Integrity Management of Spoolable Reinforced Line Pipe

API RECOMMENDED PRACTICE 15SA
FIRST EDITION, XXXX 202X

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts, NW, Washington, DC 20001, standards@api.org.

Contents

To be developed by the API editors prior to publication

1.0 Scope

This recommended practice is for integrity management of an existing API 15S asset including threat identification, identification of potential failure modes, risk assessment, testing requirements, initial and ongoing inspection practices, end-fitting and coupling inspection, potential mitigations, repair, and associated documentation.

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2.0 Normative References

Deleted: *There are several existing API standards that address integrity management of both metallic and non-metallic pipeline systems including including* the following. ¶
API Recommended Practice 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines¶
API Recommended Practice 17B – Recommended Practice for Flexible Pipe¶
The intent of this recommend practice is not to replace the principles embodied in these standards, but to compliment them for spoolable reinforced plastic line pipe. If there is a conflict between API 1160 and RP 15SA, then 15SA is the governing document. A secondary effort has also been made to provide a consistent approached in API recommended practices for integrity management of pipeline systems. To meet this intent, these two standards are referenced throughout this document and apply many of the same principles. ¶

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

API Specification 15S – Spoolable Reinforced Plastic Line Pipe

API Recommend Practice 15SIH – Installation and Handling of Spoolable Reinforced Line Pipe

Deleted: API Recommended Practice 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines¶
API Recommended Practice 17B – Recommended Practice for Spoolable Flexible Pipe¶
API Recommended Practice 1173 - Pipeline Safety Management Systems¶

3.0 Terms and Definitions

3.1
blistering
Damage in the form of gas-filled pockets caused by the release of absorbed gas on depressurization within a solid polymer layer (e.g. polymeric liner).

3.2
brittle failure
A component failure mode which exhibits no visible (to the naked eye) permanent material deformation (stretching, elongation, or necking down) in the area of the break.

3.3
connector
Device used to provide a leak-tight (except to vent gas where applicable) structural connection between the end-fitting and adjacent piping (e.g. bolted flanges, clamped hubs, weld necks, and proprietary connectors).

3.4
coupling
Specific type of fitting developed for joining one section of pipe to another (e.g. in-line connector).

3.5
coupon
A test piece cut from a representative specimen.

3.6
cover
Protective outer sheath of the pipe.

3.7
cyclic loading
More than 7000 pressure cycles and ΔP/NPR > 6 % where ΔP is maximum to minimum amplitude.

3.8
end-fitting
A mechanical device that forms the transition from the pipe to the connector.

3.9
field-fitting
End-fitting with connector or coupling designed for permanent installation.

3.10
liner
Continuous polymeric layer that is in contact with the conveyed fluid.

3.11
liner collapse
Movement of the liner away from the structural layer on reduction of internal pressure.

3.12
nominal pressure rating (NPR)
Pressure rating of the pipe as defined by the manufacturer and does not exceed the maximum pressure rating (MPR).

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3.13
operating minimum bend radius (MBR)
Minimum allowable bend radius for the installed and pressurized pipe.

3.14
maximum pressure rating (MPR)
The estimated maximum internal hydrostatic pressure that can be applied continuously to a pipe with a high degree of certainty that failure of the component will not occur.

3.15
purchaser's agent
An installation contractor, inspector, or manufacturer hired by the purchaser to perform specific tasks (e.g. storing, unspooling, joining, handling, inspecting).

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3.16
road crossing
A design feature in pipeline construction that accounts for the placement of a spoolable reinforced line pipe across a road such that vehicular traffic can pass over the pipe without damage to the pipe or vehicle.

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3.17
rupture
A tear, break, or fracture in the pipe.

3.18
service life

Period of time during which the pipe fulfills all performance requirements.

3.19
spoolable pipe
Pipe that is flexible enough to be provided as a coil or on a structural reel for transportation.

3.20
test coupons
Test coupons incudes liner coupons inserted into a sample trap for exposure to production fluid.

3.21
test spools
Test spools are full-scale sections of pipe removed for testing.

NOTE For the purposes of this specification, the terms coils, reels, and spools may be used interchangeably.

4.0 Integrity Management Program

A pipeline integrity management program is a documented set of policies, processes, and procedures to manage pipeline risk. The program should begin with threat identification and then facilitate appropriate and timely actions on the part of a pipeline operator to ensure that a pipeline system is continually operated in a manner that manages risk to the public, employees, the environment, and customers. In addition to traditional integrity management activities related to assessment, inspection, and maintenance of the pipeline system, a comprehensive pipeline integrity management program should also include activities that assess and improve the performance of the program itself.

The program elements that should be included in an integrity management program are shown in Figure 1. Also, Figure 1 reflects the way this continuous cycle aligns with the Plan-Do-Check-Act cycle (PDCA) cycle of a pipeline safety management system (pipeline SMS). A pipeline SMS provides a mechanism for enhanced risk assessment and continuous pipeline safety performance improvement. API RP 1173 – Pipeline Safety Management Systems discusses pipeline SMS in greater detail.

To address pipeline risk changing over time, a pipeline operator should assess its pipelines at specified intervals and periodically evaluate the integrity of its pipelines. A pipeline operator ensures these periodic reassessments are effective through a continuous cycle of monitoring pipeline condition, identifying and assessing risks, and taking action to reduce the most significant risks. Risk assessments should be periodically updated and revised to reflect current conditions so operators can most effectively use their finite resources to achieve the goal of error-free, spill-free operation.

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A more detailed description of the elements of integrity management program can be found in API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines. ¶ ...

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Note –A more detailed description of the elements of integrity management program can be found in API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines as an additional reference.

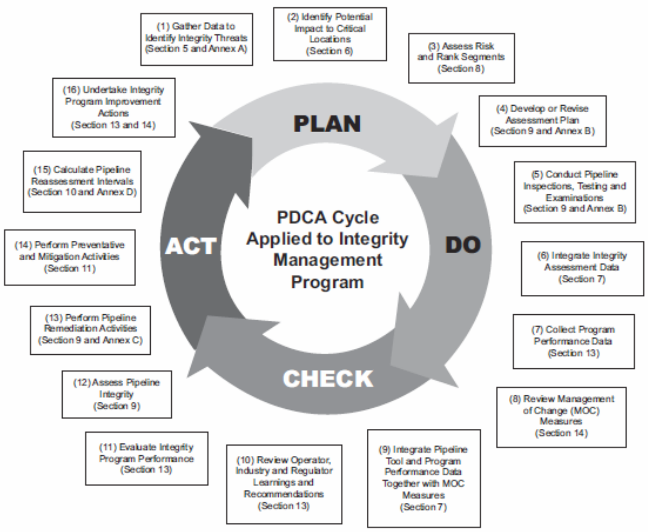

Figure 1: PDCA Cycle Applied to an Integrity Management Program

5.0 Threat Assessment

Integrity management of a spoolable pipe system begins with a systematic and comprehensive consideration of potential integrity threats. These threats describe one possible process by which a spoolable pipe system could fail. A single failure mode typically represents a succession of pipe/ancillary equipment defects and/or operational conditions which exceed specified allowable values that have the potential to culminate in pipe failure. The identification of relevant failure modes should be based on a detailed knowledge of spoolable pipe behavior.

Table 1 identifies potential integrity threats (i.e., defects or failure mechanisms) that apply to the integrity of spoolable pipe systems. Each defect/failure mechanism is numbered, and the likely cause and consequence of the defect has been identified.

Table 2 applies to defects/failure mechanisms associated with system components and pipe attachments and damage that can affect the condition or integrity of the spoolable pipe itself.

These tables should be reviewed during the development of integrity management program. The review allows identification of critical components in the pipe system and potentially critical defects/failure mechanisms, thereby facilitating a better definition of the requirement and relevancy of available monitoring methods.

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Table 1: Potential Threats to Spoolable Pipe Systems

Pipe Layer	Defect Ref.	Failure Defect / Mechanism / Mode	Consequence	Possible Cause	Inspection / Detection Method
Internal Liner	1.1	Crack or hole.	Leak of medium into or through reinforcement layer.	a) Hole, bubble, or inclusion during fabrication; b) Reinforcement failure; c) Ageing (embrittlement); d) Temperature above design levels; e) Operating at pressure above specified limits; f) Pigging damage; g) Environment assisted cracking; h) Erosion i) Product composition outside design limits; j) Fatigue related failure due to bending, tension, or compression load cycling k) Fatigue related failure due to thermal and pressure load cycling. l) Hydrate and paraffin formation m) Scale formation	Visual detection during production or other QC methods such as factory acceptance testing. Field hydrotest program Record-keeping and chemical compatibility assessments Monitoring venting system Fiberoptic leak detection (imbedded or in ditch) Floating spheres with acoustic emission sensors Computational pipeline monitoring leak detection systems

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Pipe Layer	Defect Ref.	Failure Defect / Mechanism / Mode	Consequence	Possible Cause	Inspection / Detection Method
	1.2	Rupture.	Failure of pipe.	a) Violation of allowable bending radius b) Ageing and embrittlement c) Overpressurization d) Fatigue failure due to multiple shutdowns associated with vacuum conditions e) Fatigue related failure due to bending, tension, or compression load cycling f) Fatigue related failure due to thermal and pressure load cycling.	Monitoring venting system Fiberoptic leak detection (imbedded or in ditch) Computation pipeline monitoring leak detection systems
	1.3	Collapse.	Reduced structural capacity. Restricted flow.	a) Excessive reduction in product pressure b) Differential pressure (annulus minus bore) exceeding allowable which may result from a plugged or restricted flow annulus c) Reduced liner stiffness due to swelling or chemical degradation d) Reinforcement layer crush or ovalization during installation	Geometry and free floating inspection tools Flow or pressure monitoring Pigging Annulus monitoring
	1.4	Ageing embrittlement/chemical degradation.	Reduced elasticity and greater susceptibility to cracking; material properties degradation.	a) Exposure to conveyed fluids at temperatures and durations incompatible with liner material	Coupon testing Removed test spools

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Pipe Layer	Defect Ref.	Failure Defect / Mechanism / Mode	Consequence	Possible Cause	Inspection / Detection Method
	1.5	Blistering	Possible hole or crack, or rupture.	a) Rapid decompression from operation at pressures and/or temperatures outside limits; b) Reduction in blistering resistance due to conveyed fluids incompatibility with liner material	Geometry and free floating inspection tools Bore Inspection
	1.6	Erosion of Internal Liner	Reduced collapse resistance and/or loss of liner containment and leak	a) Sand/particulate erosion; b) pigging damage	Bore velocity monitoring Monitoring sand production Test spools
Reinforcement Layer	2.1	Metallic Reinforcement Rupture	Reduced structural capacity, pipe rupture (burst), Extrusion/leakage into internal liner Rupture of the metallic reinforcement which reduce the pipe integrity with potential rupture (burst)	a) Corrosion; b) Stress corrosion cracking (SSC); c) Hydrogen induced cracking (HIC); d) Excess internal pressure; e) Manufacturing defect. f) Fatigue failure due to cyclic loading (pressure, tension / compression, bending) g) Bending in excess of installation or operating MBR (installation or improper bedding/backfill) h) Over-tension i) Impact damage	Annulus monitoring Monitoring for H2S Periodic hydrotest Test spools / coupons

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Pipe Layer	Defect Ref.	Failure Defect / Mechanism / Mode	Consequence	Possible Cause	Inspection / Detection Method
	2.2	Non-metallic Reinforcement Rupture	Reduced structural capacity, pipe rupture (burst). Extrusion/leakage into internal liner Rupture of the non-metallic reinforcement which reduce the pipe integrity with potential rupture (burst)	a) Aging b) Stress corrosion cracking (SCC) (glass fibers) c) Hydrolysis (polyesters, aramids) d) Operating at pressure above specified limits; e) Fatigue failure due to cyclic loading (pressure, tension / compression, bending) j) Bending in excess of installation or operating MBR (installation or improper bedding/backfill) f) Over-tensioning g) Impact damage h) Water ingress leading to accelerating aging	Periodic hydrotesting Test spools / coupons
	2.3	Crush or Ovalization.	Reduced bore. Reduced structural capacity and collapse resistance.	a) Impact; b) Point contact; c) Excess tension or subsidence d) Radial compression at installation. e) Bending in excess of installation or operating MBR f) Over-tensioning during unspooling	Visual inspection during or after installation Geometry and free floating inspection tools Bore inspection
	2.4	Bonded – matrix cracking Unbonded-disarrangement of reinforcement fibers	Reduced pressure capacity.	a) Overtwist; b) Compression; c) Bending in excess of installation or operating MBR d) Point contact	Visual inspection during installation or operation Tracking pipe movement

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Pipe Layer	Defect Ref.	Failure Defect / Mechanism / Mode	Consequence	Possible Cause	Inspection / Detection Method
	2.5	Kinking of pipe.	Reduced pressure capacity.	a) Impact; b) Point contact; c) Bending in excess of installation or operating MBR d) Pipe movement during operation (bending around fixed object).	Visual inspection during or after installation Tracking pipe movement
Outer Cover	3.1	Hole, tear, rupture, or crack.	Ingress of contaminants from external environment (if through wall).	a) Manufacturing defect; b) Tear during installation; c) Impact; d) Point contact; e) Improper clamp / restraint design or fit; f) Overpressurization of annulus; g) Blocked vent valve; h) Bending in excess of installation or operating MBR i) Ageing, weathering (ultraviolet radiation). j) Abrasion due to pipe movement	Annulus testing and/or monitoring if applicable Visual inspection during and after installation
Field Fitting	4.1	Pullout	Loss of primary containment / leak	a) Improper installation (includes crimping and swaging) b) Manufacturing defect c) Corrosion d) Over tension e) Operating above pressure/temperature design limits f) Bending at the end-fitting outside of specified limits	Periodic hydrotest Visual inspection during and after installation

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Visual monitoring during operation

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Deleted: <#>Internal liner leak/hole;¶

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Deleted: 3rd party / outside force¶
Weather and outside forces

Deleted: End fitting

Deleted: Visual Inspection¶
Maintain pipe straight length at fitting/MBR/tension within specified limits

Pipe Layer	Defect Ref.	Failure Defect / Mechanism / Mode	Consequence	Possible Cause	Inspection / Detection Method
	4.2	Vent port blockage.	Outer cover burst or liner collapse	a) Debris; b) Biological growth; c) Corrosion d) Fabrication errors; e) Installation/operation error.	Visual inspection during and after installation Annulus testing or monitoring Annulus vent port flow verification
Field Fitting (cont.)	4.3	Failure of sealing system	Leak of medium into annulus, with fluid leak to environment through vent ports or due to outer cover rupture.	a) Fabrication defects b) Operating at pressure above specified limits; c) Tension or torsion above specified limits; d) Improper installation; e) Production temperature below specified limit	Visual inspection during and after installation Periodic hydrotest
	4.6	Structural failure of end-fitting body or flange.	Pipe rupture.	a) Fabrication defects b) SSC; c) HIC; d) Operating at pressures above specified limits; e) Excess tension or torsion loads; f) Corrosion/chemical degradation; g) Brittle fracture due to operating at temperature below specified limit h) Fatigue. i) Improper Installation j) Impact	Visual inspection during and after installation Periodic hydrotest

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Table 2: Potential Threats to Spoolable Pipe System Components

Pipe Layer	Defect Ref.	Failure Defect / Mode / Mechanism	Consequence	Possible Cause
Riser Sweep / Spoolable Riser (pipe itself)	1.1	Riser design not in accordance with manufacturer specifications Disarrangement of risers	Leaking at end connection	Exceeding OPERATING MBR at connection points
	1.2		Kinking of the pipe – leaking / reduced pressure integrity	Free floating pipe between steel connection and where pipe comes out of the ground
	1.3		Cutting into the pipe outer jacket and reinforcement layer	Piping supports at transition from below ground and soil subsidence
Steel Riser	2.1	Unsecure risers	Kinking of the pipe Shifting to external impingement	Pipe shifting during hydrotest or operation
	2.2	Soil settlement	Bending loads on end connection Rupture / leaking of end connection	Soil subsidence Improper bedding or backfill
	2.3	Galvanic corrosion	Steel connection corrosion Connection leak	Dissimilar metals pair in connection
Road Crossings	3.1		Cutting into the pipe outer jacket and reinforcement layer	Thermal expansion and/or pressure changes – pipe movement and bending in the casing
	3.2		Overbending or kinking of the pipe Unacceptable deflection in the pipe	Pipe offset with differential settlement (not supported properly while burying pipeline)
Cathodic protection	4.1	Disarrangement.	Inoperative cathodic protection with risk of excessive corrosion.	a) Method of attachment
	4.2	Electrical discontinuity.	Inoperative cathodic protection with risk of excessive corrosion.	a) Inadequate manufacturing QA; b) .
	4.3	Anode exhaustion.	Inoperative cathodic protection with risk of excessive corrosion.	Anode depletion in excess of design assumptions, cathodic protection drawn by adjacent equipment, damaged area to outer cover
Uneven trench bottom	5.1	Free span	Loss of pressure capacity or rupture	Kinking or overbending of the pipe
Backfill	6.1	Loss of cover.	Pipe exposure, external strike damage, UV damage, free spans	Weather related or water runoff

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Pipe Layer	Defect Ref.	Failure Defect / Mode / Mechanism	Consequence	Possible Cause
Spoolable pipe layout	7.1	Upheaval buckling or upheaval of buried pipe.	Possible overbending impact damage.	a) Axial compression or tension (temperature and/or pressure induced elongation); b) inadequate installation for buried pipe.
Spoolable pipe layout (cont.)	8.1	Pipe shifting (compared to designed or as-built layout).	Possible overbending or possible excess tension/compression or possible ovalization or possible tear of outer sheath, clashing with neighboring lines or other equipment.	a) Impingement with neighboring lines or other equipment b) Temperature cycles c) Surge operation
	9.2	Pipe free spans.	Possible overbending.	a) Routing over sharp feature; b) loss of cover.

6.0 Identifying Critical Locations with Respect to the Consequence of Release

The main goal of pipeline integrity management is to reduce risk to the public, employees, the environment, and the customers. As such, a pipeline operator should place a high priority on the inspection, evaluation, and maintenance of pipeline segments in areas where the consequences of a spill would be most likely to affect a critical location. In some regions, critical location may be identified as a high consequence area (HCA) and therefore additional requirements may apply

Note that commercial software including geographic information system (GIS) technology is available to perform many of the tasks described in the following sections. This technology is available from numerous service providers.

Information about pipeline segments and facilities that may affect critical locations is used in several key elements of an integrity management program, such as:

— data gathering;

— risk assessment;

— inspection and mitigation;

— decisions on placement of emergency flow restriction devices;

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API Recommended Practice 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines maintains a description of a process to identify critical locations with respect to the consequence of a release. A summary of this description is provided below. See API RP 1160 (2019), for additional details. ¶
Per API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines, …t
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— installation and use of leak detection systems;

— preventive and mitigative measures;

— development and implementation of spill response plans.

Note –A more detailed description of identifying critical locations with respect to the consequence of release can be found in API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines as an additional reference.

7.0 Data Integration

The structure and breadth of many pipeline companies may result in relevant data being produced and stored in different locations, by disparate owners, using potentially inconsistent formats. Policies and procedures within the SMS are one way to ensure that the necessary inputs are effectively aggregated and normalized. Operators should develop and implement procedures to:

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a) identify the types of data needed to support integrity management,

b) identify the location of the data within the organization,

c) deliver identified information from the data owner to the group responsible for data integration and analysis,

d) disseminate integrated data and the knowledge generated to the applicable stakeholders across the enterprise responsible for identifying and managing integrity threats.

API Recommended Practice 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines provides additional details for the types of data to integrate into an integrity management program. For spoolable pipe systems, this includes items such as:

1. Pipeline attributes such as pipe manufacturer, size, NPR, date of installation, appurtenances (valves, fittings, etc.) field-fittings, crossings, and any corrosion mitigation equipment.

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2. Construction factors such as right-of-way (soil type, depth of burial, etc.), inspections, pipeline weights.

3. Operating parameters and history such as pressure histories, temperature ranges, liquids transported, inspections, and leak reports.

4. Integrity assessment history such as hydrostatic tests, repair cutouts, results from test coupons, and any other monitoring method.

Note –A more detailed description of a data management program can be found in API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines as an additional reference

8.0 Risk Assessment Implementation

Potential failure modes and mechanisms should be identified for the specific spoolable pipe technology and application. The spoolable pipe system's functional and operational requirements should be considered when assessing potential failure modes. Table 1 and 2 provide a list of common threats to spoolable pipe components and systems for reference when completing the risk assessment. These tables provide the most common threats to spoolable pipe systems. Other threats may exist for specific applications.

A risk analysis should be conducted to quantify the risk attributed to each failure mode, typically as a function of the probability of occurrence and consequence of failure. This information feeds into the establishment of an inspection and monitoring strategy that should relate the degree of required monitoring or an inspection to the calculated level of risk.

Typically, a team comprising of manufacturer representative, installation and pipe subject matter experts, and purchaser representatives is formed to complete the risk assessment.

Note –A more detailed description on approaches for developing risk assessments can be found in API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines as an additional reference.

9.0 Integrity Assessment

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9.1 General

This section provides guidance on integrity assessment methods for spoolable pipe systems and includes the following topics:

— record keeping and as-built documentation

— visual inspection

— hydrotest program

— test coupons

— test spools

— monitoring methods

Table 1 and 2 provide a list of typical threats for spoolable pipes and spoolable pipe system components.

9.2 Records and As-Built Documentation

Records shall be preserve with relevant data for current and future integrity assessments. These records should include but are not limited to the following:

a) Installation records and quality control reports according to API RP 15JH.

b) Records of past data collection and conclusions from prior integrity assessments.

c) Records of hazards/threats considered when conducting risk assessments (if any) for the system in question.

d) Records of all hydrostatic testing and annulus pressure testing (as applicable) conducted on the line, including any initial as-installed hydrostatic test.

e) Record of any operational excursions above rated temperature or pressure.

Records of any fluid analyses and injected chemicals

f) Record keeping of any remediation or repairs conducted on the system.

Records shall be retained at a minimum for the entire in-service lifetime of the system, and longer if required by regulation.

9.3 Visual Inspection

Visual inspection is a significant component of data collection for a spoolable pipe integrity assessment. For surface-laid lines, an inspection and monitoring program involving periodic pipe walking and measurement of any expansion, pipe shifting, or soil settlement is a best practice.

For buried lines, attention should be paid to riser locations to ensure that settlement or shifting of risers does not lead to damage to end connections or pipe. For both buried and surface-laid pipe, visual inspection should record any signs of soil disturbance, third-party interference, external impact, or impingement of the line on any fixed objects. Measurement of the pipe deflection angle at end connections is the best practice. Significant changes to any of these parameters should be considered as part of the integrity/risk assessment. Visual inspection reports should contain the following, at a minimum:

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a) Any evidence of current or prior leak.

b) Documentation of any pipe deformation including kinking, bulging, crushing, external impacts including tire tracks, deformation, foreign objects in the line.

c) Other pipe damage including scratches, chips, or gouges as recommended by the manufacturer.

d) Measurement and photographic documentation of significant pipe shifting.

e) Documentation of any impingement on other bodies such as trees, rocks, or structures.

f) Documentation and location of flanges, mechanical pipe supports, etc. for comparison to previous and subsequent inspections (for signs of shifting or deformation).

g) Documentation of evidence of any damage or corrosion on exposed field fittings.

9.4 Hydrotest Program

Periodic hydrostatic testing of the installed spoolable reinforced line pipe may be performed to demonstrate continued integrity and fitness for purpose of the pipe and fittings assembly. Duration of hydrostatic testing should be determined based on the consideration of the installation layout and consultation with the manufacturer. Testing should be performed at a pressure equal to or greater than 1.25x the maximum operating pressure (MOP) of the line, but not to exceed 100% of the nominal pressure rating (NPR). Exceeding 100% of the maximum pressure rating (MPR) could result in shortening the life of the piping assembly.

Frequency of hydrostatic testing should be determined based on a consideration of the normal operating conditions of the line (cyclic vs. static, external loads, thermal expansion) and consultation with the manufacturer's qualification data as performed according to API 15S. Based on this evaluation the integrity management plan should select a testing interval that meets local regulatory requirements.

It is not recommended that this interval exceed more than 1 test per 2 years, and re-evaluate this interval at the end of service life. Exceeding the number of hydrostatic tests defined by this interval could shorten the life of the piping assembly.

Note: service life depends on operating conditions and may be estimated in collaboration with the manufacturer.

Accurate hydrostatic testing of spoolable reinforced line pipe may require pre-conditioning of the pipe before a stable pressure level is reached. This is because the pipe wall may relax, allowing pressure to drop at the start of the hydrotest. Manufacturers recommendations for duration and level of pre-conditioning pressure tests should be followed.

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9.5 Test Spools

Periodic removal and testing of pipe spools or coupons from areas identified in failure mode and risk analysis of a pipeline provide a means to evaluate the long-term performance of the spoolable pipe when subjected to the actual pipeline operating conditions. Test spools are full-scale sections of pipe removed for testing. Test coupons include liner coupons inserted into a sample trap for exposure to production fluid.

These test spools can either be designed into the field originally and operated in parallel, or sections of the original pipeline can be cut out and replaced. Acceptance criteria for the periodic test shall be discussed and agreed upon between the operator and manufacturer based on the manufacturers test data.

Recommended testing intervals should be evaluated based on the previously completed risk assessment. The time between test spools can be extended based on sufficient test data indicating expected behavior.

Test spool locations should be selected to reflect the severity of service conditions in terms of loading, deformation, and internal or external environmental conditions. Areas of critical design loading may include one or more of the following for spoolable pipes:

a) Near wellheads or other areas of elevated temperature.

b) Immediately downstream of pumping/compressor stations.

c) Where separation of fluids is known to occur

Test spools should be exposed to the same pressures, stresses, and fluid conveyance conditions as those existing in the spoolable pipe, if practicable.

The test spool or sample trap, for polymer coupon monitoring of production fluid, should be located nearest the highest operating temperature or else the temperature at the test spools should be controlled to a temperature at least as high. Alternatively, although less ideal, samples can be analyzed knowing their conditions (pressure, temperature) with the ageing model and the ageing associated with the elevated temperature conditions may be extrapolated. If erosion is known to be an issue within the pipeline, the test spools should be designed to reflect the operating MBR of the spoolable pipe in service.

Destructive and non-destructive test methods relevant to the materials and design should be used to evaluate the test spools based on manufacturers recommendations

9.6 Monitoring Methods

In some spoolable pipe designs, the annulus between the liner and outer cover may require venting in service to relieve permeated gases. The manufacturer should determine whether the annulus contains sufficient free volume and communication between end-fittings to allow annulus pressure testing or monitoring as a form of integrity assessment. Annulus pressure testing may be performed post-installation

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prior to line commissioning and/or at regular intervals post line commissioning to confirm that the outer cover is intact.

The manufacturer should provide guidance on the following items:

a) recommended annulus testing method (vacuum or positive pressure);

b) acceptable gases for positive pressure annulus testing;

c) maximum allowable annulus test pressure to prevent liner collapse or outer cover rupture, considering the effects of manufacturing tolerances, pipe ovality, temperature, and outer cover dimensional acceptance criteria;

d) expected volume of test gas required to raise the annulus pressure to the test pressure (determined theoretically or via testing);

e) recommended hold period at the annulus test pressure;

f) annulus test acceptance criteria;

g) remedial actions in the event of unacceptable test results;

h) recommended training and/or certification for annulus testing personnel.

The annulus testing equipment should include a gas-relief valve designed to prevent unintended over-pressurization of the annulus.

In some cases, permanent monitoring systems may be connected to the annulus vent ports as a method of real-time or periodic integrity assessment. These systems may include pressure, temperature, flow rate, or gas composition monitoring. The intent of annulus monitoring may be to detect liner breach or outer cover damage in-service, or to confirm that the annulus conditions and permeation rates are as expected.

10.0 Preventive and Mitigative Measures

10.1 General

In addition to conducting integrity assessments, a pipeline operator should implement preventive and mitigative measures that reduce the probability of a release or the consequences of a release from threats such as third-party damage, equipment failure, and incorrect operations.

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This section provides guidance for establishing and implementing preventive and mitigative measures to reduce the probabilities of releases and the consequences of releases from all threats. Preventative and mitigative measures should also be addressed and included in risk assessments.

10.2 Anomalies and Repair

When damage occurs to a spoolable pipe, the following items should be reviewed:

— implications for ongoing safe operation,

— repair requirements,

— system improvements to avoid occurrence of damage to other lines.

Typically, a team including manufacturer representative, installation and pipe subject matter experts, and purchaser representatives (as required) should be formed to assess the damage and identify remedial actions. The key to preventing further damage from occurring due to a primary source of damage is to take remedial actions as soon as damage is identified. The manufacturer's representative is the best source for evaluating damage to the spoolable product and identifying if it is acceptable to continue operation, complete repairs, or cutout of the damaged section.

Acceptable levels of damage to a spoolable pipe product will vary between technologies as each technology is different. The manufacturing representative should provide guidance on what is acceptable vs. unacceptable damage for a specific technology and work closely with the purchasing agent when making these determinations.

10.3 Establishment of Inspection and Monitoring Program

The establishment of an inspection and monitoring program should relate the degree of required monitoring or an inspection to the calculated level of risk from the risk assessment. Table 3 lists methods available for the monitoring and inspection of spoolable pipes in service. As risks are quantified, they feed into the inspection and monitoring plan.

Visual inspection, annulus pressure testing, hydrotesting, and destructive analysis of removed samples and/or test spools are the most common forms of in-service condition monitoring used for the demonstration of continued fitness for purpose. Monitoring methods should only be used if they have been qualified for the particular application and/or have had successful track record on previous field developments.

Table 3: Integrity and Condition Monitoring Methods

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Damage to the outer cover. The amount of outer layer damage that is acceptable be specified by manufacturer's representative.¶
Damage or suspected damage to the reinforcement layer. Reinforcement layer damage will likely lead to a cutout but should be confirmed with manufacturer representative. ¶
End fitting cover pullout. Immediately notify manufacturer representative¶
Pipe overbending or kinking. This will likely lead to a cutout but should be confirmed with manufacturer representative.
Excess ovality from third-party damage. The manufacturer will specify what degree of ovality is acceptable.

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Method No.	Monitoring Method	Description	Purpose
1.	Visual inspection: (i) external;	Walking the pipeline during installation/operation Drone inspection	To establish the overall integrity of visible sections of the pipe and the general arrangement of the pipe system. To establish the amount of burial of sections of the pipe and compare this to the design. Data to maintain: pictures, position, measurements (future comparison).
	(ii) internal.	By camera device/crawler inserted into the pipe.	To check the condition of the internal liner and fitting internals
2.	Pressure test [hydrotest].	Pressure applied to pipe and decay measured as a function of time. Leakages or anomalies identified.	To establish the ability of the pipe to withstand pressure loads, typically in excess of max. allowable operating pressure, at a given time.
3.	Destructive analysis of removed samples.	Generally applied to coupon testing for ageing of internal liner whereby ageing coupons of polymer are exposed to flow environment in a coupon holder and removed periodically for destructive testing.	To predict the state of ageing or degradation of the internal liner by extrapolation from tensile or other testing of thermoplastic material samples removed from actual flow conditions.
4.	Destructive analysis of test spools	Test spools periodically removed from services that are in series or in parallel with the flow for destructive or nondestructive testing.	Pressure integrity, structural integrity, state of ageing or degradation of liner and reinforcement layer.
5	In-line inspection tools	For example, floating spheres with acoustic emission sensors.	Acoustic leak detection devices
6	Acoustic emission		
7	Computational Pipeline Monitoring	Methods of leak detection using pressure and/or flow rates to determine size and location of a leak.	To detect and locate leaks in operation.

Method No.	Monitoring Method	Description	Purpose
8	Load, deformation and environment monitoring.	Ground movement Road crossing (soil movement)	Used for design verification or remaining life assessment. Actual loads and environmental conditions may be compared with those predicted during design, thereby establishing the degree of conservatism in the design. Service life calculations may also predict remaining life based on measured environment or loads, to predict actual fatigue cycles used during operation to date. Product composition can help to determine the potential for hydrate buildup and or blockage due to deposits/wax. Some spoolable pipe cross-section designs may be restricted to a maximum depressurization rate as advised by the manufacturer.
9.	Geometry measurement	Geometry pigs to determine pipe ovality or check for obstructions.	To check for collapse, ovality, kinks, and dents along the line
10.	Annulus monitoring or testing: (i) gas diffusion monitoring. (ii) pressure monitoring. (iii) functionality of the vent port	Measurement of permeation rate Measurement of vented gas composition Measurement of annulus pressure	To confirm annulus conditions are as expected and not blocked and outer cover is intact.
11.	Cathodic protection tests.	Measurement of potential and current density.	To predict the effectiveness of the cathodic protection system at reducing corrosion. To determine if cathodic protection system is active, indicating possible coating damage
12	Polymer degradation.	Use of predictive techniques using production fluid data including pressure, temperature, pH data, pressure cycles, shutdowns/startups, etc. .	To predict the ageing of the liner and reinforcement layer due to material degradation by monitoring pressure, fluid conditions etc. and compare against the integrity envelopes for the equipment.
13.	Produced sand monitoring.	Measurement of production sand levels and fluid velocity.	To review levels against design criteria and assess the potential for increased erosion rates.

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Method No.	Monitoring Method	Description	Purpose
14.	Fiber optic monitoring.	Fiber optics are embedded into the pipe wall or fitted externally.	To monitor strain levels, temperature, 3rd party encroachment / damage in the spoolable asset during operation. Leak detection

10.4 Repair

Typical repair for spoolable pipe technologies involves cutout and replacement of the damage section of pipe. The length of the cutout is dependent on the extent of damage. Damage assessment is most commonly based on visual examination. Consultation with the manufacturer's representative shall be required when assessing damage.

Reinforcement repair is not typical for spoolable pipe technologies but the outer cover can be repaired in some instances. Consult manufacturer's representative for guidance on reinforcement repair.

Post-installation hydrostatic testing should be performed following a cutout and repair as described in section 9.3. Manufacturer's representative should specify maximum allowable test pressure. Pressure and duration of hydrotest may be dependent on local regulations and/or operator requirements.

11.0 Program Evaluation

Operators should periodically measure and evaluate the effectiveness of their integrity management program. The review should include both measures of integrity performance, as well as measures of the program itself. The intent of this section is to provide operators with a methodology that can be used to evaluate the effectiveness of their pipeline and facility integrity management.

An integrity management program evaluation should help an operator answer the following questions:

a) Were all integrity management program objectives accomplished?

b) Were pipeline and facility integrity and safety effectively improved through the integrity management program?

Note –A more detailed description on program evaluation can be found in API RP 1160 – Managing Systems Integrity for Hazardous Liquid Pipelines as an additional reference.

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Table 1: Potential Threats to Spoolable Pipe Systems

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Table 3: Current Integrity and Condition Monitoring Methods

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Bibliography

API Recommend Practice 1160, 3rd Edition, February 2019, Managing System Integrity for Hazardous Liquid Pipelines

API Recommended Practice 1173 – Pipeline Safety Management Systems