PART 2, ANNEX F CONTENTS

Risk-Based Inspection Methodology
Part 2—Probability of Failure Methodology
Annex 2.F—Levels of Inspection Effectiveness

2.F.1 Overview

Inspection effectiveness directly impacts the calculation of the POF. Consequently, the POF provided in Part 2 is intended to be used to provide a risk ranking and inspection plan for a component subject to process and environmental conditions typically found in the refining and petrochemical industry. Inspection effectiveness is thus an integral part of a robust inspection planning methodology.

2.F.2 Inspection Effectiveness

2.F.2.1 The Value of Inspection

An estimate of the probability of failure for a component is dependent on how well the independent variables of the limit state are known [15]. In the models used for calculating the probability of failure, the flaw size (e.g. metal loss for thinning or crack size for environmental cracking) may have significant uncertainty especially when these parameters need to be projected into the future. An inspection program may be implemented to obtain a better estimate of the damage rate and associated flaw size.

An inspection program is the combination of NDE methods (i.e. visual, ultrasonic, radiographic, etc.), frequency of inspection, and the location and coverage of an inspection. These factors at a minimum define the "inspection effectiveness". Inspection programs vary in their effectiveness for locating and sizing damage and thus for determining damage rates. Once the likely damage mechanisms have been identified, the inspection program should be evaluated to determine the effectiveness in finding the identified mechanisms. The effectiveness of an inspection program may be limited by:

a) lack of coverage of an area subject to damage;

b) inherent limitations of some inspection methods to detect and quantify certain types of damage;

c) selection of inappropriate inspection methods and tools;

d) application of methods and tools by inadequately trained inspection personnel;

e) inadequate inspection procedures;

f) the damage rate under some conditions (e.g. start-up, shutdown, or process upsets) may increase the likelihood or probability that failure may occur within a very short time; even if damage is not found during an inspection, failure may still occur as a result of a change or upset in conditions;

g) inaccurate analysis of results leading to inaccurate trending of individual components (problem with a statistical approach to trending); and

h) probability of detection of the applied NDE technique for a given component type, metallurgy, environment (including temperature), and geometry.

It is also important to evaluate the benefits of multiple inspections and to also recognize that the most recent inspection may best reflect the current state of the component under the current operating conditions. If the operating conditions have changed, damage rates based on inspection data from the previous operating conditions may not be valid.

Determination of inspection effectiveness should consider, but not be limited to, the following:

1) equipment or component type;

2) active and credible damage mechanism(s);

3) susceptibility to and rate of damage;

4) NDE methods, coverage and frequency; and

5) accessibility to expected damaged areas.

Refer to API RP 580for more information on using inspection effectiveness with RBI programs.

2.F.2.2 Inspection Effectiveness Categories

Levels of inspection effectiveness (LoIE) examples for specific equipment types (heat exchangers, pressure-relief valves, tanks, and buried components) are provided in Sections 2.F.3 through 2.F.7. The associated inspection effectiveness examples (i.e. NDE technique and coverage) for each damage mechanism are provided in Section 2.F.8 through 2.F.11.

Inspection effectiveness is graded "A" through "E", with an "A" inspection providing the most effective inspection available (90 % effective) and an "E" inspection representing an ineffective or "no inspection" category. The inspection categories presented are intended as examples and to provide a guideline for assigning inspection effectiveness grades. The effectiveness grade of any inspection technique depends on many factors such as the skill, competency, and training of inspectors, as well as the level of expertise used in selecting inspection locations. Refer to Table 2.F.2.1 for a description of the inspection effectiveness categories.

The tables describing the levels of inspection effectiveness per damage mechanism included in this annex are examples only. It is the responsibility of the user to review these tables and do the following.

a) Adapt and adopt similar tables for their specific use.
b) Adapt user-specific knowledge and experience to add NDE techniques and areas of concern not currently in the tables.
c) Implement these strategies as part of the user's RBI program as an aid for inspection planning.

It is not the intent of this document to specifically prescribe the exact NDE and/or areas of concern for the included damage factors. The user has the responsibility to utilize competent subject matter experts to review the tables and create similar items to be utilized in the user's inspection program. Inspections are ranked according to their expected effectiveness at detecting damage and correctly predicting the rate of damage. The actual effectiveness of a given inspection technique depends on the characteristics of the damage mechanism, and total inspection credit can be approximated to an equivalent higher effectiveness inspection in accordance with the relationships in Part 2, Section 3.4.3. Furthermore, damage factors are determined as a function of inspection effectiveness.

2.F.2.3 Tables

Table 2.F.2.1—Inspection Effectiveness Categories

Inspection Effectiveness Category	Inspection Effectiveness Description	Description
A	Highly Effective	The inspection methods will correctly identify the true damage state in nearly every case (or 80 % to 100 % confidence)
B	Usually Effective	The inspection methods will correctly identify the true damage state most of the time (or 60 % to 80 % confidence)
C	Fairly Effective	The inspection methods will correctly identify the true damage state about half of the time (or 40 % to 60% confidence)
D	Poorly Effective	The inspection methods will provide little information to correctly identify the true damage state (or 20 % to 40 % confidence)
E	Ineffective	The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20 % confidence)

NOTE On an inspection effectiveness Category E, the terminology of Ineffective may refer to one or more of the following cases.

1. No inspection was completed.
2. The inspection was completed at less than the requirements stated above.
3. An ineffective inspection technique and/or plan was utilized.
4. An unproven inspection technique was utilized.
5. Insufficient information was available to adequately assess the effectiveness of the inspection.

2.F.3 Pressure Relief Valves

Inspection programs vary in their effectiveness for determining failure rates. Examples of inspection effectiveness for PRDs are provided in Table 2.F.3.1. The inspection effectiveness is based on the ability of the inspection to adequately predict the failure (or pass) state of the PRD being inspected. Limitations in the ability of a program to improve confidence in the failure rate result from the inability of some test methods to detect and quantify damage.

Refer to the Part 1, Section 7.2.4 for further discussion on the inclusion of inspection effectiveness ranking into the determination of POF for PRDs.

2.F.3.1 Tables

Table 2.F.3.1—Inspection and Testing Effectiveness for Pressure-Relief Devices

Inspection Effectiveness	Component Type	Description of Inspection
Highly Effective A	Pressure-relief device	A bench test has been performed on the PRD in the as-received condition from the unit, and the initial leak pressure, opening pressure, and reseat pressure have been documented on the test form. The inlet and outlet piping has been examined (e.g. visual or radiographic techniques) for signs of excessive plugging or fouling [2].
	Rupture disk	No inspection methods are available to meet the requirements for an A level inspection.
Usually Effective B	Pressure-relief device	A bench test has been performed; however, the PRD was cleaned or steamed out prior to the bench test. Additionally, a visual inspection has been performed where detailed documentation of the condition of the PRD internal components was made. The inlet and outlet piping has been examined (e.g. visual or radiographic techniques) for signs of excessive plugging or fouling [2]. An in situ test has been performed using the actual process fluid to pressurize the system. The inlet and outlet piping has been examined (e.g. visual or radiographic techniques) for signs of excessive plugging or fouling [2].
	Rupture disk	The rupture disk is removed and visually inspected for damage or deformations. The inlet and outlet piping has been examined (e.g. visual or radiographic techniques techniques) for signs of excessive plugging or fouling [2].
Fairly Effective C	Pressure-relief device	A visual inspection has been performed without a pop test, where detailed documentation of the condition of the PRD internal components was made. The inlet and outlet piping has been examined (e.g. visual or radiographic techniques) for signs of excessive plugging or fouling [2]. An assist-lift test or in situ test has been performed where the actual process fluid was not used to pressurize the system.
	Rupture disk	No inspection methods are available to meet the requirements for a C level inspection.
Ineffective D	Pressure-relief device	Valve overhaul performed with no documentation of internal component conditions; No pop test conducted/documented. Any test (bench, assist-lift, in situ, or visual test) performed without examining the inlet and outlet piping for excessive plugging or fouling.
	Rupture disk	No details of the internal component were documented.

NOTE 1 This table does not prescribe specifically to the five effectiveness categories as discussed in this annex. However, given the methodology presented, it is in agreement with the division of those categories.

NOTE 2 This table assumes the PRD is in fouling service. If the PRD is in a documented, non-fouling service, the owner–operator may decide to waive the inlet and outlet piping inspection requirement.

2.F.4 Heat Exchanger Tube Bundles

2.F.4.1 Inspection Planning with Inspection History

2.F.4.1.1 Effect of Inspection on Probability of Failure

The information gained from an inspection of the tube bundle can be used to assess the actual condition of the bundle and to make adjustments to the probability of failure rate curves as necessary.

An inspection provides the following two things.

a) Reduction in condition uncertainty due to the effectiveness of the inspection resulting in the use of a more accurate failure rate curve, e.g. moving from a 50 % AU curve (no inspection history) to a curve 20 % AU curve (Usually Effective Inspection); see Section 2.F.4.1.1 b) for a discussion of inspection effectiveness.

b) Knowledge of the true condition of the bundle. This can result in a shift of the failure rate curve to the right or to the left. The current condition of the bundle could either be quantified by remaining wall thickness data or by an estimate of the remaining life that comes directly from an actual inspection; see Part 1, Section 8.6.4 c).

2.F.4.1.2 Reduction in Uncertainty Due to Inspection Effectiveness

If the tube bundle has been inspected, the uncertainty is reduced and the probability of failure at any time changes. Table 2.F.4.1 provides the recommended default values for the uncertainty applied to the failure rate curve as a function of inspection effectiveness.

At this point the concept of inspection effectiveness is introduced, similar to the methodology used in other modules. Table 2.F.4.1 provides the recommended default values for the uncertainty applied to the failure rate curve as a function of inspection effectiveness.

As improved inspection techniques are used, the amount of uncertainty decreases and the Weibull plot shifts to the right. Using this concept will result in more rigorous inspection techniques being implemented as the bundle reaches end of life.

In the example bundle problem, the impact of more rigorous inspection techniques can be seen by evaluating the predicted duration as a function of inspection effectiveness in Table 2.F.4.1. The definitions for inspection effectiveness are provided in Table 2.F.2.1.

As explained in various sections of this recommended practice, it is the responsibility of the owner operator to interpret and define inspection strategies that satisfy the level of desired effectiveness to achieve the level of confidence in the condition of the tubes (susceptible population) in question. This may involve a defined logic to establish sample size and the use of one or multiple inspection techniques to find a single or multiple potential damage mechanisms at the desired level of effectiveness. Owner/operators may elect to create inspection effectiveness tables specific to that company or site’s practices that satisfy the effectiveness criteria (A, B, C, D, and E) to help with consistency.

Typical examples of heat exchanger tube damage/degradation include and are not limited to, in relation to the tubes:

a) internal and/or external, localized or generalized corrosion;

b) preferential weld corrosion;

c) pitting (may be localized or generalized, ID and/or OD);

d) cracking (circumferential and/or longitudinal);

e) fretting;

f) tube end damage (cracking and/or corrosion);

g) seal weld cracking/failure;

h) erosion/erosion-corrosion, etc.

Examples of various typical NDE methods for tube inspection include and are not limited to:

a) visual inspection;

b) UT thickness readings where accessible;

c) eddy current testing;

d) remote field eddy current testing;

e) near field eddy current testing;

f) rotating/spinning UT probe examination;

g) laser scanning;

h) halide leak, hydrostatic, soap bubble, and other leak testing;

i) acoustic testing;

j) splitting of tubes for visual and other types of inspection like PT, pit depth gauging, caliper measurements, etc.

These lists of types of damage/degradation and typical NDE methods is provided as an example of items that the user should review when considering and/or creating inspection effectiveness tables. Understand that there are no specific LoIE tables developed as an example for tube bundle inspection. Rather Table 2.F.4.1 is provided as a basic guideline for the owner–operator created LoIE table(s), which is based on their experience and confidence in the results.

2.F.4.1.3 Tables

Table 2.F.4.1—Inspection Effectiveness and Uncertainty

Inspection Effectiveness	Uncertainty (%)
A—Highly Effective	5
B—Usually Effective	10
C—Moderately Effective	20
D—Usually Not Effective	30
E—Ineffective	50

2.F.5 Atmospheric Storage Tank Components

2.F.5.1 Inspection Effectiveness for Atmospheric Storage Tanks

API 653 states that RBI may be utilized as an alternative to establishing the initial internal inspection date as well as the reassessment date. However, when an RBI assessment is performed, the maximum initial internal interval shall not apply to ASTs storing the following:

a) highly viscous substances that solidify at temperatures below 110 °F—some examples of these substances are asphalt, roofing flux, residuum, vacuum bottoms, and reduced crude, or

b) any substance or mixture that

   1) is not identified or regulated either as a hazardous chemical or material under the applicable laws of the jurisdiction, and

   2) the owner/operator has determined will not adversely impact surface or groundwater beyond the facility or affect human health or the environment.

In order for the owner/operator to establish the internal inspection interval using RBI, a methodology of assigning inspection effectiveness must be provided. API 581 provides for several areas of inspection that are accounted for within the risk assessment methodology. Overall, the results of the RBI assessment can be used to establish an AST inspection strategy that defines the most appropriate inspection methods, appropriate frequency for internal, external, and in-service inspections, and prevention and mitigation steps to reduce the likelihood and consequence of AST leakage or failure.

Furthermore, API 653 requires that when using RBI, the assessments shall:

a) follow all requirements listed in API 653;

b) consist of a systematic evaluation of both the likelihood of failure and the associated consequences of failure;

c) be thoroughly documented, clearly defining all factors contributing to both likelihood and consequence of AST leakage or failure;

d) be performed by a team including inspection and engineering expertise knowledgeable in the proper application of API 580 principles, AST design, construction, and types of damage.

LoIE Tables 2.F.5.1 through 2.F.5.3 outline inspection areas combined with examples of inspection effectiveness categories for AST components.

2.F.5.2 Tables

Table 2.F.5.1—LoIE Example for AST Shell Course Internal Corrosion

Inspection Category	Inspection Effectiveness Category	Inspection [1]
A	Highly Effective	Both inspections shall be done: — intrusive inspection—good visual inspection with pit depth gage measurements at suspect locations — UT scanning follow up on suspect location and as general confirmation of wall thickness
B	Usually Effective	Both inspections shall be done: — external spot UT scanning based on visual information from previous internal inspection of this AST or similar service ASTs — internal video survey with external UT follow-up
C	Fairly Effective	External spot UT scanning based at suspect locations without benefit of any internal inspection information on AST type or service
D	Poorly Effective	External spot UT based at suspect locations without benefit of any internal inspection information on AST type or service
E	Ineffective	Ineffective inspection technique/plan was utilized

NOTE: Inspection quality is high.

Table 2.F.5.2—LoIE Example for AST Shell Course External Corrosion

Inspection Category	Inspection Effectiveness Category	Insulated Tank Inspection Example [1]	Non-Insulated Tank Inspection Example [1]
A	Highly Effective	— >95 % external visual inspection prior to removal of insulation — Remove >90 % of insulation at suspect locations **OR** >90 % pulse eddy current inspection — Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required	>95 % visual inspection of the exposed surface area **AND** Follow-up by UT or pit gauge as required
B	Usually Effective	— >95 % external visual inspection prior to removal of insulation — Remove >50 % of insulation at suspect locations **OR** >50 % pulse eddy current inspection — Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required	>50 % visual inspection of the exposed surface area **AND** Follow-up by UT or pit gauge as required
C	Fairly Effective	— >95 % external visual inspection prior to removal of insulation — Remove >30 % of insulation at suspect locations **OR** >30 % pulse eddy current inspection — Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required	>25 % visual inspection of the exposed surface area **AND** Follow-up by UT or pit gauge as required
D	Poorly Effective	— >95 % external visual inspection prior to removal of insulation — Remove >10 % of insulation at suspect locations **OR** >10 % pulse eddy current inspection — Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required	>10 % visual inspection of the exposed surface area **AND** Follow-up by UT or pit gauge as required
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE Inspection quality is high.

Table 2.F.5.3—LoIE Example for Tank Bottoms

Inspection Category	Inspection Effectiveness Category	Soil Side [1]	Product Side [1]
A	Highly Effective	Floor scan >90 % **AND** UT follow-up *NOTE* — *Include welds if warranted from the results on the plate scanning* — *Hand scan of the critical zone*	Bare plate: — Commercial blast — Effective supplementary light — Visual 100 % (API 653) — Pit depth gauge — 100 % vacuum box testing of suspect welded joints Coating or liner: — Sponge test 100 % — Adhesion test — Scrape test
B	Usually Effective	Floor scan >50 % **AND** UT follow-up **OR** Extreme value analysis (EVA) or other statistical method with floor scan follow-up (if warranted by the result)	Bare plate: — Brush blast — Effective supplementary light — Visual 100 % (API 653) — Pit depth gauge Coating or liner: — Sponge test >75 % — Adhesion test — Scrape test
C	Fairly Effective	Floor scan 5 to 10+% plates **AND** Supplement with scanning near shell **AND** UT follow-up **OR** Use a “Scan Circle-and-X” pattern (progressively increase if damage found during scanning) Other testing: — Helium/argon test — Hammer test — Cut coupons	Bare plate: — Broom swept — Effective supplementary light — Visual 100 % — Pit depth gauge Coating or liner: — Sponge test 50 % to 75 % — Adhesion test — Scrape test
D	Poorly Effective	Possible testing: — Spot UT — Flood test	Bare plate: — Broom swept — No effective supplementary lighting — Visual >50 % Coating or liner: — Sponge test <50 %
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE Inspection quality is high.

2.F.6 Buried Components

2.F.6.1 Inspection Effectiveness for Buried Components

Similar to other equipment, components that are buried may use RBI to assign inspection intervals. LoIE Table 2.F.6.1 provides an example of inspection effectiveness categories for buried components.

2.F.6.2 Tables

Table 2.F.6.1—LoIE Example for Buried Components

<table>
<tr><th>Inspection Category</th><th>Inspection Effectiveness Category</th><th>Intrusive Inspection Example [1]</th><th colspan="2">Non-intrusive Inspection Example [1]</th></tr>
<tr><td rowspan="2">A</td><td rowspan="2">Highly Effective</td><td rowspan="2">100 % internal inspection via state-of-the-art pigging and in-line inspection technologies (UT, MFL, internal rotary UT, etc.)</td><td colspan="2">100 % external inspection of equipment that is only partially buried using an NDE crawler with circumferential inspection technology (MFL, lamb-wave UT)</td></tr>
<tr><td>— Complete excavation, 100 % external visual inspection, and 100 % inspection with NDE technologies [2]
— Sample soil and water resistivity and chemistry measurements along entire structure</td><td>— Cathodic protection (CP) system maintained and managed by NACE certified personnel and complying with NACE SP0169 [14] includes stray current surveys on a regular basis
— Pipe-to-soil potentials should be measured at properly determined intervals</td></tr>
<tr><td rowspan="2">B</td><td rowspan="2">Usually Effective</td><td rowspan="2">Internal inspection via pigging and in-line inspection technologies (UT, MFL, internal rotary UT, etc.) of selected areas/sections, combined with statistical analysis or EVA</td><td colspan="2">External inspection of equipment that is only partially buried using an NDE crawler with circumferential inspection technology (MFL, lamb-wave UT) on selected areas/sections, combined with statistical analysis or EVA</td></tr>
<tr><td>— Close interval survey used to assess the performance of the CP system locally and utilized to select the excavation sites (based on the findings)
— Excavation at “selected” locations, 100 % external visual, and 100 % inspection with NDE technologies [2]</td><td>— CP system maintained and managed by NACE certified personnel and complying with NACE SP0169 [14] includes stray current surveys on a regular basis
— Sample soil and water resistivity and chemistry measurements along entire structure
— DC voltage gradient (DCVG) to determine coating damage</td></tr>
<tr><td>C</td><td>Fairly Effective</td><td>Partial inspection by internal smart pig or specialized crawler device, including a representative portion of the buried pipe (<25 %)</td><td colspan="2">Partial excavation guided-wave UT global search inspection in each direction of pipe. Corrosion inspection and maintenance managed by NACE certified and CP specialist, or equivalent.</td></tr>
<tr><td>D</td><td>Poorly Effective</td><td>Hydrostatic testing</td><td colspan="2">Spot check with conventional NDE technologies [2] equipment of local areas exposed by excavation.</td></tr>
<tr><td>E</td><td>Ineffective</td><td colspan="3">Ineffective inspection technique/plan was utilized</td></tr>
<tr><td colspan="5">NOTE 1 Inspection quality is high.
NOTE 2 “NDE technologies” include, but are not limited to, UT thickness measurement such as handheld devices at close-interval grid locations, UT B-scan, automated ultrasonic scanning, guided-wave UT global search, crawler with circumferential inspection technology such as MFL or lamb-wave UT, and digital radiography in more than one direction.</td></tr>
</table>

2.F.7 Inspection Effectiveness for Thinning

2.F.7.1 Use of the Inspection Effectiveness Tables

LoIE Table 2.F.7.1 and Table 2.F.7.2 are examples for levels of inspection effectiveness for thinning damage mechanisms. The LoIE tables for Thinning damage include inspection examples for non-metallic liners, if applicable.

Table 2.F.7.1—LoIE Example for General Thinning

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2,3,4]	Non-intrusive Inspection Example [1,2,3,4]
A	Highly Effective	**Components with and without Cladding** For the total surface area: >50 % visual examination (partial internals removed) **AND** >50 % of the spot ultrasonic thickness measurements **Components with Internal Liners** For the total surface area: 100 % visual inspection **AND** 100 % holiday test **AND** 100 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total surface area: 100 % UT/RT of CMLs **OR** For selected areas: 10 % UT scanning **OR** 10 % profile radiography **Components with Internal Liners** No inspection techniques are yet available to meet the requirements for an “A” level inspection
B	Usually Effective	**Components with and without Cladding** For the total surface area: >25 % visual examination **AND** >25 % of the spot ultrasonic thickness measurements **Components with Internal Liners** For the total surface area: >65 % visual inspection **AND** >65 % holiday test **AND** >65 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total surface area: >75 % spot UT **OR** >5 % UT scanning, automated or manual **OR** >5 % profile radiography of the selected area(s) **Components with Internal Liners** For the total surface area: 100 % automated or manual ultrasonic scanning

C	Fairly Effective	**Components with and without Cladding** For the total surface area: >5 % visual examination **AND** >5 % of the spot ultrasonic thickness measurements **Components with Internal Liners** For the total surface area: >35 % visual inspection **OR** >35 % holiday test **OR** >35 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total surface area: >50 % spot UT or random UT scans (automated or manual) **OR** random profile radiography of the selected area(s) **Components with Internal Liners** For the total surface area: >65 % automated or manual ultrasonic scanning
D	Poorly Effective	**Components with and without Cladding** For the total surface area: <5 % visual examination without thickness measurements **Components with Internal Liners** For the total surface area: >5 % visual inspection **OR** >5 % holiday test **OR** >5 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total surface area: >25 % spot UT **Components with Internal Liners** For the total surface area: >35 % automated or manual ultrasonic scanning
E	Ineffective	**Components with and without Cladding** Ineffective inspection technique/plan was utilized **Components with Internal Liners** Ineffective inspection technique/plan was utilized	**Components with and without Cladding** Ineffective inspection technique/plan was utilized **Components with Internal Liners** Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.
NOTE 2 Inspection points (CMLs, scans, etc.) are set up by knowledgeable individuals.
NOTE 3 That the number of CMLs and area for scanning (UT or profile radiography) is one that will detect damage if occurring.
NOTE 4 Percentage refers to percent of established CMLs examined (e.g. for spot UT) or the percent surface area examined.

Table 2.F.7.2—LoIE Example for Local Thinning

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2,3,4]	Non-intrusive Inspection Example [1,2,3,4]
A	Highly Effective	**Components with and without Cladding** For the total surface area: 100 % visual examination (with removal of internal packing, trays, etc.) **AND** 100 % follow-up at locally thinned areas **Components with Internal Liners** For the total surface area: 100 % visual inspection **AND** 100 % holiday test **AND** 100 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total suspect area: 100 % coverage of the CMLs using ultrasonic scanning or profile radiography **Components with Internal Liners** No inspection techniques are yet available to meet the requirements for an “A” level inspection
B	Usually Effective	**Components with and without Cladding** For the total surface area: >75 % visual examination **AND** 100 % follow-up at locally thinned areas **Components with Internal Liners** For the total surface area: >65 % visual inspection **AND** >65 % holiday test **AND** >65 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total suspect area: >75 % coverage of the CMLs using ultrasonic scanning or profile radiography **Components with Internal Liners** For the total surface area: 100 % automated or manual ultrasonic scanning

C	Fairly Effective	**Components with and without Cladding** For the total surface area: >50 % visual examination **AND** 100 % follow-up at locally thinned areas **Components with Internal Liners** For the total surface area: >35 % visual inspection **OR** >35 % holiday test **OR** >35 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total suspect area: >50 % coverage of the CMLs using ultrasonic scanning or profile radiography **Components with Internal Liners** For the total surface area: >65 % automated or manual ultrasonic scanning
D	Poorly Effective	**Components with and without Cladding** For the total surface area: >20 % visual examination **AND** 100 % follow-up at locally thinned areas **Components with Internal Liners** For the total surface area: >5 % visual inspection **OR** >5 % holiday test **OR** >5 % UT or magnetic tester for disbonding for bonded liners	**Components with and without Cladding** For the total suspect area: >20 % coverage of the CMLs using ultrasonic scanning or profile radiography **Components with Internal Liners** For the total surface area: >35 % automated or manual ultrasonic scanning
E	Ineffective	**Components with and without Cladding** Ineffective inspection technique/plan was utilized **Components with Internal Liners** Ineffective inspection technique/plan was utilized	**Components with and without Cladding** Ineffective inspection technique/plan was utilized **Components with Internal Liners** Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Percentage coverage in non-intrusive inspection includes welds.

NOTE 3 Follow-up inspection can be UT, pit gauge, or suitable NDE techniques that can verify minimum wall thickness.

NOTE 4 Profile radiography technique is sufficient to detect wall loss at all planes.

2.F.8 Inspection Effectiveness Tables for Stress Corrosion Cracking

2.F.8.1 Use of the Inspection Effectiveness Tables

LoIE Tables 2.F.8.1 through 2.F.8.9 are examples for levels of inspection effectiveness for SCC damage mechanisms.

2.F.8.2 Tables

Table 2.F.8.1—LoIE Example for Amine Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2]	Non-intrusive Inspection Example [1,2]
A	Highly Effective	For the total weld area: 100 % WFMT/ACFM with UT follow-up of relevant indications	For the total weld area: 100 % automated or manual ultrasonic scanning
B	Usually Effective	For selected welds/weld area: >75 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >75 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected welds/weld area: >35 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >35 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing
D	Poorly Effective	For selected welds/weld area: >10 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >10 % automated or manual ultrasonic scanning **OR** >10 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

Table 2.F.8.2—LoIE Example for ACSCC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2]	Non-intrusive Inspection Example [1,2]
A	Highly Effective	For the total weld area: 100 % WFMT/ACFM with UT follow-up of relevant indications	For the total weld area: 100 % automated or manual ultrasonic scanning
B	Usually Effective	For selected welds/weld area: >75 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >75 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected welds/weld area: >35 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >35 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing
D	Poorly Effective	For selected welds/weld area: >10 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >10 % automated or manual ultrasonic scanning **OR** >10 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

Table 2.F.8.3—LoIE Example for Caustic Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2,3]	Non-intrusive Inspection Example [1,2,3]
A	Highly Effective	For the total weld area: 100 % WFMT/ACFM with UT follow-up of relevant indications	For the total weld area: 100 % automated or manual ultrasonic scanning
B	Usually Effective	For selected welds/weld area: >75 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >75 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected welds/weld area: >35 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >35 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing
D	Poorly Effective	For selected welds/weld area: >10 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >10 % automated or manual ultrasonic scanning **OR** >10 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.
NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).
NOTE 3 Cold bends may need inspection also for caustic cracking.

Table 2.F.8.4—LoIE Example for ClSCC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,8,a]	Non-intrusive Inspection Example [1,8,a]
A	Highly Effective	For the total surface area: 100 % dye penetrant or eddy current test with UT follow-up of relevant indications	No inspection techniques are yet available to meet the requirements for an “A” level inspection
B	Usually Effective	For selected areas: >65 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: 100 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected areas: >35 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: >65 % automated or manual ultrasonic scanning **OR** >65 % radiographic testing
D	Poorly Effective	For selected areas: >10 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: >35 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

NOTE 3 Internal stress corrosion cracking.

Table 2.F.8.5—LoIE Example for PTA Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2,3]	Non-intrusive Inspection Example [1,2,3]
A	Highly Effective	For the total surface area: 100 % dye penetrant or eddy current test with UT follow-up of relevant indications	No inspection techniques are yet available to meet the requirements for an “A” level inspection
B	Usually Effective	For selected areas: >65 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: 100 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected areas: >35 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: >65 % automated or manual ultrasonic scanning **OR** >65 % radiographic testing
D	Poorly Effective	For selected areas: >10 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: >35 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing.
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

NOTE 3 There is no highly effective inspection without a minimum of partial insulation removal and external VT and PT.

Table 2.F.8.6—LoIE Example for SSC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2]	Non-intrusive Inspection Example [1,2]
A	Highly Effective	For the total weld area: 100 % WFMT/ACFM with UT follow-up of relevant indications	For the total weld area: 100 % automated or manual ultrasonic scanning
B	Usually Effective	For selected welds/weld area: >75 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >75 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected welds/weld area: >35 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >35 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing
D	Poorly Effective	For selected welds/weld area: >10 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >10 % automated or manual ultrasonic scanning **OR** >10 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

Table 2.F.8.7—LoIE Example for HIC/SOHIC-H_2S Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2,3]	Non-intrusive Inspection Example [1,2,3]
A	Highly Effective	For the total surface area: — >95 % A or C scan with straight beam — Followed by TOFD/shear wave — 100 % visual	For the total surface area: — SOHIC: — >90 % C scan of the base metal using advanced UT — For the weld and HAZ—100 % shear wave and TOFD **AND** — HIC: Two 1-ft^2 areas, C scan of the base metal using advanced UT on each plate and the heads
B	Usually Effective	For the total surface area: — >75 % A or C scan with straight beam — Followed by TOFD/shear wave — 100 % visual	For the total surface area: — >65 % C scan of the base metal using advanced UT **AND** — HIC: Two 0.5-ft^2 areas, C scan of the base metal using advanced UT on each plate and the heads
C	Fairly Effective	For the total surface area: — >35 % A or C scan with straight beam — Followed by TOFD/shear wave — 100 % visual **OR** — >50 % WFMT/ACFM — UT follow-up of indications — 100 % visual of total surface area	For the total surface area: — >35 % C scan of the base metal using advanced UT **AND** — HIC: One 1-ft^2 area, C scan of the base metal using advanced UT on each plate and the heads
D	Poorly Effective	For the total surface area: — >10 % A or C scan with shear wave — 100 % visual **OR** — >25 % WFMT/ACFM — UT follow-up of indications — 100 % visual of total surface area	For the total surface area: — >5 % C scan of the base metal using advanced UT **AND** — HIC: One 0.5-ft^2 area, C scan of the base metal using advanced UT on each plate and the heads
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

NOTE 3 Inspection area: welds and plates that are susceptible to the damage mechanism.

Table 2.F.8.8—LoIE Example for HSC-HF Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2]	Non-intrusive Inspection Example [1,2]
A	Highly Effective	For the total weld area: 100 % WFMT/ACFM with UT follow-up of relevant indications	For the total weld area: 100 % automated or manual ultrasonic scanning
B	Usually Effective	For selected welds/weld area: >75 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >75 % automated or manual ultrasonic scanning **OR** AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected welds/weld area: >35 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >35 % automated or manual ultrasonic scanning **OR** >65 % radiographic testing
D	Poorly Effective	For selected welds/weld area: >10 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >10 % automated or manual ultrasonic scanning **OR** >35 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

Table 2.F.8.9—LoIE Example for HIC/SOHIC-HF Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example [1,2]	Non-intrusive Inspection Example [1,2]
A	Highly Effective	For the total surface area: — 100 % A or C scan with straight beam — Followed by TOFD/shear wave — 100 % visual	For the total surface area: — SOHIC: — >90 % C scan of the base metal using advanced UT — For the weld and HAZ—100 % shear wave and TOFD **AND** — HIC: Two 1-ft^2 areas, C scan of the base metal using advanced UT on each plate and the heads
B	Usually Effective	For the total surface area: — >65 % A or C scan with straight beam — Followed by TOFD/shear wave — 100 % visual	For the total surface area: — >65 % C scan of the base metal using advanced UT **AND** — HIC: Two 0.5 ft^2 areas, C scan of the base metal using advanced UT on each plate and the heads.
C	Fairly Effective	For the total surface area: — >35 % A or C scan with straight beam — Followed by TOFD/shear wave — 100 % visual **OR** — >50 % WFMT/ACFM — UT follow-up of indications — 100 % visual of total surface area	For the total surface area: — >35 % C scan of the base metal using advanced UT **AND** — HIC: One 1-ft^2 area, C scan of the base metal using advanced UT on each plate and the heads
D	Poorly Effective	For the total surface area: — >10 % A or C scan with shear wave — >50 % visual **OR** — >25 % WFMT/ACFM — UT follow-up of indications — 100 % visual of total surface area	For the total surface area: — >5 % C scan of the base metal using advanced UT **AND** — HIC: One 0.5-ft^2 area, C scan of the base metal using advanced UT on each plate and the heads
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Inspection points (CMLs, scans, etc.) are set up by knowledgeable individuals.

NOTE 3 Inspection area: welds and plates that are susceptible to the damage mechanism.

2.F.9 Inspection Effectiveness for External Damage

2.F.9.1 Use of the Inspection Effectiveness Tables

LoIE Tables 2.F.10.1 through 2.F.10.4 are example for levels of inspection effectiveness for external damage mechanisms.

2.F.9.2 Tables

Table 2.F.9.1—LoIE Example for External Corrosion

Inspection Category	Inspection Effectiveness Category	Inspection [1]
A	Highly Effective	Visual inspection of >95 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
B	Usually Effective	Visual inspection of >60 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
C	Fairly Effective	Visual inspection of >30 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
D	Poorly Effective	Visual inspection of >5 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
E	Ineffective	Ineffective inspection technique/plan was utilized

NOTE Inspection quality is high.

Table 2.F.9.2—LoIE Example for External ClSCC Cracking

Inspection Category	Inspection Effectiveness Category	Inspection [1,2]
A	Highly Effective	For the suspected surface area: 100 % dye penetrant or eddy current test with UT follow-up of relevant indications
B	Usually Effective	For the suspected surface area: >60 % dye penetrant or eddy current testing with UT follow-up of all relevant indications
C	Fairly Effective	For the suspected surface area: >30 % dye penetrant or eddy current testing with UT follow-up of all relevant indications
D	Poorly Effective	For the suspected surface area: >5 % dye penetrant or eddy current testing with UT follow-up of all relevant indications
E	Ineffective	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.

NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).

NOTE 3 Inspection area: welds and plates that are susceptible to the damage mechanism.

Table 2.F.9.3—LoIE Example for CUI

Inspection Category	Inspection Effectiveness Category	Insulation Removed [1,2,3,4]	Insulation Not Removed [1,2,3,4]
A	Highly Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation **AND** Remove 100 % of the insulation for damaged or suspected areas **AND** 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge follow-up of the selected corroded areas	For the total surface area: 100 % external visual inspection **AND** 100 % profile or real-time radiography of damaged or suspect area **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
B	Usually Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation **AND** Remove >50 % of suspect areas **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge	For the total surface area: 100 % external visual inspection **AND** Follow-up with profile or real-time radiography of >65 % of suspect areas **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
C	Fairly Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation **AND** Remove >25 % of suspect areas **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge	For the total surface area: 100 % external visual inspection **AND** Follow-up with profile or real-time radiography of >35 % of suspect areas **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
D	Poorly Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation **AND** Remove >5 % of total surface area of insulation including suspect areas **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge	For the total surface area: 100 % external visual inspection **AND** Follow-up with profile or real-time radiography of >5 % of total surface area of insulation including suspect areas **AND** Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

NOTE 1 Inspection quality is high.
NOTE 2 Suspect area shall be considered the total surface area unless defined by knowledgeable individual (subject matter expert).
NOTE 3 Suspect areas include damaged insulation, penetrations, terminations, etc.
NOTE 4 Surface preparation is sufficient to detect minimum wall for the NDE technique used to measure thickness.

Table 2.F.9.4—LoIE Example for CUI ClSCC

Inspection Category	Inspection Effectiveness Category	Insulation Removed [1]	Insulation Not Removed [1]
A	Highly Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation **AND** >100 % dye penetrant or eddy current test with UT follow-up of relevant indications	No inspection techniques are yet available to meet the requirements for an “A” level inspection
B	Usually Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation **AND** >60 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	No inspection techniques are yet available to meet the requirements for a “B” level inspection
C	Fairly Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation **AND** >30 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	No inspection techniques are yet available to meet the requirements for a “C” level inspection
D	Poorly Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation **AND** >5 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	No inspection techniques are yet available to meet the requirements for a “D” level inspection
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized
NOTE Inspection quality is high.			

2.F.10 Inspection Effectiveness Tables for High Temperature Hydrogen Attack Damage

2.F.10.1 Use of the Inspection Effectiveness Tables

Currently there is no LoIE for HTHA damage. Please refer to Part 2, Section 19, which has a discussion on HTHA as it pertains to this document. It is the owner–operator's responsibility and accountability to develop an effective inspection program for assets potentially affected by HTHA and document their methodology, investigation, and results.

2.F.11 Inspection Effectiveness for Steam Traps, Mechanical Pumps and Control Valves

2.F.11.1 Use of the Inspection Effectiveness Tables

LoIE Table 2.F.11.1 is an example for levels of inspection effectiveness for steam traps, mechanical pumps and control valves.

2.F.11.2 Tables

Table 2.F.11.1 – Inspection and Testing Effectiveness for Steam Traps, Mechanical Pumps and Control Valves

~~Inspection Effectiveness~~	~~Failure Mode~~	~~Description of Inspection or Testing~~
~~Highly Effective~~	~~Leakage~~	~~Certified[1] tools and certified[1] inspector and comprehensive data collection as per Table 6.3 (e.g., including related valves, piping and location data)~~
	~~Blockage~~	
~~Usually Effective~~	~~Leakage~~	~~On-line monitoring with diagnostic function~~
	~~Blockage~~	
~~Fairly Effective~~	~~Leakage~~	~~Non-certified tools and/or non-certified inspector,~~ ~~OR~~ ~~Certification unknown,~~ ~~OR~~ ~~On-line monitoring without diagnostic function~~
	~~Blockage~~	
~~Ineffective~~	~~Leakage~~	~~No inspection,~~ ~~OR~~ ~~Incorrect inspection method~~
	~~Blockage~~	
~~[1]The tool and inspector should be certified to relevant standard or code.~~		

Inspection Effectiveness	Description of Inspection or Testing
Highly Effective	The steam trap inspection system/tool that is certified according to recognized standard and can be used for the energy management system. The inspectors are trained and certified to use the test equipment or the inspection tool. Comprehensive data collection as per Table 7.3 (e.g. including related valves, piping and location data).
Usually Effective	On-line monitoring with diagnostic functions such as: failure detection and early warning signs of failure.
Fairly Effective	Non-certified tools and/or non-certified inspector, OR Certification unknown, OR On-line monitoring without diagnostic function.
Poorly Effective	Visual assessment OR Incorrect inspection method.
Ineffective	No inspection.