses) and their effect on the tensile strain capacity of the girth weld. Information on transitional welds, their effects on a weld's TCS, and guidance on how to adjust strain-based models is provided in the PHMSA report *Strain-Based Design and Assessment in Critical Areas of Pipeline Systems with Realistic Anomalies* [25].

Full GWA Characterization Model – API 1104

A well established and industry accepted FFS process that utilizes fracture mechanics for the evaluation of girth welds currently exists as detailed in API 1104 Annex A [46]. Similar FFS processes exist within *CSA Z662 Annex K* [47] and other industry publications; however, these will not be expanded upon in this RP.

The API model lays out a foundation for evaluating the FFS for welds that do not meet the workmanship criteria presented within the standard. This FFS approach is based on fracture mechanics and evaluates weld imperfections as if they are planar or crack-like, regardless of their geometric attributes. Three "options" are presented within API 1104 Annex A for determining the acceptance limits of planar girth weld anomalys, with each "option" becoming more complex and wider in range of applicability [46].

Additionally, use of API 1104 Annex A is restricted to the following conditions:

- Circumferential welds between pipes of equal specified wall thickness;
- Non-destructive inspection performed for essentially all welds;
- No gross weld strength undermatching;
- Maximum axial design stress no greater than the specified minimum yield strength (SMYS);
- Maximum axial design strain no greater than 0.5%;
- Welds in pump and compressor stations, fittings, and valves in the main line are excluded; and
- Repair welds are excluded for Options 1 and 2 but can be assessed using Option 3 if desired.

4.7.3 Wrinkle Bend Evaluations

Wrinkle bends are considered resident features that do not pose an FFS concern so long as they are not disturbed through external forces, fatigue inducing conditions, or other interacting threats [4]. While advanced modeling techniques exist for wrinkle bends interacting with select threats and conditions (e.g., metal loss, cyclic fatigue), full FFS analysis of wrinkle bends with potentially destabilizing interactions are often impractical due to the complexity of the interactions and limitation on existing inspection

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technologies and analysis models. For the purposes of the MAOP-R, the simplest approach is to screen for potential threat interactions.

Wrinkle bends identified on a pipeline segment should be evaluated using a structured screening process to determine the presence and significance of interacting threats, specifically,

- Pipe body or seam cracking
- External forces (e.g., geotechnical or hydrotechnical movement)
- Mechanical damage

If interaction with any of these threats is suspected, the wrinkle bend should be excavated and remediated through repair or replacement.

For wrinkle bends interacting with metal loss or subject to cyclic fatigue, further evaluation may be considered based on the availability of high-resolution data and the practicality of conducting detailed analysis.

- Metal loss features interacting with a wrinkle bend should be assessed independently using appropriate metal loss FFS models [24], [41]. See Section 4.7.1 for guidance on model selection and implementation.
- Fatigue life models may be applied where wrinkle bends are subject to aggressive pressure cycling or environmental fatigue loading (i.e., surface loading, thermal cycles). These models require detailed wrinkle geometry and stress data and are generally reserved for critical assets where excavation is not feasible. Details on these modes are provided below.

In most cases, screening for threat interaction followed by repair or replacement is expected to be the primary method for managing wrinkle bends with potential integrity concerns.

FFS Approach for Wrinkle Bends Subject to Cyclic Fatigue

Multiple models for determining the fatigue life of wrinkle bends exist. The majority of these models focus on establishing stress/strain concentration factors (SCFs) using FEA, then applying a simplification schema to reduce the FEA results to a closed form.

4.7.4 Dents and Other Mechanical Damage

Dent and dent-gouge flaw evaluation is addressed in API 1183 and should be reviewed for details on data requirements and the assessment process. Dents that meet the acceptance criteria outlined in that Standard, including assessments for interaction with other threats (coincident features), may be considered acceptable for MAOP-R. Features that do not meet these criteria or that exhibit interaction shall be addressed in accordance with applicable integrity management procedures. Scrapes and gouges, where present, should be evaluated as metal loss using API 579-1/ASME FFS-1 or an equivalent validated method.

A FFS assessment of dents shall consider three primary failure mechanisms:

- Cracking initiated during dent formation;
- Dent failure pressure limits; and
- Fatigue damage accumulation.

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For each failure mechanism the effects of interacting features shall be evaluated. Additionally, it is important to evaluate the potential for crack initiation resulting from dent formation such that the FFS assessment can evaluate the potential for the existence of a crack in the dent. Due to the reduction in pressure containment capacity of a dent due to the presence of cracking, in some instances the presence of cracking is used as the failure pressure limit condition. Alternatively, a FAD approach is applicable in conjunction with FEA.

Assessment of an MAOP-R segment for dents should utilize key dent feature parameters gathered through ILI or NDE, including:

- Dent geometry and shape;
- Dent feature clock position;
- Dent restrain condition (restrained or unrestrained)
- Presence of coincident features (e.g., metal loss, cracks, welds, gouges)

Based on comprehensive data for the feature and operational loading history, operators can assess the condition of the target MAOP-R segment for identified dents. Testing has shown that plain dents (regardless of shape) with depths up to 10% of the pipe diameter and without coincident metal loss, weld, or crack features, have the same failure pressure as plain line pipe [48]. When coincident features are present within or near the dent, failure pressure may be evaluated using dent shape and material properties. The assessment shall consider future operating pressure conditions.

For MAOP-R, operators should assess the dent fatigue life based on integrated data gathered for the feature. Fatigue life implications may be evaluated at three levels depending on dent shape [49]:

- Level 1 – Fatigue Severity Ranking
- Level 2 – Closed Form Fatigue Life Assessment
- Level 3 – Finite Element Analysis

Level 1 and Level 2 approaches are applicable for restrained and unrestrained single-peak dents. A Level 3 FEA-based detailed fatigue life assessment may be used to assess any dent shape, regardless of restraint characterization. The effects of interacting features on fatigue life should be evaluated when performing any fatigue assessment.

Further information on detailed dent fitness-for-service assessments can be found in API 1183. The approaches presented in API 1183 represent a summary of available techniques; alternate engineering analysis approaches, such as those in the Pipeline Defect Assessment Manual (PDAM) [50], and testing techniques may be used to complete dent FFS assessment. Alternate methods and processes applied should be documented [49].

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5 Analysis

5.1 Demonstration of Remaining Strength Supporting MAOP

Following completion of the threat susceptibility assessment, characterization of feature populations and their critical dimensions, verification of material properties, and selection of appropriate FFS methodologies to assess the behavior of identified or postulated anomalies, the pipeline remaining strength shall be calculated using the selected analytical models and compared against the target MAOP. For MAOP-R applications subject to location-based (i.e., Class) regulatory margins, the acceptance check

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is based on the lowest predicted failure pressure for any known, postulated, or interacting defect, divided by the greater of 1.25 or the applicable location factor for the asset being evaluated. If the lowest predicted failure pressure among all known or potential anomalies, when accounting for interacting conditions and uncertainties (e.g., tool tolerance, assumed growth), can be shown to exceed the target MAOP by a sufficient safety margin, the MAOP may be considered reconfirmed. Features that do not demonstrate an adequate safety margin at the target MAOP should be addressed in accordance with the operator's IMP and any applicable regulatory requirements for remediation.

While execution of the chosen FFS model(s) to evaluate known features and validate the pipeline segment's fitness for continued operation at the established MAOP is a central element of the MAOP-R ECA process, it is not the only requirement.

5.2 Postulated Features

Postulated features to consider for the purposes of an ECA include hypothetical remaining anomalies that may be below the size detection capabilities (or reporting thresholds) of an integrity assessment method (i.e., usually an ILI tool), referred to as "just-missed flaws" (JMF) and hypothetical remaining flaws that may have survived a previous pressure test, referred to as "just-surviving flaws" (JSF).

Just-Missed Flaws (JMF)

JMFs should be considered for certain susceptible threats and where a suitable ILI survey has been completed to characterize the remaining anomalies related to that threat. The consideration of JMFs recognizes that certain undetected or unreported anomalies could remain in the pipe and, for time-dependent threats, continue to grow after the inspection. Since detected and reported flaws from ILI would meet the associated vendor thresholds, the consideration of JMFs is most important when there are no feature calls from the ILI inspection which can often be the case for crack-like feature detection. Therefore, the application of a JMF analysis primarily lends itself to the threat assessment approach for SCC, SSWC and manufacturing-related flaws (long seam) where crack-like feature inspection technologies such as EMAT or MFL-C have been applied. While this does not preclude its application with the external/internal corrosion and mechanical damage threats, the minimum detection and reporting thresholds of these mature MFL-A and geometry ILI technologies are not expected to result in limiting features in the analysis (i.e., undetected or unreported features that would have dimensions larger than actual remaining features already assessed as part of the analysis or dimensions that would require a remediation response). Therefore, the consideration of a JMF after a metal loss MFL ILI or geometry ILI would not represent any critical or limiting feature with respect to an ECA. Also, consideration of a JMF after a hard spot MFL ILI would involve a hard spot that is well below the criteria of a defined hard spot,[21] and, with no response requirement or growth mechanism, would not represent a critical or limiting feature with respect to an ECA. See Annex F for a detailed example of this analysis.

Just-Surviving Flaws (JSF)

Typically, JSFs should be considered for susceptible threats, particularly in the absence of remaining flaw information that would be available from ILI. Similar to JMFs, the application of a JSF analysis primarily lends itself to the threat assessment approach for crack-like features such as SCC, SSWC and Manufacturing-related Flaws (long seam). Most ECAs are expected to be driven by the lack of a TVC pressure test. It is expected that this approach may be applied in limited ECA circumstances where the

[21] API 5L defines hard spot defects as: "a localized area with a hardness greater than 35 HRC, 345 HV10, or 327 HBW and with a dimension greater than 2.0 in (50 mm) in any direction".

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pressure test is available but may not be relied upon to establish the MAOP (e.g., MAOP established using high-operating pressures but where a pressure test has been completed, or a legacy pressure test that may not meet current regulatory stress or documentation requirements). In these cases, information on previous pressure test levels, can still provide supporting, complementary value to the overall threat assessment and consideration of JSFs within an ECA. Similarly, information on mill pressure test levels that are supported by Material Test Reports (MTR) or by mapping the pipe information to API 5L mill pressure test requirements associated with that pipe can also provide value in understanding the JSF profile of resident manufacturing features. See Annex F for a detailed example of this analysis.

5.3 Establishing and Applying Growth Rates

Growth rates may be established using various approaches to support the evaluation of corrosion and crack-like features, if a growth mechanism exists. Crack growth rates may be derived from industry guidance such as API RP 1176 [28], or through validated fracture mechanics models that account for fatigue and cyclic loading effects. These rates are applied to align feature dimensions with the evaluation period or to assess future behavior up to the established MAOP. When used for MAOP-R, historical ILI data (including assumptions for a hypothetical JMF, if applicable), or a hypothetical JSF should be adjusted using growth from the date of the assessment to the completion date of the ECA to reflect current conditions.

5.4 Remaining Life Assessment for Cracks

Where time-dependent cracking or crack growth is credible, growth assumptions shall be also applied to assume future condition by projecting feature growth to evaluate remaining life. The crack-growth methodology should be selected according to the governing mechanism. For fatigue-driven growth, remaining life may be expressed as cycles-to-failure or life fraction. For environmentally assisted cracking, remaining life should be based on time-dependent growth to critical flaw size, with cycle-dependent contributions included where applicable. Where both mechanisms are credible, a coupled crack-growth analysis or the more limiting justified approach should be used.

The ECA shall calculate and document the remaining life for the governing flaw set including the growth models applied, including assumptions, limitations, and conservatism applied and should establish the estimated remaining life. The estimated remaining life does not affect MAOP-R conclusion; however, the results should be incorporated into the operator's IMP to support reassessment planning and long-term integrity decisions.

6 Conclusions and Acceptance

The reconfirmed MAOP is based on the lowest predicted failure pressure for any known, postulated, or interacting defect, divided by the greater of 1.25 or the applicable location-based factor. Any probabilistic or supplemental analytical output does not replace this minimum acceptance basis for MAOP-R.

The completed ECA demonstrates that the pipe maintains adequate safety margins against internal pressure failure. Where certain conditions cannot be directly modeled with failure pressure equations, the ECA demonstrates through susceptibility analysis, inspection data, or other engineering evidence that those conditions are not credible or do not exceed serviceability limits.

All MAOP-R ECA methods including FFS analysis performed, results, and conclusions shall be reviewed and confirmed by qualified SMEs and shall be approved by designated competent personnel.

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To be considered complete, the report shall be approved by a designated competent authority within the operator's organization.

7 Record Keeping

The MAOP-R ECA report forms a new basis for MAOP. Supporting data, information, and internal procedures in place at the time of the ECA shall be maintained for the life of the asset, similar to a hydrostatic test record.

MAOP-R ECA reports shall include, (where applicable);

- Source records (or specific references to sources) for all data and information used as a basis for analysis;
- Descriptions of data quality and integration processes used and process results;
- Failure criteria used in the determination of predicted failure pressures for each flaw type evaluated and justification of the criteria used;
- Documentation of all evaluations and any assumptions used in the MAOP-R ECA process;
- Documentation of all investigations, tests, analyses, assessments, repairs, replacements, alterations, and other actions taken to complete the MAOP-R ECA.
- Vendor performance specifications
- Software name and version
- Model configuration and libraries used
- SME/Technical basis supporting any alternate or non-routine assessment method used in the final ECA conclusion

In many cases MAOP-R ECAs rely upon data contained in operators' GIS or other data repositories. Data is often classified using criteria such as TVC and is routinely validated against engineering specifications, manufacturing standards and specifications, business rules, or trusted sources. In these cases, the ECA report should include (or specifically reference) the processes and procedures that establish the data validation criteria, evaluate records and data against the criteria, integrate records and data from multiple sources, and perform data validation. Any deviations from the processes and procedures related to the MAOP-R ECA scope and a statement of the suitability of the data as a basis for the specific ECA should also be included.

The processes used and results of the evaluation of threats, including susceptibility, interaction, identification, and FFS analysis shall be documented. A statement of the suitability of the results as a basis for the specific FFS assessment should also be included. Annex A – MAOP-R ECA Report Outline contains an MAOP-R ECA report outline and includes sections for records assessment and appendices for: Pipeline/Facility Attribute Data, Records Assessment and Relevant Operating Procedures.

8 Qualification of Personnel

Any company employee or contracted personnel that complete activities associated with an ECA for MAOP-R shall possess the technical competency to complete the required activities and analysis.

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Personnel qualifications should be commensurate with the complexity and significance of the assessment, and the ECA (or supporting procedure) should define minimum roles for preparation, technical review, approval, and subject matter expert support. Alternate, non-routine, or especially complex analyses should receive an independent technical review.

The qualifications of personnel should be documented and retained in the appropriate operator defined record retention system or in project specific documentation.

The following factors should be considered:

- Performance of applicable calculations and interpretation of test data and results.
- Knowledge of code requirements and regulations
- Familiarity with data collection methods and limitations
- Familiarity with FFS models including limitations

As the MAOP-R ECA relies upon activities already performed by integrity management functions, this is not expected to add undue burden or new training in engineering or analysis approaches. Technical competency to complete the MAOP-R ECA can likely be achieved through leveraging a combination of existing operator training, competency, and quality assurance programs.

9 Additional Considerations

An ECA for MAOP-R is a one-time event, analogous to a qualifying post-construction pressure test to establish MAOP and does not need to be updated solely due to age or periodically revised once completed, provided the supporting data were accurate and complete at the time of the assessment. However, conclusions should be reassessed if material new information, data errors, or updated verification results affect the original technical basis using sound engineering judgement. If integrity threats are identified that were not present at the time of the ECA, established integrity management processes govern.

The integration of material attribute and threat condition data from multiple sources is critical to the FFS evaluation process. Any management or regulatory review will focus primarily on the completeness and traceability of records supporting the analysis. While the engineering methodologies embodied in the specific FFS approaches are each well-established and validated by industry, their effectiveness is contingent upon proper application and use of accurate input data.

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Annex A – MAOP-R ECA Report Outline

(Informative)

The following is an example of a MAOP-R ECA report outline.

Contents

Executive Summary

1. Introduction and Background
2. Objective and Scope
3. Pipeline/Facility Overview
   - 3.1 Pipeline/Facility Configuration and Operating Parameters
   - 3.2 Pipe Properties
   - 3.3 Pipe Appurtenances (if relevant)
4. Pipeline/Facility History
   - 4.1 Incident History
   - 4.2 Operating Conditions and Pressure Cycling
   - 4.3 Integrity Assessment History
   - 4.4 Prior Pressure Tests (if available)
5. Records Assessment
   - 5.1 Background
   - 5.2 Material Verification
   - 5.3 Assessment of Material Properties
6. Engineering Critical Assessment
   - 6.1 Corrosion
     - 6.1.1 Corrosion Management Programs
     - 6.1.2 External Corrosion
     - 6.1.3 Internal Corrosion
     - 6.1.4 Selective Seam Weld Corrosion
   - 6.2 Stress Corrosion Cracking
     - 6.2.1 Stress Corrosion Cracking Management Programs
     - 6.2.2 Susceptibility Analysis
     - 6.2.3 Stress Corrosion Cracking History
     - 6.2.4 Integrity Assessment Results
     - 6.2.5 Stress Corrosion Cracking Conclusion
   - 6.3 Third Party/Mechanical Damage – Dents and Deformations
     - 6.3.1 Damage Prevention and Public Awareness Programs
     - 6.3.2 Integrity Assessment Results
     - 6.3.3 Analysis of Dent and Deformation Inspection Data
     - 6.3.4 Third Party/Mechanical Damage Conclusion
   - 6.4 Manufacturing Threats
     - 6.4.1 Manufacturing Threat Management Programs
     - 6.4.2 Seam Cracking
     - 6.4.3 Hard Spot Cracking
   - 6.5 Construction-Related Threats
     - 6.5.1 Construction-Related Threat Management Programs
     - 6.5.2 Girth Weld Cracking

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6.5.3 Wrinkle Bends
6.5.4 Other Construction-Related Features
6.6 Interacting Threats
6.6.1 Incorrect Operations
6.6.2 Geotechnical and Hydrotechnical Threats
6.6.3 Interacting Features
6.6.4 Interacting Threats Conclusion
7. Conclusions and Recommendations

Appendices

(Delete specific Appendices if not applicable)

Appendix A Pipeline/Facility Attribute Data
Appendix B Records Assessment
Appendix C ILI Tool Performance Validation *(Delete if not applicable)*
Appendix D Relevant Operating Procedures and Fitness for Service Guides
Appendix E ECA Personnel and Roles
Appendix F Abbreviations
Appendix G References

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Annex B – Data Threat Mapping

(Informative)

This table provides a detailed mapping of threat-related data, operating conditions, and loading conditions relevant to FFS evaluations for each threat category. The table is intended as non-mandatory guidance. Operators should evaluate the applicability of the identified data and conditions to their specific circumstances and may consider additional factors, as appropriate.

Attribute	EC	IC	SSWC	MD	MFG	CT	SCC	IO	OF	EQP	Source
Pipe Specific											
Outside Diameter	EC	IC	SSWC	MD	MFG	CT	SCC				Records / ILI
Wall Thickness	EC	IC	SSWC	MD	MFG	CT	SCC				Records / ILI
Seam Type (incl. age)			SSWC		MFG	CT					Records / ILI / Lab Testing / In-the Ditch NDT
Yield Strength	EC	IC	SSWC	MD	MFG	CT	SCC				Records / Lab Testing / In-the Ditch NDT / Assumptions
Tensile Strength			SSWC		MFG	CT	SCC				Records / Lab Testing / In-the Ditch NDT / Assumptions[Error! Bookmark not defined.]
MAOP	EC	IC	SSWC	MD	MFG	CT	SCC	IO		EQP	Records
Installation Date	EC	IC	SSWC	MD	MFG	CT	SCC	IO		EQP	Records
Construction Records (NDT, as-builts, weld procedures, bending methods)					MFG	CT					Records
Operating History (pressure and temperature)	EC	IC	SSWC		MFG	CT	SCC				Records
Integrity History (assessments and incidents)					MFG	CT	SCC				Records
Loading Conditions	EC	IC									Calculation, Simulations
Mainline Coating	EC		SSWC	MD	MFG		SCC				Records / Inspections / Assumptions[Error! Bookmark not defined.]
Joint Coating	EC		SSWC				SCC				Records / Inspections / Assumptions[Error! Bookmark not defined.]
Coating Condition	EC		SSWC		MFG		SCC				Records / Inspections / Assumptions[Error! Bookmark not defined.]
Future Corrosion Allowance	EC	IC	SSWC								Reinspection Interval needs
Coating Year	EC						SCC				Records
Cathodic Protection Data	EC										Records
Desired Operating Period	EC	IC									Reinspection Interval needs
Pipe Manufacturer	EC		SSWC		MFG		SCC				Records
Pipe Manufacture Date	EC		SSWC		MFG						Records

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Attribute	EC	IC	SSWC	MD	MFG	CT	SCC	IO	OF	EQP	Source
Pipe Material Toughness	EC	IC	SSWC		MFG	CT					Records / Lab Testing / In-the Ditch NDT / Assumptions Error! Bookmark not defined.
Crack-Tip Opening Displacement (CTOD) Values for Welds			SSWC		MFG	CT					Records / Material Testing / Assumptions Error! Bookmark not defined.
Hardness Values [weld metal, base metal, HAZ]					MFG						Records / Material Testing / Assumptions Error! Bookmark not defined.
Toughness Values – Weld Metal and HAZ [22] (e.g., Charpy V-notch values)			SSWC		MFG	CT	SCC				Records / Material Testing / Assumptions Error! Bookmark not defined.
Exposed Pipe	EC			MD			SCC		OF		
Water Crossing				MD							
Pressure Cycle			SSWC		MFG		SCC				
Hard Spot Presence					MFG						
Longitudinal Weld Joint Factor			SSWC		MFG						Records / Material Testing / Assumptions Error! Bookmark not defined.
Exceeds 110% MOP (liq) or MAOP (gas)								IO			
Tensile Strain Capacity						CT					Records / Inspections / Assumptions Error! Bookmark not defined.
Threat Specific Data											
Wrinkle Bend presence						CT					ILI / In-the Ditch NDT
Wrinkle Height						CT					ILI / In-the-Ditch NDT
Wrinkle Length						CT					ILI / In-the-Ditch NDT
Wrinkle spacing						CT					ILI / In-the-Ditch NDT
Wrinkle Orientation (clock position)						CT					ILI / In-the-Ditch NDT
Wrinkle Circumferential Extend						CT					ILI / In-the-Ditch NDT
Seam Orientation (relative to 12 o'clock pipe position)			SSWC		MFG						ILI / In-the-Ditch NDT
Crack Growth			SSWC		MFG		SCC				ILI / In-the-Ditch NDT
Crack –Length			SSWC		MFG		SCC				ILI / In-the-Ditch NDT
Crack - Width			SSWC		MFG		SCC				ILI / In-the-Ditch NDT
Crack - Depth			SSWC		MFG		SCC				ILI / In-the-Ditch NDT
Crack – Location (bond line, HAZ)			SSWC		MFG						ILI / In-the-Ditch NDT
Crack –Orientation					MFG		SCC				ILI / In-the-Ditch NDT
GWA Length (circumferential extent)						CT					ILI / In-the-Ditch NDT
GWA Depth						CT					ILI / In-the-Ditch NDT

[22] Research into seam weld defects has shown that the toughness in an ERW seam can vary significantly in the same joint of pipe [39].

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Attribute	EC	IC	SSWC	MD	MFG	CT	SCC	IO	OF	EQP	Source
GWA Orientation (Clock Position)						CT					ILI / In-the-Ditch NDT
Tensile Strain Capacity						CT					Records / Material Testing / Modeling
Hard Spot – Hardness					MFG						ILI / In-the-Ditch NDT
Hard Spot – Length					MFG						ILI / In-the-Ditch NDT
Hard Spot – Width					MFG						ILI / In-the-Ditch NDT
Corrosion Feature Length – maximum	EC	IC									ILI / In-the-Ditch NDT
Corrosion Feature Width – maximum	EC	IC									ILI / In-the-Ditch NDT
Corrosion Feature Depth – maximum	EC	IC									ILI / In-the-Ditch NDT
Effective profile dimensions	EC	IC									ILI / In-the-Ditch NDT or Laser Profile
Corrosion growth rate	EC	IC									SOPs, calculations, coupons / probes, ILI run comparisons
Method used to evaluate uncertainties	EC	IC									POE
Standard deviation of input data	EC	IC									Calculated: min/avg/COV in values
CP System Performance			SSWC		MFG						Records
Coating Type and Condition			SSWC		MFG						Records / In-the-Ditch NDT
Threat Interaction											
Length – Metal Loss			SSWC	MD	MFG	CT	SCC				ILI / In-the-Ditch NDT
Width – Metal Loss			SSWC	MD	MFG	CT	SCC				ILI / In-the-Ditch NDT
Depth – Metal Loss			SSWC	MD	MFG	CT	SCC				ILI / In-the-Ditch NDT
Metal Loss Orientation (relative to wrinkle apex)				MD		CT					ILI / In-the-Ditch NDT
Metal Loss – Orientation (relative to crack features)			SSWC	MD	MFG		SCC				ILI / In-the-Ditch NDT
Crack - Length			SSWC	MD	MFG	CT					ILI / In-the-Ditch NDT[23]
Crack – Depth			SSWC	MD	MFG	CT					ILI / In-the-Ditch NDT**Error! Bookmark not defined.**
Crack Orientation (relative to wrinkle apex)			SSWC	MD	MFG	CT					ILI / In-the-Ditch NDT**Error! Bookmark not defined.**
Seam Orientation (relative to wrinkle apex)			SSWC	MD		CT					ILI / In-the-Ditch NDT
Mechanical Damage Orientation (relative to wrinkle apex)				MD		CT					ILI / In-the-Ditch NDT
Mechanical Damage Dimensions (length, width, depth)				MD		CT					ILI / In-the-Ditch NDT
Geological / Hydrotechnical Information				MD		CT	SCC		OF		Records / Assumptions**Error! Bookmark not defined.**

[23] At the time of this RP development, existing ILI technology is not considered to be effective at identifying and/or characterizing cracks in a wrinkle deformation.

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Attribute	EC	IC	SSWC	MD	MFG	CT	SCC	IO	OF	EQP	Source
Local Linear Polarization Resistance (LPR)					MFG						In-the-Ditch NDT
Strain Demand				MD		CT					ILI / In-the-Ditch NDT
Deformations				MD	MFG						ILI / In-the-Ditch NDT
CP System Training and Operator Performance History								IO			Records / Assumptions

EC – External Corrosion
IC – Internal Corrosion
SSWC – Selective Seam Weld Corrosion
MEC – Mechanical Damage (i.e., dents, gouges, scrapes)
MFG – Manufacturing Flaws (i.e., seam weld flaws)
CT – Construction Threat
SCC – Stress Corrosion Cracking
IO – Incorrect Operations
OF – Outside Forces
EQP – Equipment Failure

Material Testing in this table includes both Laboratory Metallurgical Analysis and In-the-Ditch NDT Methods

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Annex C

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Annex D – 49 CFR Part 192 MAOP Reconfirmation Boundaries

(Informative)

Operators should develop guidance detailing the process for identifying emergency valve(s) and/or isolation valve(s) as the boundary for piping and components requiring MAOP-R. When establishing the extent of pipe and components requiring MAOP-R consideration should be given to the relative spatial accuracy of various data sources and potential future changes to data and information that may impact the extent. Examples of changes that may impact the extent of the MAOP-R include; updates to the location or identification of new dwellings or other features that impact the extent of class or consequence areas, updates to material attributes resulting from material verification processes. The potential for such changes should be considered at the outset of the MAOP-R process and the extents determined accordingly.

Piping and ancillary components should be evaluated based on the methodology for establishing the MAOP in alignment with 49 CFR § 192.619 to determine if MAOP-R is required. Piping and components smaller than 2 inches with MAOP established by § 192.619(c) can be eliminated from MAOP-R requirements when the maximum operating stress is < 30% SMYS. However, there is no regulatory basis for eliminating any piping and components from MAOP-R requirements when MAOP is established by § 192.619(a). Additional general guidance is provided below to assist operators in determining MAOP-R facility boundaries that meet the requirements of 49 CFR Part 192. The following diagrams are not intended to be fully comprehensive of all scenarios.

Gas Transmission Mainline Valve and Bypass – MAOP-R is applicable to all piping and components that are not isolated from mainline pressure up to the isolation valve(s) where the MAOP was established in accordance with § 192.619(a), and all piping and components that are not isolated from mainline pressure up to the isolation valve(s) where the MAOP was established in accordance with § 192.619(c) operating at ≥ 30% SMYS.

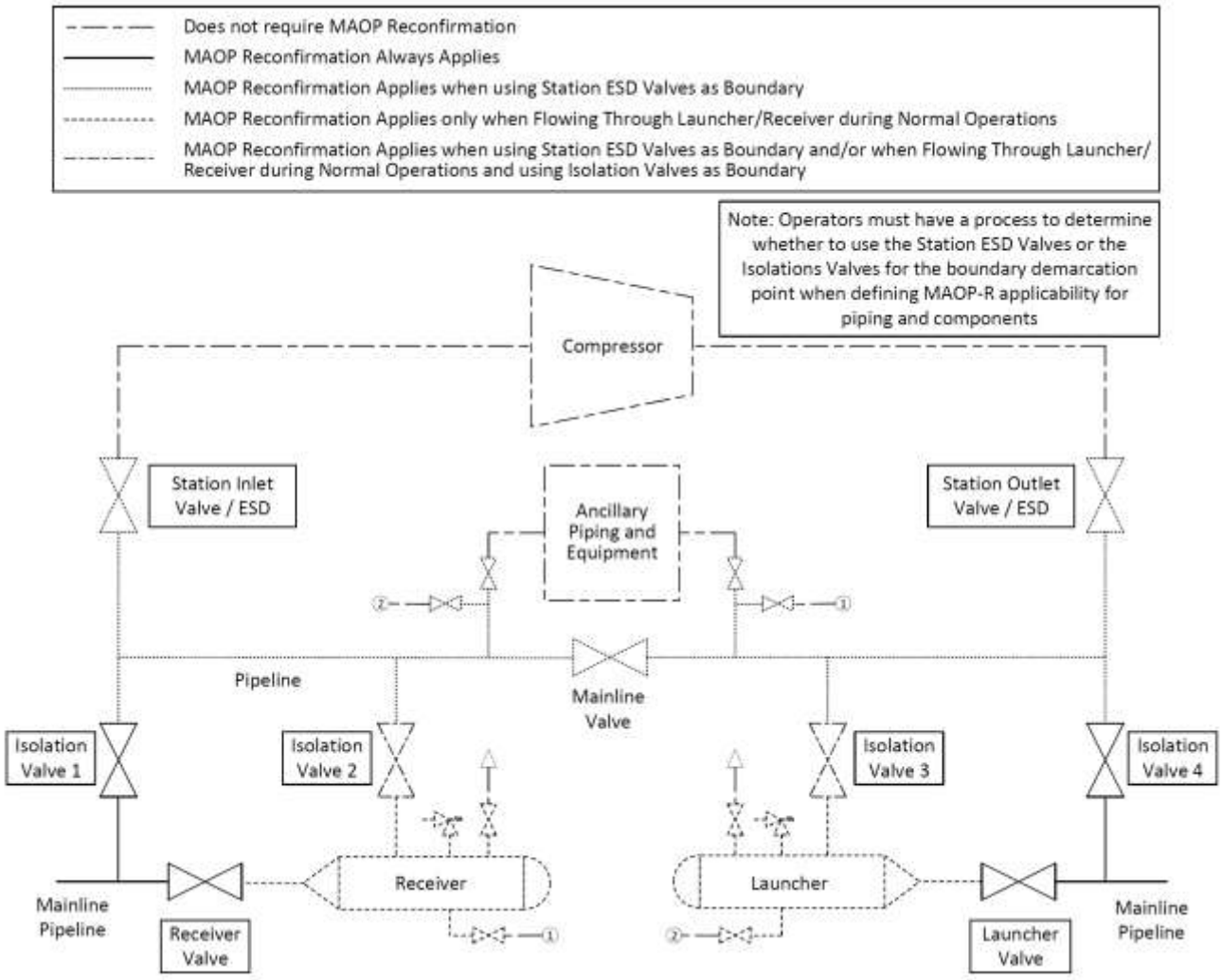
Compressor Station Launcher and Receiver Traps – The applicability of MAOP-R at compressor stations follows the same guidelines regarding § 192.619(a) and § 192.619(c) detailed in the second paragraph of this Annex. If the launcher or receiver trap isolation valves are normally in the closed position, MAOP-R is applicable to all piping and components that are not isolated from mainline pressure up to the isolation valve(s) or station ESD valve(s) where the MAOP was established in accordance with § 192.619(a), and all piping and components that are not isolated from mainline pressure up to the isolation valve(s) or station ESD valve(s) where the MAOP was established in accordance with § 192.619(c) and is ≥ 30% SMYS. If the launcher and receiver trap isolation valves are normally in the open position, MAOP-R is applicable to all piping and components that are not isolated from mainline pressure up to the isolation valve(s) or station ESD valve(s) where the MAOP was established in accordance with § 192.619(a), and all piping and components that are not isolated from mainline pressure up to the isolation valve(s) or station ESD valve(s) where the MAOP was established in accordance with § 192.619(c) with the MAOP ≥ 30% SMYS. This includes the launcher and receiver barrels, connections to bypass piping, kicker lines and other piping and components. Launcher and receiver barrels should meet the material properties and pressure verification determination requirements for non-line pipe components detailed in § 192.607(f)(3).

Depending on the valves used as the boundary limit, the entire gas path should be evaluated to determine if MAOP-R is applicable. As an example, if the station ESD valves are used as the boundary, and the launcher and receiver are isolated from the gas path, the piping and components requiring MAOP-R include the launcher valve, receiver valve, four isolation valves, mainline valve, station inlet and outlet ESD valves, and all directly connected piping and valves. As an alternative example, if isolation valves one (1) through four (4) are used as the boundary and the gas flow path is through the launcher and receiver, the launcher valve, receiver valve, all four isolation valves, along with the launcher and receiver and any directly connected piping and components, would require

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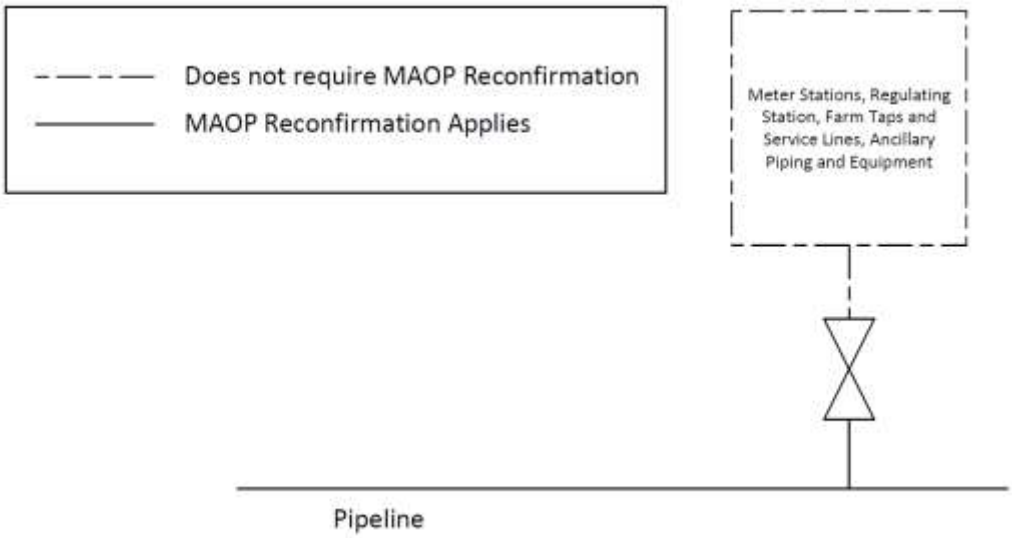
MAOP-R.



Gas Transmission with Meter Station, Regulator Stations, Farm Taps and Service Lines – MAOP-R is applicable to all piping and components that are not isolated from mainline pressure up to the isolation valve(s) or station ESD valve(s) at meter and regulator stations where the MAOP was established in accordance with § 192.619(a), and all piping and components that are not isolated from mainline pressure up to the isolation valve(s) or station ESD valve(s) where the MAOP was established in accordance with § 192.619(c) operating at ≥ 30% SMYS.

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Drips – MAOP-R is applicable to all piping and components associated with drips that are not isolated from mainline pressure where the MAOP was established in accordance with § 192.619(a), and all piping and components that are not isolated from mainline pressure where the MAOP was established in accordance with § 192.619(c) operating at ≥ 30% SMYS.

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Annex E – 49 CFR § 192.632 Reference Index

(Informative)

Each threat and loading/operational condition that is required to be considered within *CFR § 192.632* is mapped to threat categories defined in consensus industry standards and commonly used in operator IMPs. This mapping is intended to provide intuitive, structured guidance to facilitate execution of this process using data and records regularly generated through standard integrity activities.

Table 6: Integrity Management to MAOP-R ECA Threat Mapping [4]

		Integrity Management Threat Categories									
		External Corrosion	Internal Corrosion	Selective Seam Weld Corrosion	Environmentally Assisted Cracking	Manufacturing	Construction	Equipment[1]	Mechanical Damage	Incorrect Operations	Weather and Outside Forces
MAOP-R ECA Threat & Loading Conditions	Loadings and Operational Conditions										
	Geo/Hydrotechnical-based Movement								X		X
	Surface Loading										X
	Cyclic Fatigue (pressure cycle-, vibrational-, thermal-induced)									X	
	Operational Temperature Changes									X	
	Overpressure and Other Abnormal Operating Condition									X	
	Crack or Crack-like Features										
	Seam Weld Cracking			X		X					
	Pipe-Body Cracking – Axial				X						
	Pipe-Body Cracking – Circumferential				X						
	Girth / Fabrication Weld Flaws					X					
	Wall Loss / Metal Loss	X	X				X		X		
	Dents								X		
	Wrinkle Bends						X				
	Hard Spots					X					
	ASME B31.8S Threat Categories	**Time Dependent**				**Resident**			**Time Independent**		

1. Equipment devices are not subject to FFS evaluations beyond their commensurate status to the target MAOP

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Table 7: § 192.632 to API RP11xx Reference Index

§ 192.632 Requirements	§ 192.632 Category	Details	Section Reference
ECA Analysis	Data Integration and Analysis	Material Properties	4.3.2, 4.3.3
		Results of all tests, direct examinations, destructive tests, and assessments performed	4.3.4, 4.3.5, 4.3.6
		Close interval surveys, coating surveys, interference surveys required by subpart I of Part 192	4.3.6
		Cause analyses of prior incidents	4.3.6
		Prior pressure test leaks and failure, and other leaks	4.3.5 4.3.6
		Pipe inspections	4.3.6
		Prior integrity assessments	4.3.6
	Material Properties	Diameter	4.3.2, 4.3.3
		Wall thickness	4.3.2, 4.3.3
		Seam type	4.3.2, 4.3.3
		Grade (minimum yield strength and ultimate tensile strength	4.3.2, 4.3.3
		Charpy v-notch energy (where required)	4.3.2, 4.3.3
	Predicted Failure Pressure	Crack or crack-like defects.	4.7.2
		Metal loss defects not associated with a dent. ASME/ANSI B31G or R-STRENG	4.7.1
		Gouges, scrapes, SSWC, crack-related defects, or any defect within a dent. Provide appropriate failure criteria and justification of the criteria must be used and documented	4.7.2, 4.7.2.1, 4.7.4
		Unknown SMYS or actual material yield and ultimate tensile strength.	4.3.2
	Interacting defects	Conservatively determine the most limiting predicted failure pressure	4.5.10
	MAOP establishment	Lowest predicted failure pressure for any known or postulated defect, or interacting defects, remaining in the pipe.	5.1, 5.2
Assessment to determine defects remaining in the pipe	Previous subpart J compliant pressure test	Calculate the largest defect that could have survived the pressure test	5.2
		Predict defects growth since date of pressure test	5.2, 5.3
		Analyze the predicted size of the largest defect that could have survived the pressure test that could remain in the pipe at the time the ECA is performed	5.2
		Calculate the remaining life of the most severe defects that could have survived the pressure test	5.2, 5.3, 5.4
		Establish a re-assessment interval in accordance with the methodology in § 192.712	5.4
	Inline inspection program	Completed in accordance with paragraph (c) of [§ 192.632]	4.6
	Other technology	Validated by a subject matter expert to produce an equivalent understanding of the condition of the pipe equal to or greater than pressure testing or an inline inspection program. Requires PHMSA notification in accordance with § 192.18.	4.6
In-line inspection	Must include a tool that can detect hard spots if susceptible		4.6
	Must include a tool that can detect girth weld defects if a reportable incident attributed to a girth weld failure since the last pressure test	Not required if the ECA analysis performed in accordance with this section includes an engineering evaluation program to analyze and account for the susceptibility of girth weld failure due to lateral stresses	4.6

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§ 192.632 Requirements	§ 192.632 Category	Details	Section Reference
	Must be preformed in accordance with § 192.493		4.6
	Validate the performance of the ILI tools	Identifying and sizing actionable manufacturing and construction related anomalies	4.4.1.1
		Validate tool performance at the same or better statistical confidence level provided in the tool specifications	
		Must have a process for identifying defects outside the tool performance specifications and following up with the ILI vendor to conduct additional in-field examinations, reanalyze ILI data, or both	
	Interpretation and evaluation of assessment results must meet the requirements of §§ 192.710, 192.713, and subpart O	Must conservatively account for the accuracy and reliability of ILI, in-the-ditch examination methods and tools, and any other assessment and examination results used to determine the actual sizes of cracks, metal loss, deformation and other defect dimensions by applying the most conservative limit of the tool tolerance specification	4.4.1, 4.4.1.1
		ILI and in-the-ditch examination tools and procedures for crack assessments (length and depth) must have performance and evaluation standards confirmed for accuracy through confirmation tests for the defect types and pipe material vintage being evaluated	4.4.1.2
		Inaccuracies must be accounted for in the procedures for evaluations and fracture mechanics models for predicted failure pressure determinations	4.4.3
		Anomalies detected by ILI assessments must be remediated in accordance with applicable criteria in §§ 192.713 and § 192.933	5.1
Defect remaining life	Must estimate the remaining life of the pipeline in accordance with § 192.712.	If any pipeline segment contains cracking or may be susceptible to cracking or crack-like defects found through or identified by assessments, leaks, failures, manufacturing vintage histories, or any other available information about the pipeline.	5.4
Records	Record retention	Must retain records of investigations, tests, analyses, assessments, repairs, replacements, alterations, and other actions taken in accordance with the requirements of this section for the life of the pipeline.	7

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Annex F – Just Missed Flaw Analysis & Just Surviving Flaw Analysis

(Informative)

JMF Example - SCC

This example considers an EMAT ILI completed on a pipeline to assess the SCC threat for an ECA. Fracture mechanics models can be used to define an array of flaw dimensions (lengths and depths) that correspond to a predicted failure pressure. Figure 4 represents a critical flaw size analysis (pertaining to SCC) developed using CorLas™. For this example pipeline, the top curve (blue) represents the critical flaw curve associated with an MAOP of 1,000 psig and corresponds to 76.9% SMYS. The bottom curve (orange) represents 1.25 x MAOP (1,250 psig, 96.2% SMYS).

For the segments requiring MAOP-R, there are no reportable features from the ILI. A hypothetical just-missed-flaw (JMF) with dimensions 50 mm (1.97 in) long x 2.03 mm (0.080 in) deep (based on vendor reporting thresholds) which has been grown (SCC growth applied to both length and depth) from the time of inspection to the date of the ECA is plotted in the figure (example growth of 4-years). The objective of this is to represent the criticality of this hypothetical feature in comparison to the MAOP and the MAOP with the applicable factors of safety applied. As such, Figure 4 illustrates that the hypothetical JMF feature size does not cross the MAOP or 1.25 x MAOP critical flaw size curves and; therefore, meets ECA requirements for Class 1 locations.

It is noted that, for manufacturing-related long seam flaws, if it can be demonstrated that the JMF is stable (i.e., no growth mechanism or time dependency), then it is appropriate to not apply growth to the feature.

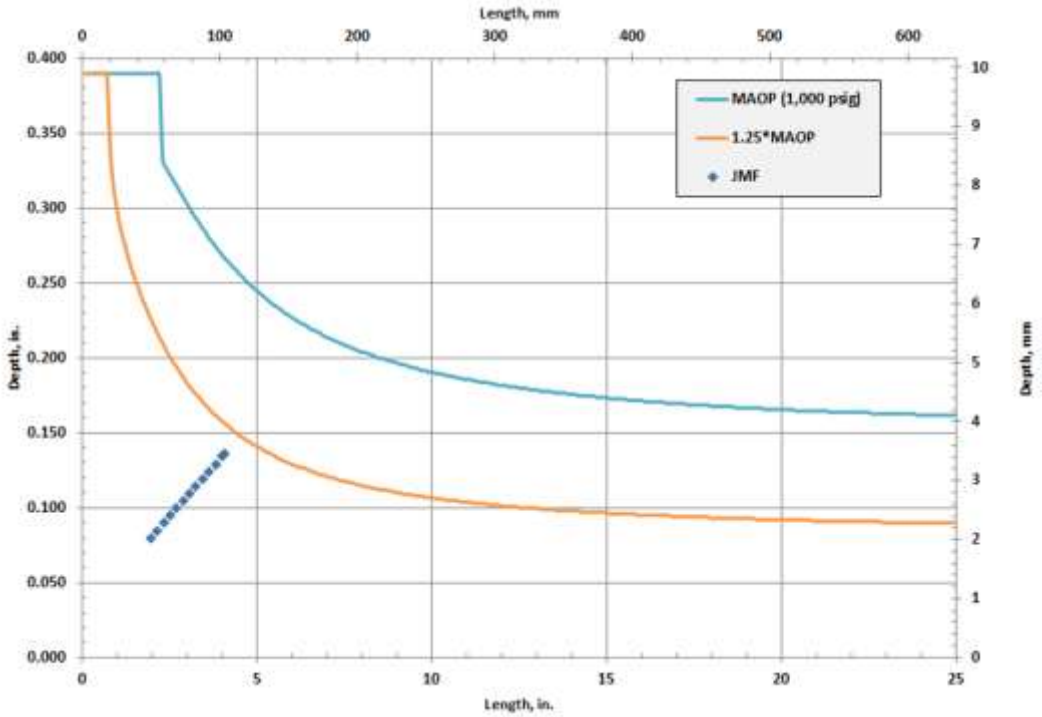


Figure 4: JMF Analysis – Critical Flaw Sizes at Key Pressure Thresholds (Class 1)

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JSF Example – SCC

This example considers use of a previous pressure test to complete the SCC assessment for the MAOP-R ECA. Similar to the JMF analysis, fracture mechanics models can be used to define an array of flaw dimensions (lengths and depths) that correspond to a predicted failure pressure. Figure 5 represents a critical flaw size analysis (pertaining to SCC) developed using CorLas™. For this example, the top curve (blue) represents the critical flaw curve associated with the MAOP and corresponds to 72% SMYS. The middle curve (red) represents 1.25 x MAOP (90% SMYS). The bottom curve (green) represents a previous pressure test to 100% SMYS (1.39 x MAOP). A 6 in.-long, largest just-surviving SCC feature is assumed from the pressure test, placed on the "green" critical flaw size curve, and then grown (assumed SCC growth applied to both length and depth) from the time of the pressure test to the date of the MAOP-R ECA. This provides for the assessment of compliance (for Class 1 location in this case) by ensuring the feature size does not cross the 1.25 x MAOP critical flaw size curve.

It is noted that, for manufacturing-related long seam threats, if it can be demonstrated that the JSF is stable (i.e., no growth mechanism or time dependency), then it is appropriate to not apply growth to the feature.

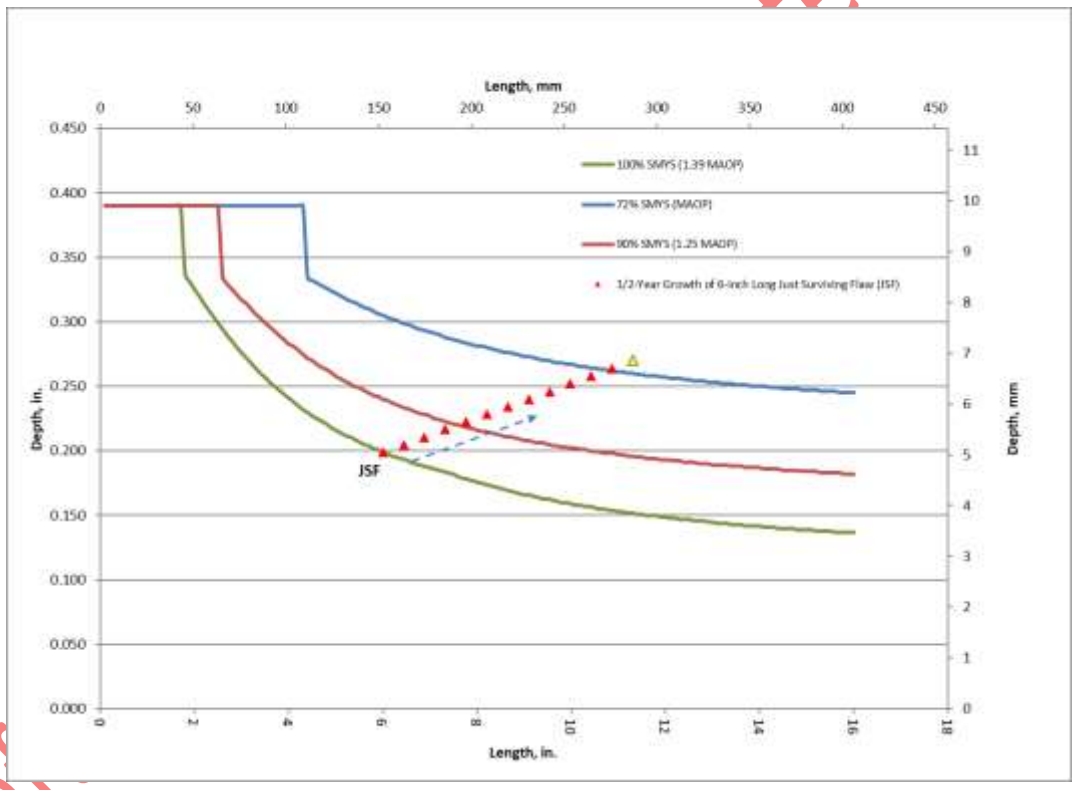


Figure 5: JSF Analysis – Critical Flaw Sizes at Key Pressure Thresholds (Class 1)

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Annex G – Material Toughness

(Informative)

Material toughness values are required for the fitness-for-service assessment of pipelines containing cracks or crack-like flaws, using fracture mechanics-based assessment methods. The Charpy V-Notch (CVN) impact energy is commonly used to characterize the fracture toughness of steel pipe materials. In accordance with 49 CFR § 192.632(a)(1), CVN toughness values used in an ECA are to be based on the lowest operational temperature, if applicable. For analyses under § 192.712(d)(3), CVN toughness values are to be based on the minimum operational temperature and be equivalent to a full-size specimen value.

Where documented material-toughness data required for an analysis are unavailable, § 192.712(e)(2)(i)(A) permits the use of "Charpy v-notch toughness values from comparable pipe with known properties of the same vintage and from the same steel and pipe manufacturer" while the undocumented material properties are obtained through § 192.607. This appendix provides an example of a four-tier protocol, based on the methodology presented in IPC2024-133503 [51], for establishing an appropriate CVN value from "*comparable pipe*". It provides guidance on the interpretation of the attributes used to define comparable pipe and the determination of characteristic and statistical CVN parameters for use in deterministic and probabilistic assessment methods, where applicable. Qualified CVN data selected using this protocol may subsequently be evaluated using the Level 2 characterization methods developed under PRCI IM-1-08 [52] [53]. The relationship among the data-source tiers and the Level 1, Level 2, and Level 3 toughness-characterization methods is discussed below. Industry experience and published studies indicate that CVN value is strongly influenced by vintage, pipe manufacturer, steel grade, and seam weld type. Accordingly, comparable pipe may be defined as consisting of the same or similar manufacturing vintage, with similarity established based on relevant manufacturing, material and metallurgical attributes, including pipe manufacturer steel grade and seam weld type. The uncertainty associated with CVN values should be appropriately considered in both deterministic and probabilistic fracture mechanics-based assessments. Deterministic assessments typically require a characteristic CVN value while probabilistic assessments require additional statistical descriptors of the toughness population, including the mean, standard deviation, and probability distribution of the CVN data. The protocol presented in this appendix is intended to establish representative CVN values from a population of comparable pipe while accounting for the inherent variability of CVN data. By incorporating data from a suitably defined comparable pipe population and applying appropriate statistical treatment, the resulting toughness values provide a level of conservatism that is consistent with, or greater than, approaches based on a limited number of CVN test results obtained directly from the assessed segment.

The CVN impact energy of a pipe material is strongly dependent on test temperature. A CVN transition curve can be developed by conducting Charpy impact tests over a range of temperatures for a given material. This curve typically exhibits three distinct regions: a lower-shelf (brittle) region at low temperatures, an upper-shelf (ductile) region at high temperatures, and a transition region between the two. The CVN value within the upper shelf region is typically called upper-shelf CVN.

The mostly commonly used crack assessment models such as API 579, CorLas™ and PRCI MAT-8 were originally developed and calibrated using the upper shelf CVN value. Therefore, the upper shelf CVN should be used in the crack assessment. This is because the fracture behavior of a material during Charpy impact testing does not reflect the fracture behavior of a surface crack in pipeline operation, largely due to the difference in loading rate and constraint effects. Table 8 describes a data-driven four-tier protocol for collecting CVN data from coupon testing when material toughness data are not available in TVC records. Each measured CVN value can be converted to a full size equivalent upper-shelf CVN value using the methodologies developed under the PRCI project IM-1-08 [52] [53] as part of a level analysis.

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Table 8: Four-Tier Protocol for the upper shelf CVN Determination

Tier	Classification	Criteria for Measured CVN Data Collection	CVN Data Analysis
1	Same pipe	• Same pipe vintage • Same pipe grade • Same manufacturer • Same weld type • Same outside diameter • Same wall thickness • CVN data samples at any testing temperatures with corresponding specimen subsize ratio and percentage of shear area	• Convert measured CVN value to a full-size equivalent upper-shelf CVN value using methodologies developed under the PRCI project IM-1-08 • Establish the characteristic values of the upper shelf CVN for deterministic assessment • Obtain the best fit the probability distribution of the upper shelf CVN for probabilistic assessment
2	Comparable pipe	• Same pipe vintage or similar pipe vintage where compliance can be demonstrated • Same pipe grade • Same manufacturer • Same weld type • CVN data samples at any temperatures with corresponding specimen subsize ratio and percentage of shear area	
3	Comparable pipe with embedded conservatism[1]	• Older-vintage pipe, or pipe within +x years of the target vintage where compliance can be demonstrated • Same pipe grade plus lower grade pipe • Same manufacturer plus known poorer-quality manufactures based on SME judgement • For DSAW weld material use CVN data samples from base material. For base material use CVN data samples from ERW/EFW weld material • CVN data sample at any testing temperatures with corresponding specimen subsize ratio and percentage of shear area	
4	Unknown pipe	• One or more of the four attributes (vintage, manufacturer, pipe grade, or weld type) is unknown or data is unavailable	Characteristic CVN values should be selected in accordance with §192.712(e)(2)(i)(C) and (D) and the probability distribution can be established considering additional valid assumptions.

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Use of the CVN data selected through the four-tier approach should be supported by a documented basis addressing their applicability to the assessed pipe and the material region represented by the data. Other data-selection approaches may also be used when adequately documented.

An adequate sample size is necessary to characterize the statistical properties of CVN values. Larger data samples generally provide a more reliable representation of the overall distribution of CVN values. As a practical guideline, a data sample containing more than 30 CVN test results is generally considered sufficient to support statistical characterization of the comparable pipe population. API 579 recommends the use of a toughness value

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approximately corresponding to the 20th percentile of various limited number of CVN data sample [54]. Other statistical measures, such as the 10th percentile value, mean or median value, can also be used as the characteristic value provided their applicability and associated level of safety implication are supported by appropriate technical validation and evaluation.

The procedures developed under the PRCI IM-1-08 reports provide technically supported methods for three levels of toughness characterization. Level 1 provides default or bounding toughness values where representative material test data are unavailable. Level 2 uses representative CVN data to evaluate the fracture regime and establish a process to determine an appropriate toughness input. Level 3 uses representative direct fracture-toughness data to establish an input applicable to the assessed pipe flaw and fracture-assessment method. A higher numerical level does not necessarily produce a higher toughness value or a less conservative assessment, and it produces a more accurate representative toughness value of pipe material to enable a more reliable assessment of pipeline containing cracks.

The four-tier comparable-pipe approach and the toughness-characterization levels serve different but related functions. The data-source tier addresses the source and applicability of the CVN data, while the characterization level addresses how the available information is evaluated to establish the toughness input. The selected characterization level should be supported by the available data and be consistent with the selected fracture-assessment method. Alternative characterization methods may be used where they address the applicable material, temperature, fracture-regime, and specimen considerations.

Level 1: Where representative toughness test data are unavailable to support Level 2 or Level 3, the operator should use an applicable regulatory default, a technically supported bounding value, or another value authorized through the applicable regulatory process. The selected value should represent the applicable material region and be appropriate for the selected fracture-assessment method. A Level 1 value should not be represented as measured material variability unless a separate technical basis establishes the applicable distribution and uncertainty.

Level 2: Representative CVN data may be obtained from the assessed material or a qualified comparable-pipe population. The evaluation should consider the material region represented by the data, specimen size and orientation, test temperature, absorbed energy, fracture appearance or shear area where available, pipe wall thickness, and the minimum assessment temperature. Subsize results should be converted to a full-size-equivalent basis using an applicable method.

Where the fracture-assessment method requires upper-shelf or plateau CVN energy, the Level 2 evaluation should determine whether ductile fracture initiation is expected at the minimum assessment temperature. Where ductile initiation is demonstrated, the evaluated CVN data may be used to establish a full-size-equivalent upper-shelf or plateau toughness input. Where ductile initiation is not demonstrated, an applicable transition- or cleavage-regime treatment, additional information, or an appropriate Level 1 value should be used. The resulting Level 2 dataset may support a characteristic toughness value for a deterministic ECA or a probability distribution for a probabilistic ECA.

Level 3: Representative direct fracture-toughness data J or K that can be measured through C(T), SEN(B), SEN(T), CTOD, or equivalent test techniques. The evaluation should consider the represented material region and orientation, test temperature, specimen geometry, validity of the test result, fracture mode, and constraint relative to the assessed pipe flaw.

The selected fracture-toughness property should apply at the minimum assessment temperature and be compatible with the selected fracture-assessment method. Any adjustment for temperature, specimen size, crack geometry, or constraint should use an applicable method within its documented limits. Where the available data do not support their application to the assessed pipe flaw or fracture-assessment method, the operator should

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use an appropriate lower-bound treatment, use a lower characterization level where supported by the available information, or obtain additional testing.

The toughness input and any conversion between toughness parameters should be consistent with the basis and documented applicability limits of the selected fracture-assessment method. The characterization should account for material-region, temperature, specimen-size, fracture-regime, and constraint uncertainties. Where toughness materially affects predicted failure pressure, a sensitivity assessment using a lower or bounding toughness value should be performed.

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