PART 2 CONTENTS

Risk-Based Inspection Methodology
Part 2—Probability of Failure Methodology

1 Scope

The calculation of the POF of a component is covered in this document. This document is Part 2 of a three-volume set presenting the API 581 methodology. The other two parts are: Part 1—Inspection Planning Methodology, and Part 3—Consequence of Failure Methodology.

The POF calculated using the methodology in this Part is used with the COF to provide a risk ranking and not for a rigorous reliability analysis of a component. Alternatively, the POF provided in this Part provides a risk ranking and inspection plan for a component subject to process and environmental conditions typically found in refining, petrochemical industry, and exploration and production facilities.

2 NORMATIVE References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 580 Recommended Practice for Risk-Based Inspection, American Petroleum Institute, Washington, D.C.

API Recommended Practice 581, Risk-Based Inspection Methodology, Part 1—Inspection Planning Methodology, American Petroleum Institute, Washington, DC.

API Recommended Practice 581, Risk-Based Inspection Methodology, Part 3—Consequence of Failure Methodology, American Petroleum Institute, Washington, DC.

API Recommended Practice 581, Risk-Based Inspection Methodology, Part 5—Risk-Based Inspection Methodology for Special Equipment, American Petroleum Institute, Washington, DC.

3 Probability of Failure (POF) Methodology

3.1 Overview

The POF is computed from Equation (2.1).

$$P_f(t) = gff_{total} \cdot D_f(t) \cdot F_{MS} \tag{2.1}$$

In this equation, the POF, $P_f(t)$, is determined as the product of a total GFF, gff_{total}, a DF, $D_f(t)$, and a management systems factor, F_{MS}.

The adjustment factors on the generic frequency of failure reflect differences between damage mechanisms and the reliability management processes within a plant. The DF adjusts the GFF based on the active damage mechanisms the component is subject to and considers the susceptibility to the damage mechanism and/or the rate at which the damage accumulates. The DF also takes into consideration historical inspection data and the effectiveness of both past and future inspections. The management systems factor adjusts for the influence of the facility's management system on the mechanical integrity of the plant. The DF is applied on a component and damage mechanism specific basis, while the management systems factor is applied equally to all components within a plant.

Adjustment factors with a value greater than 1.0 will increase the POF, and those with a value less than 1.0 will decrease it. Both adjustment factors are always positive numbers.

3.2 Calculation of POF

The POF may be determined based on one, or a combination of, the following methods.

a) Structural Reliability Models—In this method, a limit state is defined based on a structural model that includes all relevant damage mechanisms and uncertainties in the independent variables of this model are defined in terms of statistical distributions. The resulting model is solved directly for the POF.

b) Statistical Models Based on Generic Data—In this method, generic data are obtained for the component and damage mechanism under evaluation and a statistical model is used to evaluate the POF.

c) Expert Judgment—In this method, where expert solicitation is used to evaluate the component and damage mechanism, a POF can be assigned on a relative basis.

A combination of the above is used to evaluate the POF in terms of a GFF and DF.

3.3 Generic Failure Frequency (GFF)

If enough data are available for a given component, true probabilities of failure can be calculated from actual observed failures. Even if a failure has not occurred in a component, the true POF is likely to be greater than zero because the component may not have operated long enough to experience a failure. As a first step in estimating this non-zero probability, it is necessary to examine a larger set of data of similar components to find enough failures so that a reasonable estimate of a true POF can be made. This generic component set of data is used to produce a GFF for the component. The GFFs provided in Table 3.1 are representative of the refining and petrochemical industry's failure data.

The GFF of a component type is estimated using records from all plants within a company or from various plants within an industry, from literature sources, and from commercial reliability databases. Therefore, these generic values represent an industry in general rather than the true failure frequencies for a specific component subject to a specific damage mechanism. The GFF is intended to be the failure frequency in relatively benign service prior to accounting for any specific operating environment and is provided for several discrete hole sizes for various types of processing equipment (i.e. process vessels, drums, towers, piping systems, tankage, etc.).

The failure frequencies associated with discrete hole sizes and an associated failure frequency are introduced into the methodology to model release scenarios. Four hole sizes are used to model the release scenarios covering a full range of events (i.e. small leak to rupture). The overall GFF for each component type was divided across the relevant hole sizes, i.e. the sum of the GFF for each hole size is equal to the total GFF for the component, and are provided in Table 3.1 [1–8]. The GFFs are assumed to follow a log-normal distribution, with error rates ranging from 3 % to 10 %. Median values are given in Table 3.1. The data presented in the Table 3.1 are based on the best available sources and experience to date from owner–operators.

Adjustment factors are applied to the GFF to reflect departures from the industry data to account for damage mechanisms specific to the component's operating environment and for reliability management practices within a plant. The DF is applied to a component and damage mechanism specific basis, while the management systems factor (F_{MS}) is applied equally to all equipment within a plant. DFs with a value greater than 1.0 will increase the POF, and those with a value less than 1.0 will decrease it. Both adjustment factors are always positive numbers.

3.4 Damage Factor (DF)

3.4.1 Overview

DFs provide a screening tool to determine inspection priorities and optimize inspection efforts. DFs do not provide a definitive FFS assessment of the component. The basic function of the DF is to statistically evaluate the amount of damage that may be present as a function of time in service and the effectiveness of an inspection activity. DFs are calculated based on the techniques described in Section 3.2 but are not intended to reflect the actual POF for the purposes of reliability analysis. DFs reflect a relative level of concern about the component based on the stated assumptions in each of the applicable sections of the document.

DF estimates are currently provided for the following damage mechanisms.

a) Thinning— D_{f-gov}^{thin} .

b) SCC— D_{f-gov}^{scc} .

c) External damage— D_{f-gov}^{extd} .

d) HTHA— D_{f}^{htha} .

e) Mechanical fatigue (piping only)— D_{f}^{mfat} .

f) Brittle fracture— D_{f-gov}^{brit} .

3.4.2 DF Combination for Multiple Damage Mechanisms

Damage factors for multiple mechanisms are assessed using the following statements:

a) Total DF, $D_{f-total}$—If more than one damage mechanism is present, the following rules are used to combine the DFs. The total DF is given by Equation (2.2) when the external and thinning damage are classified as local and therefore unlikely to occur at the same location.

$$D_{f-total} = \max\left[D_{f-gov}^{thin},\ D_{f-gov}^{extd}\right] + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat} \tag{2.2}$$

If the external or thinning damage are general or if both external and thinning damage are general, damage is likely to occur at the same location and the total DF is given by Equation (2.3).

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat} \tag{2.3}$$

NOTE 1: the summation of DFs can be less than or equal to 1.0. This means that the component can have a POF less than the GFF.

b) Governing thinning DF, D_{f-gov}^{thin} —The governing thinning DF is determined based on the presence of an internal liner using Equation (2.4) and Equation (2.5).

$$D_{f-gov}^{thin} = \min\left[D_{f}^{thin},\ D_{f}^{elin}\right] \quad \text{when an internal liner is present} \tag{2.4}$$

$$D_{f-gov}^{thin} = D_{f}^{thin} \quad \text{when an internal liner is not present} \tag{2.5}$$

c) Governing SCC DF, D_{f-gov}^{scc} —The governing SCC DF is determined by using Equation (2.6).

$$D_{f-gov}^{scc} = \max\left[\begin{matrix} D_f^{caustic},\ D_f^{amine},\ D_f^{ssc},\ D_f^{HIC/SOHIC-H_2S},\ D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{ClSCC}, D_f^{HSC-HF}, D_f^{HIC/SOHIC-HF} \end{matrix}\right] \tag{2.6}$$

d) Governing external DF, D_{f-gov}^{extd} —The governing external DF is determined from Equation (2.7).

$$D_{f-gov}^{extd} = max\left[D_f^{extf}, D_f^{CUIF}, D_f^{ext-ClSCC}, D_f^{CUI-ClSCC}\right] \tag{2.7}$$

e) Governing brittle fracture DF, D_{f-gov}^{brit} —The governing brittle fracture DF is determined from Equation (2.8). When performing the summation of DFs in Equation (2.8), if a DF is less than or equal to 1.0 (i.e. the damage is inactive), then this DF shall be set to zero in the summation.

$$D_{f-gov}^{brit} = \max\left[\left(D_f^{brit} + D_f^{tempe}\right), D_f^{885F}, D_f^{sigma}\right] \tag{2.8}$$

f) A description of the DFs shown above and the associated section number that contains the step-by-step calculations is provided in Table 3.2.

3.4.3 Inspection Effectiveness Category

DFs are determined as a function of inspection effectiveness. A discussion of inspection effectiveness and example tables are provided in Annex 2.C. The inspection effectiveness categories are meant to be examples in order to provide a guideline for the user in assigning actual inspection effectiveness.

The effectiveness of each inspection performed within the designated time period is characterized for each damage mechanism. The number of inspections and effectiveness of each inspection is used to calculate the DF. The number and effectiveness of each inspection for thinning and external corrosion is included directly in the calculation of the DFs (see Sections 4, 15, and 16).

If multiple inspections have been performed, equivalent relationships are used for SCC, external damage [external chloride stress corrosion cracking (ExtClSCC), external chloride stress corrosion cracking under insulation (CUI ClSCC)], and HTHA. Inspections of different grades (A, B, C, and D) are approximated as equivalent inspection effectiveness in accordance with the following relationships.

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A.

b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) Inspection, or 2C = 1B.

c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) Inspection, or 2D = 1C.

NOTE 1: Equivalent inspection values are not used for thinning and external corrosion DF calculations.

NOTE 2: The equivalent higher inspection rules shall not be applied to No Inspections (E).

3.5 Management Systems Factor

3.5.1 General

The effectiveness of a company's PSM system can have a pronounced effect on mechanical integrity. The methodology includes an evaluation tool to assess the portions of the facility's management system that most directly impact the POF of a component. The POF is generally increased by the MSF when the Management Systems in place show issues that could influence the confidence in the RBI program in a negative way. POF is decreased by the MSF when Management Systems are above average, providing a higher than typical confidence in the RBI analysis. This evaluation consists of a series of interviews with plant management, operations, inspection, maintenance, engineering, training, and safety personnel. The importance of an effective management system evaluation has long been recognized in preventing releases of hazardous materials and maintaining the mechanical integrity of process equipment.

The MSF globally impacts the risk assessment of every component at a siteand can have a significant impact on inspection planning. It is an evaluation of the site culture, which typically changes slowly over time. Therefore, Management System Factor reviews and adjustments should not be taken lightly or performed on a frequent basis. A good practice is to include a review of the evaluation during the periodic RBI reassessment effort.

3.5.2 Overview

A management systems factor is used to adjust POF for differences in process safety management systems. This factor is derived from the results of an evaluation of a facility or operating unit's management systems that affect plant risk. Different practices within units at a facility might create differences in the management systems factors between the units. However, within any one study, the management systems factor should be the same. The factor is applied equally to all components and, as a result, does not change the order of the risk-based ranking of the components. The management systems factor can, however, have a pronounced effect on the total level of risk calculated for each item and for the summed risk for the study. This becomes important when risk levels of entire units are compared or when risk values for similar components are compared between different units or plant sites.

The management systems evaluation covers all areas of a plant's management system that impact directly or indirectly on the mechanical integrity of process equipment. The management systems evaluation is based in large part on the requirements contained in API Recommended Practices and Inspection Codes. It also includes other proven techniques in effective safety management. A listing of the subjects covered in the management systems evaluation and the weight given to each subject is presented in Table 3.3.

It is not the intent of the management systems evaluation to measure overall compliance with all API recommendations or OSHA requirements; the emphasis is on mechanical integrity issues. Mechanical integrity is the largest single section, and most of the questions in the other subject areas are either closely related to mechanical integrity, or they have a bearing on total unit risk. The management systems evaluation, along with suggested auditing techniques, is provided in Annex 2.A. It consists of numerous questions, most of which have multiple parts. Each possible answer to each question is given a weight, depending upon the appropriateness of the answer and the importance of the topic. This system provides a qualitative, numerical score for the management systems evaluation. The number of questions and the breadth of subject matter covered, enable the management systems evaluation to differentiate between different levels of program effectiveness.

There is no specific score that indicates compliance vs. noncompliance. A score of 100 equates to a plant having absolutely best in industry Management Systems in place in all key areas that can influence confidence in the RBI analysis which may impact the POF. A score of about 72 indicates industry average performance and does not change the POF. Some Owner-Operators may choose to use this score rather than performing the evaluation. A score below 72 indicates there are issues with the Management Systems that negatively impact the confidence in the RBI program and will result in a larger POF to adjust the risk appropriately.

3.5.3 Auditing Technique

The management systems evaluation covers a wide range of topics and, as a result, requires input from several different disciplines within the facility to answer all questions. Ideally, representatives from the following plant functions should be interviewed:

a) Plant Management;

b) Operations;

c) Maintenance;

d) Safety;

e) Inspection;

f) Training;

g) Engineering.

The number of separate interviews required to complete the management systems evaluation will vary from application to application. In many cases, one individual can effectively answer the questions concerning two or more of the above functions. Normally at least four interviews are required.

The number of auditors involved is arbitrary, but there is some advantage in using more than one. With two or more auditors, the management systems evaluation team can compare notes and often avoid overlooking or misinterpreting important information.

The people to be interviewed should be designated, and then a subset of questions should be selected from the total management systems evaluation to match the expertise of each person being interviewed. All audit questions should be answered, and there should be no hesitance to include some of the audit questions in more than one interview. This is sometimes important to provide continuity and clarity during the interview. In addition, it can be revealing to compare answers from different disciplines as people's perceptions can differ markedly.

The intent of the management systems evaluation is to arrive at the single best answer for each question. In addition to comparing answers from different interviews, many of the responses should be verified by physical review of the appropriate written procedures, files, and records. The auditor must ensure that the facts substantiate the answer and that the intent of the question is met before credit is awarded for the answer.

3.5.4 Calculation of the Management Systems Factor

The formula for converting a management systems evaluation score, *pscore*, to a management systems factor, F_{MS}, is based on the assumption that the "average" plant would score 72% on the management systems. Based on this ranking, Equation (2.9) is used to compute a management systems factor, F_{MS}, for any management systems factor, F_{MS}, for any management systems evaluation score,

$$F_{MS} = 2.38 \bullet e^{(-0.012 \bullet pscore)} \tag{2.9}$$

The above assumptions can be modified and improved over time as more data become available on management systems evaluation results.

It should be remembered that the management systems factor applies equally to all components and therefore, does not change the risk ranking of components for inspection prioritization. The factor's value is in comparing one operating unit or plant site to another.

3.6 Nomenclature

score is the the numeric value assigned to a given score obtained from the Management Systems evaluation question, which are summed to provide a section score and further multiplied by a weight % to develop the *pscore*

e is the mathematical constant rounded to 2.718

3.7 Tables

Table 3.1—Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	GFF As a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat exchanger	HEXSS, HEXTS	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1, PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4, PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8, PIPE-10, PIPE-12, PIPE-16, PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP2S, PUMPR, PUMP1S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Tank620	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.22E-04
Tank620	TANKBOTEDGE	7.20E-04	0	0	2.00E-06	7.22E-04
Tank620	COURSE-1-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.22E-04
Tank650	TANKBOTEDGE	7.20E-04	0	0	2.00E-06	7.22E-04
Tank650	COURSE-1-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
FinFan	FINFAN TUBES FINFAN HEADER	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

Equipment Type	Component Type	GFF As a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Vessel	KODRUM, COLBTM, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

NOTE 1 See References [1] through [8] for discussion of failure frequencies for equipment.

NOTE 2 TANKBOTEDGE refers to the near shell region of the tank bottom and is considered to extend 24 to 30 inches inside the shell. This is consistent with most annular ring dimensions. This component type can be used for tanks with or without an annular ring. TANKBOTTOM refers to the entire tank bottom, or if a TANKBOTEDGE is modeled, it refers to the remaining part of the tank bottom that does not include the edge component.

NOTE 3 Tank620 Course components are the primary pressure boundary in the case of a double-walled tank. The secondary wall may be considered as having an effect on leak detection, isolation and mitigation.

Table 3.2—Damage Factor Section References

DF Variable	DF Description	Section
D_f^{thin}	DF for general and localized thinning	4
D_f^{elin}	DF of internal inorganic, organic, and strip linings for all component types	5
$D_f^{caustic}$	DF for caustic cracking	6
D_f^{amine}	DF for amine cracking	7
D_f^{ssc}	DF for SSC	8
$D_f^{HIC/SOHIC-H_2S}$	DF for HIC/SOHIC cracking in H_2S environments	9
D_f^{ACSCC}	DF for ACSCC	10
D_f^{PTA}	DF for polythionic acid cracking in austenitic stainless steel and nonferrous alloy components	11
D_f^{ClSCC}	DF for ClSCC	12
D_f^{HSC-HF}	DF for HSC in HF environments	13
$D_f^{HIC/SOHIC-HF}$	DF for HIC/SOHIC cracking in HF environments	14
D_f^{extcor}	DF for external corrosion on ferritic components	15
D_f^{CUIF}	DF for CUI on insulated ferritic components	16
$D_f^{ext-ClSCC}$	DF for ExtClSCC on austenitic stainless steel components	17
$D_f^{CUI-ClSCC}$	DF for CUI ClSCC on austenitic stainless steel insulated components	18
D_f^{htha}	DF for HTHA	19
D_f^{brit}	DF for brittle fracture of carbon steel and low alloy components	20
D_f^{tempe}	DF for low alloy steel embrittlement of Cr-Mo low alloy components	21
D_f^{885F}	DF for 885 °F embrittlement	22
D_f^{sigma}	DF for sigma phase embrittlement	23
D_f^{mfat}	DF for mechanical fatigue	24

Table 3.3—Management Systems Evaluation

Table	Title	Weight	Score	Weighted Score
2.A.1	Site Management	17%	0	0
2.A.2	Process Safety Information	5%	0	0
2.A.3	Management of Change	13%	0	0
2.A.4	Operating Procedures	5%	0	0
2.A.5	Mechanical Procedures	50%	0	0
2.A.6	Equipment Failure Investigation	10%	0	0
Total		**100%**	***pscore* =**	**0**

$$pscore = \sum[(weight\%) \cdot Score] \quad (2.10)$$

4 Thinning DF

4.1 Scope

The DF calculation for components subject to damage mechanisms that cause general or local thinning is covered in this section, including components with internal liners, strip lining or cladding. Thinning associated with external corrosion and CUI should be evaluated according to the procedures in Section 15.6.4 and Section 16.6.3, respectively.

4.2 Screening Criteria

All components should be checked for thinning.

4.3 Required Data

The basic component data required for analysis are given in Table 4.1. Component types and required geometry data are shown in Table 4.2 and Table 4.3, respectively. The data required for determination of the thinning DF are provided in Table 4.4.

4.4 Basic Assumptions

In the thinning DF calculation, it is assumed that the thinning corrosion rate is constant over time. This corrosion rate is updated based on the knowledge gained from subsequent inspections (see Section 4.5.6). An A_{rt} parameter is determined by calculating the ratio of total component wall loss (using the assigned corrosion rate during the in-service time period) to the wall thickness.

The DF is calculated using structural reliability theory[17,18,91]. A statistical distribution is applied to the thinning corrosion rate, accounting for the variability of the actual thinning corrosion rate, which can be greater than the rate assigned. The amount of uncertainty in the corrosion rate is determined by the number and effectiveness of inspections and the on-line monitoring that has been performed (see Section 4.5.3). Confidence that the assigned corrosion rate is the rate experienced in service increases with more thorough inspection, a greater number of inspections, and/or more relevant information gathered through the on-line monitoring. The DF is updated based on increased confidence in the measured corrosion rate provided by using Bayes Theorem (see Section 4.5.3 and Table 4.5) and the improved knowledge of the component condition (see Section 4.5.5, Section 4.5.6, and Table 4.6). The composite wall may consist of three separate components that affect the Thinning DF calculation. Each component may have factors resulting in an impact on thickness and age. The three components are:

a) Base Material – represents the structural component of the total wall thickness and is typically carbon or low alloy steel
b) Cladding Material – represents explosion-bonded cladding, roll-bonded cladding or weld overlay which are typically provided to protect the base material from thinning
c) Internal Lining – represents any organic, metallic or non-metallic protection (e.g., refractory, alloy strip lining) - see Table 4.7 for more examples

All internal liners provide a degree of protection from the operating environment. Many liners will provide protection for an indefinite period of time, essentially being immune to damage mechanisms that may otherwise occur. Other liners will slowly degrade with time and have a finite life. In cases of liners with finite life, the age of the liner (or the years since the last inspection) becomes important in calculating the Thinning DF. In the case of organic linings, the assumption is made that the liner is compatible with the environment, has operated within design temperature limits (including steam out), was applied after proper surface preparation, and followed by curing of coatings and refractories or adequate heat treatment for an alloy liner. The thinning DF is calculated for a defined time period or plan period. The start of the plan period can be the component installation date with a furnished thickness, an inspection date with a reliable thickness measurement, or the date of a process service change with a reliable thickness measurement. In the DF calculation, it is assumed that thinning damage would eventually result in failure by plastic collapse or a small leak.

4.5 Determination of the DF

4.5.1 Overview

The following sections provide additional information and the calculation procedure to determine DF. The thinning DF is calculated for a defined time period or plan period. The start of the plan period can be the component installation date with a furnished thickness, an inspection date with a reliable thickness measurement, or the date of a process service change with a reliable thickness measurement. In the DF calculation, it is assumed that thinning damage would eventually result in failure by plastic collapse or a leak or rupture.

Uncertainty in the component condition is determined with consideration for the corrosion rate assigned (see Section 4.5.2 and Section 4.5.3) and an improved confidence in the assigned rate provided by subsequent inspection (Section 4.5.5).

4.5.2 Corrosion Rate

The corrosion rate can be obtained by several methods, as follows.

a) Calculated—Annex 2.B of this document provides conservative methods for determining a corrosion rate for various corrosion environments.

b) Measured—These are based on recorded thicknesses over time at condition monitoring location(s) (CMLs). See API 510[15] and API 570[16] for definition of CML.

c) Estimated—A corrosion specialist experienced with the process is usually the best source of providing realistic and appropriate estimated rates. See API 510[15] and API 570[16] for a definition of corrosion specialist.

As discussed in Section 4.4, the thinning corrosion rate is assumed to be constant over the plan period. For this reason, using long-term average corrosion rates is recommended for the DF calculation. Since the corrosion rate in practice may not be constant over time, use of short-term corrosion rates can lead to overly conservative and, in some cases, nonconservative results.

The measured corrosion rate should be used, if available. If a measured corrosion rate based on inspection history is not available, an estimated corrosion rate based on expert advice may be used to assign the expected corrosion rate, or a calculated corrosion rate may be determined for each potential thinning mechanism using Annex 2.B. If multiple thinning mechanisms are possible, the maximum corrosion rate should be used. If cladding is present, the cladding will corrode prior to corrosion being applied to the base material. If an internal liner is present, the liner will provide corrosion protection for the liner remaining life before corrosion initiates on the base material.

4.5.3 Corrosion Rate Confidence Levels

The corrosion rate in process equipment is often not known with certainty. The ability to state the corrosion rate precisely is limited by equipment complexity, process and metallurgical variations, inaccessibility for inspection, and limitations of inspection and test methods. The best information comes from inspection results for the current equipment process operating conditions. Other sources of information include databases of plant experience or reliance on a knowledgeable corrosion specialist.

The uncertainty in the corrosion rate varies, depending on the source and quality of the corrosion rate data. For general thinning, the reliability of the information sources used to establish a corrosion rate can be put into the following three categories.

a) Low Confidence Information Sources for Corrosion Rates—Sources such as published data, corrosion rate tables, and expert opinion. Although they are often used for design decisions, the actual corrosion rate that will be observed in a given process situation may significantly differ from the design value.

b) Medium Confidence Information Sources for Corrosion Rates—Sources such as laboratory testing with simulated process conditions or limited in situ corrosion coupon testing. Corrosion rate data developed from sources that simulate the actual process conditions usually provide a higher level of confidence in the predicted corrosion rate.

c) High Confidence Information Sources for Corrosion Rates—Sources such as extensive field data from thorough inspections. Coupon data, reflecting five or more years of experience with the process equipment (assuming significant process changes have not occurred), provide a high level of confidence in the predicted corrosion rate. If enough data are available from actual process experience, the actual corrosion rate is very likely to be close to the expected value under normal operating conditions.

Thinning DF calculations are based on the probability of three damage states being present. The three damage states used in Section 4.5.7 are defined as follows.

1) Damage State 1—Damage is no worse than expected, or a factor of 1 applied to the expected corrosion rate.

2) Damage State 2—Damage is somewhat worse than expected, or a factor of 2 applied to the expected corrosion rate.

3) Damage State 3—Damage considerably worse than expected, or a factor of 4 applied to the expected corrosion rate.

General corrosion rates are rarely more than four times the expected rate, while localized corrosion can be more variable. The default values provided here are expected to apply to many plant processes. The uncertainty in the corrosion rate varies, depending on the source and quality of the corrosion rate data. Table 4.5 provides suggested probabilities (prior probabilities) for the damage states based on the reliability of the information sources used with Bayes Theorem. However, the user may choose to customize the prior probabilities based on actual experience and confidence in the measured thickness values.

4.5.4 Thinning Type

Whether the thinning is expected to be localized wall loss or general and uniform in nature, this thinning type is used to define the inspection to be performed. Thinning type is assigned for each potential thinning mechanism. If the thinning type is not known, guidance provided in Annex 2.B should be used to help determine the local or general thinning type expected for various mechanisms. If multiple thinning mechanisms are possible and both general and localized thinning mechanisms are assigned, the localized thinning type should be used.

4.5.5 Thickness and Age

The thickness used for the DF calculation is either the furnished thickness (the thickness at the start of component in-service life) or the measured thickness (the thickness at any point of time in the component in-service life as a result of an inspection).

A furnished thickness may be replaced with a measured thickness as a result of a high-quality inspection (for thinning and external corrosion, as applicable) and high confidence in the measurement accuracy. Key reasons for replacing the furnished thickness with a measured thickness are as follows.

a) The component service start date when combined with a reasonably conservative corrosion rate predicts an unrealistically high wall loss when the measured wall loss based on quality inspection is much lower than predicted.

b) The process conditions differ significantly from historical service conditions that are the basis for historical measured corrosion rate.

c) The furnished thickness based on design is significantly different than the thickness measured by a baseline inspection or lack of reliable baseline data.

The start date for DF calculation should be consistent with the date of the installation in the case of a furnished thickness, or date of inspection in the case of a measured thickness. The inspection credit for the DF calculation should be only for those inspections performed during the time period assessed. Inspection performed prior to the start date is not typically included in the DF calculation.

The component corrosion rate is used to calculate DF and is assumed to be constant over time. Since this is not the case in reality, using long-term average rates for the current process conditions may be the preferred rate to use.

4.5.6 Inspection Effectiveness

Inspections are ranked according to their expected effectiveness at detecting thinning and correctly predicting the rate of thinning. Table 4.6 provides the conditional probabilities for each inspection effectiveness category in the thinning DF calculations. These probabilities are used with the three damage states and Bayes Theorem described in Section 4.5.3. The actual effectiveness of a given inspection technique depends on the characteristics of the thinning mechanism (i.e. whether it is general or localized).

Examples of inspection activities for specific applications are provided in Annex 2.F for:

a) general and localized thinning that are either intrusive or nonintrusive in Table 2.F.7.1 and Table 2.F.7.2,

b) buried components in Table 2.F.6.1,

For localized thinning, selection of locations for examination must be based on a thorough understanding of the damage mechanism in the specific process.

The effectiveness of each inspection performed within the designated time period must be characterized in a manner similar to the examples provided in Annex 2.F, as applicable. The number and effectiveness of each inspection is used to determine the DF. Inspections performed prior to the designated time period are typically not used to determine the DF.

4.5.7 Calculation of Thinning DF

The following procedure may be used to determine the DF for thinning. This procedure assumes that if cladding is present, it corrodes prior to any corrosion of the base material. If an internal liner is used, the procedure assumes that the liner prevents corrosion during the internal liner life.

a) STEP 1—Determine the furnished thickness, t, and age, age. For components with cladding determine the cladding thickness, t_{cm}, for the component from the installation date. If the component has an internal liner, determine the liner age, age_{liner} from the liner installation date.

b) STEP 2—Determine the base material corrosion rate, $C_{r,bm}$, and the cladding corrosion rate, $C_{r,cm}$, as applicable, based on the material of construction and process environment, using guidance from Section 4.5.2 and examples in Annex 2.B for establishing corrosion rates.

c) STEP 3—Determine the time in service, age_{tk}, since the last inspection and last known thickness, t_{rdi}. The last know thickness is the furnished thickness, t, or measured thickness reading from a previous inspection, t_{rdi} (see Section 4.5.5).

   1) Determine the date of the last inspection with a measured thickness and calculate the service age since the inspection, age_{tk} , and the measured thickness, t_{rdi} . If no measured thickness is available, set $t_{rdi} = t$ and $age_{tk} = age$ from STEP 1.

   2) For pressure vessels with cladding, calculate the remaining life of the cladding, age_{rc} , using the cladding thickness, t_{cm} and corrosion rate, $C_{r,cm}$, using Equation (2.11). If the component does not contain cladding, set $C_{r,cm} = 0$ and go to next step.

$$age_{rc} = max\left[\left(\frac{t_{cm}}{C_{r,cm}}\right),\ 0.0\right] \tag{2.11}$$

   NOTE 1: t_{cm} *is calculated by* $t_{rdi} - t_{bm}$.

   3) For pressure vessel components with internal liners, determine the liner type and expected age using Table 4.7, the condition of liner during the last inspection using Table 4.8, and remaining life of the internal liner, age_{rc} , using age_{liner} from STEP 1 and Equation (2.12). If the component does not contain an internal liner, set $age_{rc} = 0$ and go to STEP 4.

$$age_{rc} = \frac{RL_{liner}^{exp} - age_{liner}}{F_{LC}} \cdot F_{liner,OM} \tag{2.12}$$

i. Adjustment for Lining Condition, F_{LC} – The adjustment factors are given in Table 4.8 based on a qualitative assessment of the lining condition.

ii. Adjustment for On-Line Monitoring, $F_{liner,OM}$, – Some lined components have monitoring to allow early detection of a leak or other failure of the lining. The monitoring allows orderly shutdown of the component before failure occurs. If on-line monitoring is used and it is known to be effective at detecting lining deterioration, $F_{OM} = 0.1$ = ; otherwise $F_{OM} = 1.0$. Examples of monitoring systems include thermography or heat sensitive paint (refractory linings), weep holes with detection devices (loose alloy linings), and electrical resistance detection (glass linings).

d) STEP 4—Determine t_{min} using one of the following methods.

1) For cylindrical, spherical, rectangular or head components, determine the allowable stress, S, weld joint efficiency, E, and calculate the minimum required thickness, t_{min}, using component type in Table 4.2, geometry type in Table 4.3, and per the original construction code or API 579-1/ASME FFS-1 [10].

2) In cases where components are constructed of uncommon shapes or where the component's minimum structural thickness, t_c, may govern, the user may use the t_c in lieu of t_{min}.

3) A specific t_{min} calculated by another method and documented in the asset management program may be used at the owner–operator's discretion.

e) STEP 5—Determine the A_{rt} parameter using Equation (2.13), based on t from STEP 2, and age_{tk} and t_{rdi} from STEP 3.

For components with or without cladding, use Equation (2.13).

$$A_{rt} = max\left(\frac{C_{r,bm} \cdot (age_{tk} - age_{rc})}{t_{rdi}}, 0\right) \tag{2.13}$$

f) STEP 6—Calculate the flow stress, FS^{Thin}, using E from STEP 4 and Equation (2.14).

$$FS^{Thin} = \frac{(YS + TS)}{2} \cdot E \cdot 1.1 \tag{2.14}$$

NOTE 2: Use flow stress (FS^{Thin}) at design temperature for conservative resultss, using the appropriate Equation (2.15) or Equation (2.16).

g) STEP 7—Calculate the strength ratio parameter, SR_P^{Thin}, using the appropriate Equation (2.15) or Equation (2.16) For Equation (2.15), use t_{rdi} from STEP 3, t_{min} or t_c from STEP 4, S and E from STEP 5, and flow stress, FS^{Thin}, from STEP 6.

$$SR_P^{Thin} = \frac{S \cdot E}{FS^{Thin}} \cdot \frac{max(t_{min}, t_c)}{t_{rdi}} \tag{2.15}$$

NOTE 3: The t_{min} is based on a design calculation that includes evaluation for internal pressure hoop stress, external pressure, and/or structural considerations, as appropriate.

NOTE 4: The minimum required thickness calculation is the design code t_{min}. Consideration for internal pressure hoop stress alone may not be sufficient. T_c as defined in STEP 4 should be used when appropriate.

Using Equation (2.16) with t_{rdi} from STEP 3 and FS^{Thin} from STEP 6.

$$SR_P^{Thin} = \frac{P \cdot D}{\alpha \cdot FS^{Thin} \cdot t_{rdi}} \tag{2.16}$$

where α is the shape factor for the component type. α = 2 for a cylinder, 4 for a sphere, 1.13 for a head.

NOTE 5: This strength ratio parameter is based on internal pressure hoop stress only. It is not appropriate where external pressure and/or structural considerations dominate. When t_c dominates or if the t_{min} is calculated using another method, Equation (2.15) should be used.

h) STEP 8—Determine the number of inspections for each of the corresponding inspection effectiveness, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, and N_D^{Thin}, using Section 4.5.6 for past inspections performed during the in-service time.

i) STEP 9—Calculate the inspection effectiveness factors, I_1^{Thin}, I_2^{Thin}, and I_3^{Thin}, using Equation (2.16), prior probabilities, Pr_{p1}^{Thin}, Pr_{p2}^{Thin}, and Pr_{p3}^{Thin}, from Table 4.5, the conditional probabilities (for each inspection effectiveness level), Co_{p1}^{Thin}, Co_{p2}^{Thin}, and Co_{p3}^{Thin}, from Table 4.6, and the number of inspections, N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, and N_D^{Thin}, in each effectiveness level from STEP 8.

$$\begin{aligned}
I_1^{Thin} &= Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p1}^{ThinD}\right)^{N_D^{Thin}}\\
I_2^{Thin} &= Pr_{p2}^{Thin}\left(Co_{p2}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p2}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p2}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p2}^{ThinD}\right)^{N_D^{Thin}}\\
I_3^{Thin} &= Pr_{p3}^{Thin}\left(Co_{p3}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p3}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p3}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p3}^{ThinD}\right)^{N_D^{Thin}}
\end{aligned} \tag{2.16}$$

See Section 4.5.3 for guidance on selection of the prior probabilities. Conservatively, the low confidence data could be chosen from Table 4.5.

j) STEP 10—Calculate the posterior probabilities, Po_{p1}^{Thin}, Po_{p2}^{Thin}, and Po_{p3}^{Thin}, using Equation (2.17) with I_1^{Thin}, I_2^{Thin}, and I_3^{Thin} in STEP 9.

$$\begin{aligned}
Po_{p1}^{Thin} &= \frac{I_1^{Thin}}{I_1^{Thin}+I_2^{Thin}+I_3^{Thin}}\\
Po_{p2}^{Thin} &= \frac{I_2^{Thin}}{I_1^{Thin}+I_2^{Thin}+I_3^{Thin}}\\
Po_{p3}^{Thin} &= \frac{I_3^{Thin}}{I_1^{Thin}+I_2^{Thin}+I_3^{Thin}}
\end{aligned} \tag{2.17}$$

k) STEP 11—Calculate the parameters, β_1^{Thin}, β_2^{Thin}, and β_3^{Thin}, using Equation (2.18) and assigning $COV_{\Delta t}$ = 0.20, COV_{S_f} = 0.20, and COV_p = 0.05.

$$\beta_1^{Thin} = \frac{1 - D_{S_1} \cdot A_{rt} - SR_p^{Thin}}{\sqrt{D_{S_1}{}^2 \cdot A_{rt}{}^2 \cdot COV_{\Delta t}{}^2 + \left(1 - D_{S_1} \cdot A_{rt}\right)^2 \cdot COV_{S_f}{}^2 + (SR_p^{Thin})^2 \cdot COV_P{}^2}},$$
$$\beta_2^{Thin} = \frac{1 - D_{S_2} \cdot A_{rt} - SR_p^{Thin}}{\sqrt{D_{S_2}{}^2 \cdot A_{rt}{}^2 \cdot COV_{\Delta t}{}^2 + \left(1 - D_{S_2} \cdot A_{rt}\right)^2 \cdot COV_{S_f}{}^2 + (SR_p^{Thin})^2 \cdot COV_P{}^2}}, \quad (2.18)$$
$$\beta_3^{Thin} = \frac{1 - D_{S_3} \cdot A_{rt} - SR_p^{Thin}}{\sqrt{D_{S_3}{}^2 \cdot A_{rt}{}^2 \cdot COV_{\Delta t}{}^2 + \left(1 - D_{S_3} \cdot A_{rt}\right)^2 \cdot COV_{S_f}{}^2 + (SR_p^{Thin})^2 \cdot COV_P{}^2}}.$$

Where D_{S_1} = 1, D_{S_2} = 2, and D_{S_3} = 4. These are the corrosion rate factors for damage states 1, 2, and 3 as discussed in Section 4.5.3 [17].

NOTE 6: the DF calculation is very sensitive to the value used for the coefficient of variance for thickness, $COV_{\Delta t}$. The $COV_{\Delta t}$ is in the range 0.10 ≤ $COV_{\Delta t}$ ≤ 0.20, with a recommended conservative value of $COV_{\Delta t}$ = 0.20.

l) STEP 12—For all components, calculate the base DF, D_{fB}^{thin}.

$$D_{fb}^{Thin} = \left[\frac{\left(Po_{p1}^{Thin} \Phi\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin} \Phi\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin} \Phi\left(-\beta_3^{Thin}\right)\right)}{1.56\text{E-}04}\right] \quad (2.19)$$

where Φ is the standard normal cumulative distribution function (NORMSDIST in Excel).

m) STEP 13—Determine the DF for thinning, D_f^{Thin}, using Equation (2.20).

$$D_f^{Thin} = \max\left[\left(\frac{D_{fB}^{Thin} \cdot F_{IP} \cdot F_{DL}}{F_{OM}}\right), \ 0.1\right] \quad (2.20)$$

The adjustment factors in are determined as described below.

1) Adjustment to DF for On-line Monitoring, F_{OM}—In addition to inspection, on-line monitoring of corrosion (or key process variables affecting corrosion) is commonly used in many processes to prevent corrosion failures. The advantage of on-line monitoring is that changes in corrosion rates as a result of process changes can be detected long before they would be detected with normal periodic inspections. This earlier detection usually permits more timely action to be taken that should decrease the POF. Various methods are employed, ranging from corrosion probes, corrosion coupons, and monitoring of key process variables. If on-line monitoring is employed, then credit should be given to reflect higher confidence in the predicted thinning rate. However, these methods have a varying degree of success depending on the specific thinning mechanism. Using knowledge of the thinning mechanism and the type of on-line monitoring, determine the on-line

monitoring factor from Table 4.7. If more than one monitoring method is used, only the highest monitoring factor should be used (i.e. the factors are not additive).

2) Adjustment for Injection/Mix Points, F_{IP}—An injection/mix point is defined as a point where a chemical (including water) is being added to the main flow stream. A corrosive mix point is defined as:

— mixing of vapor and liquid streams where vaporization of the liquid stream can occur;

— water is present in either or both streams; or

— temperature of the mixed streams is below the water dew point of the combined stream.

If a piping circuit contains an injection/mix point, then an adjustment factor equal to F_{IP} = 3 should be used to account for the higher likelihood of thinning activity at this location. If an effective inspection program specifically for injection/mix point corrosion within the injection point circuit (according to API 570) is performed, the adjustment factor is F_{IP} = 1.

3) Adjustment for Deadlegs, F_{DL}—A dead-leg is defined as a section of piping or piping circuit that is used only during intermittent service such as start-ups, shutdowns, or regeneration cycles rather than continuous service. Deadlegs include components of piping that normally have no significant flow. If a piping circuit contains a deadleg, then an adjustment should be made to the thinning DF to account for the higher likelihood of thinning activity at this location. The adjustment factor is F_{DL} = 3. If an effective inspection program is in place to address the potential of localized corrosion in the deadleg, the adjustment is F_{DL} = 3.

4.6 Nomenclature

age is the in-service time that the damage is applied, years

age_{liner} is the in-service time that the damage is applied, years

age_{rc} is the remaining life of the internal liner or cladding associated with the date of the starting thickness, years

age_{tk} is the component in-service time since the last inspection thickness measurement or service start date, years

A_{rt} is the component wall loss fraction since last inspection thickness measurement or service start date

$C_{r,bm}$ is the corrosion rate for the base material, mm/year (inch/year)

$C_{r,cm}$ is the corrosion rate for the cladding, mm/year (inch/year)

CA is the corrosion allowance, mm (mpy)

Co_{p1}^{Thin} is the conditional probability of inspection history inspection effectiveness for damage state 1

Co_{p2}^{Thin} is the conditional probability of inspection history inspection effectiveness for damage state 2

Co_{p3}^{Thin} is the conditional probability of inspection history inspection effectiveness for damage state 3

COV_P is the pressure coefficient of variance

COV_{S_f} is the flow stress coefficient of variance

$COV_{\Delta t}$ is the thinning coefficient of variance

D is the component inside diameter, mm (mpy)

D_{S_1} is the corrosion rate factor for damage state 1

D_{S_2} is the corrosion rate factor for damage state 2

D_{S_3} is the corrosion rate factor for damage state 3

D_f^{Thin} is the DF for thinning

D_{fB}^{Thin} is the base value of the DF for thinning

E is the weld joint efficiency or quality code from the original construction code

F_{AM} is the DF adjustment for AST maintenance per API 653

F_{DL} is the DF adjustment for dead-legs

F_{IP} is the DF adjustment for injection points

F_{LC} is the DF adjustment for lining condition

F_{OM} is the DF adjustment for online monitoring

F_{SM} is the DF adjustment for settlement

F_{WD} is the DF adjustment for welded construction

FS^{Thin} is the flow stress, MPa (psi)

I_1^{Thin} is the first order inspection effectiveness factor

I_2^{Thin} is the second order inspection effectiveness factor

I_3^{Thin} is the third order inspection effectiveness factor

N_A^{Thin} is the number of A level inspections

N_B^{Thin} is the number of B level inspections

N_C^{Thin} is the number of C level inspections

N_D^{Thin} is the number of D level inspections

P	is the pressure (operating, design, PRD overpressure, etc.), MPa (psi)
Po_{p1}^{Thin}	is the posterior probability for damage state 1
Po_{p2}^{Thin}	is the posterior probability for damage state 2
Po_{p3}^{Thin}	is the posterior probability for damage state 3
Pr_{p1}^{Thin}	is the prior probability of corrosion rate data confidence for damage state 1
Pr_{p2}^{Thin}	is the prior probability of corrosion rate data confidence for damage state 2
Pr_{p3}^{Thin}	is the prior probability of corrosion rate data confidence for damage state 3
RL_{liner}^{exp}	is the expected remaining life of the liner using Table 4.7, years
S	is the allowable stress, MPa (psi)
SR_{P}^{Thin}	is the strength ratio parameter defined as the ratio of hoop stress to flow stress
t	is the furnished thickness of the component calculated as the sum of the base material and cladding thickness, as applicable, mm (inch)
t_{bm}	is the furnished or remaining base materials thickness of the component, mm (inch)
t_c	is the minimum structural thickness of the component base material, mm (inch)
t_{cm}	is the furnished or remaining cladding material thickness of the component, mm (inch)
t_{min}	is the minimum required thickness based on the applicable construction code, mm (inch)
t_{rdi}	the furnished thickness, t, or measured thickness reading from previous inspection, mm (inch)
TS	is the tensile strength at design temperature, MPa (psi)
YS	is the yield strength at design temperature, MPa (psi)
α	is the component geometry shape factor
β_1^{Thin}	is the β reliability indices for damage state 1
β_2^{Thin}	is the β reliability indices for damage state 2
β_3^{Thin}	is the β reliability indices for damage state 3
Φ	is the standard normal cumulative distribution function

4.7 Tables

Table 4.1—Basic Component Data Required for Analysis

Basic Data	Comments
Start date	The date the component was placed in service.
Thickness, in. (mm)	The thickness used for the DF calculation that is either the furnished thickness or the measured thickness (see Section 4.5.5).
Corrosion allowance, in. (mm)	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current service.
Design temperature, °F (°C)	The design temperature, shell side and tube side for a heat exchanger.
Design pressure, psi (MPa)	The design pressure, shell side and tube side for a heat exchanger.
Operating temperature, °F (°C)	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for a heat exchanger.
Operating pressure, psi (MPa)	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for a heat exchanger.
Design code	The design code of the component containing the component.
Equipment type	The type of equipment.
Component type	The type of component; see Table 4.2.
Component geometry data	Component geometry data depending on the type of component (see Table 4.3).
Material specification	The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or of ASTM specification for piping and tankage components. Data entry is based on material specification, grade, year, UNS number, and class/condition/temper/size/thickness; these data are readily available in the ASME Code [12].
Yield strength, psi (MPa)	The design yield strength of the material based on material specification.
Tensile strength, psi (MPa)	The design tensile strength of the material based on material specification.
Weld joint efficiency	Weld joint efficiency per the Code of construction.
Heat tracing	Is the component heat traced? (Yes or No)

Table 4.2—Component and Geometry Types Based on the Equipment Type

Equipment Type	Component Type	Geometry Type
Compressor	COMPC, COMPR	CYL
Heat exchanger	HEXSS, HEXTS	CYL, ELB, SPH, HEM, ELL, TOR, CON, NOZ
Pipe	PIPE-1, PIPE-2, PIPE-4, PIPE-6, PIPE-8, PIPE-10, PIPE-12, PIPE-16, PIPEGT16	CYL, ELB
Pump	PUMP2S, PUMPR, PUMP1S	CYL
Tank620	TANKBOTEDGE	PLT
Tank620	TANKBOTTOM	PLT
Tank620	COURSE-1-10	CYL
Tank650	TANKBOTEDGE	PLT
Tank650	TANKBOTTOM	PLT
Tank650	COURSE-1-10	CYL
FinFan	FINFAN TUBE, FINFAN HEADER	CYL RECT, CYL, ELB, HEM, ELL, NOZ
Vessel	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	CYL, ELB, SPH, HEM, ELL, TOR, CON, NOZ

NOTE 1 Tank620 Course components are the primary pressure boundary in the case of a double-walled tank. The secondary wall may be considered as having an effect on leak detection, isolation and mitigation.

NOTE 2 TANKBOTEDGE refers to the near shell region of the tank bottom and is considered to extend 24 to 30 inches inside the shell. This is consistent with most annular ring dimensions. This component type can be used for tanks with or without an annular ring. TANKBOTTOM refers to the entire bottom of the tank, or if a TANKBOTEDGE is modeled, it refers to the remaining part of the tank bottom that does not include the edge component.

Table 4.3—Required Geometry Data Based on the Geometry Type

Geometry Type	Geometry Description	Geometry Data
CYL	Cylindrical shell	— Diameter — Length — Volume
ELB	Elbow or pipe bend	— Diameter — Bend radius — Volume
SPH	Spherical shell	— Diameter — Volume
HEM	Hemispherical head	— Diameter — Volume
ELL	Elliptical head	— Diameter — Major-to-minor axis ratio — Volume
TOR	Torispherical head	— Diameter — Crown radius (IR) — Knuckle (IR) — Volume
CON	Conical shell	— Diameter — Length — Cone angle — Volume
RECTNOZ	Rectangular cross section	— Length — Width — Height — Volume
NOZ	Nozzle	— Diameter — Length — Volume

Table 4.4—Data Required for Determination of the Thinning DF

Basic Data	Comments
Thinning type (general or localized)	Determine whether the thinning is general or localized based on inspection results of effective inspections. General corrosion is defined as affecting more than 10 % of the surface area and the wall thickness variation is less than 1.27 mm (50 mils). Localized corrosion is defined as affecting less than 10 % of the surface area or a wall thickness variation greater than 1.27 mm (50 mils).
Corrosion rate (mpy or mmpy)	The current rate of thinning calculated from thickness data, if available. Corrosion rates calculated from thickness data typically vary from one inspection to another. These variations may be due to variations in the wall thickness, or they may indicate a change in the actual corrosion rate. If the short-term rate (calculated from the difference between the current thickness and the previous thickness) is significantly different from the long-term rate (calculated from the difference between the current thickness and the original thickness), then the component may be evaluated using the short-term rate, but the appropriate time and thickness must be used.Consider base material corrosion rate and cladding corrosion rate, if applicable.
Inspection effectiveness category	The effectiveness category of each inspection that has been performed on the component during the time period (specified above).
Number of inspections	The number of inspections in each effectiveness category that have been performed during the time period (specified above).
On-line monitoring	The types of proactive on-line monitoring methods or tools employed, such as corrosion probes, coupons, process variables (coupons, probes, process variables, or combinations, etc.).
Thinning mechanism	If credit is to be taken for on-line monitoring, the potential thinning mechanisms must be known. A knowledgeable materials/corrosion engineer should be consulted for this information; also see API 571 [13].
Presence of injection/mix point (Yes or No)	For piping, determine if there is an injection or mix point in the circuit.
Type of injection/mix point inspection	For piping circuits that contain an injection or mix point, determine whether not the inspection program is highly effective or not highly effective to detect local corrosion at these points.
Presence of a dead-leg (Yes or No)	For piping, determine if there is a dead-leg in the circuit.
Type of inspection for dead-leg corrosion	For piping circuits that contain a dead-leg, determine if the inspection program currently being used is highly effective or not highly effective to detect local corrosion in dead-legs has been performed.
Liner Type	The type of internal liner or strip liner, if applicable. Type are provided in Table 4.7.
Liner Installation Date	The date the internal liner or strip liner was installed, if applicable
Liner Inspection Date	The date of the last internal liner inspection, if applicable
Liner Condition	The condition of the liner, if applicable
Liner On-line Monitoring	The type of on-line monitoring for liner condition, if applicable

Table 4.5—Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8
Pr_{p2}^{Thin}	0.3	0.2	0.15
Pr_{p3}^{Thin}	0.2	0.1	0.05

Table 4.6—Conditional Probability for Inspection Effectiveness

Conditional Probability of Inspection	E—None or Ineffective	D—Poorly Effective	C—Fairly Effective	B—Usually Effective	A—Highly Effective
Co_{p1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{p2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{p3}^{Thin}	0.33	0.27	0.2	0.1	0.01

Table 4.7 – Internal Liner Types

Liner Type	Lining Resistance	Expected Age
Cladding	Based on corrosion review and cladding corrosion rate assigned. Subject to failure by corrosion.	Calculated based on thickness and corrosion rate of cladding/weld overly
Alloy Strip Liner	Subject to failure at seams, particularly on flange faces in high pressure applications. Also subject to failure at areas where plug-welding was used to secure to pressure boundary.	5-15 years
Organic Coating - Low Quality Immersion Grade Coating (Spray Applied, to 40 mils)	Limited life	1-3 years
Organic Coating - Medium Quality Immersion Grade Coating (Filled, Trowel Applied, to 80 mils)	Limited life	3-5 years
Organic Coating - High Quality Immersion Grade Coating (Reinforced, Trowel Applied, ≥ 80 mils)	Limited life	5-10 years
Thermal Resistance Service: Castable Refractory Plastic Refractory Refractory Brick Ceramic Fiber Refractory Refractory/Alloy Combination	Subject to occasional spalling or collapse	1-5 years
Thermal Resistance Service: Castable Refractory Ceramic Tile	Limited life in highly abrasive service	1-5 years
Glass Liners	Complete protection, subject to failure due to thermal or mechanical shock	5-10 years
Acid Brick	Partial protection. The brick provides thermal protection but is not intended to keep the fluid away from the base material.	10-20 years

Table 4.8 – Lining Condition Adjustment

Qualitative Condition	Description	Adjustment Multiplier – F_{LC}
Poor	The lining has either had previous failures or exhibits conditions, such as distortions, thinning, cracks or seepage, that may lead to failure in the near future. Repairs to previous failures are not successful or are of poor quality.	10
Average	The lining is not showing signs of excessive attack by any damage mechanisms. Local repairs may have been performed, but they are of good quality and have successfully corrected the lining condition.	2
Good	The lining is in "like new" condition with no signs of attack by any damage mechanisms. There has been no need for any repairs to the lining.	1

Table 4.9—On-line Monitoring Adjustment Factors

Thinning Mechanism	Adjustment Factors As a Function of On-line Monitoring, F_{OM}		
	Key Process Variable	Electrical Resistance Probes [c]	Corrosion Coupons [c]
Hydrochloric acid (HCl) corrosion	10 (20 if in conjunction with probes)	10	2
High temperature sulfidic/naphthenic acid corrosion	10	10	2
High temperature H_2S/H_2 corrosion	1	10	1
Sulfuric acid (H_2S/H_2) corrosion Low velocity ≤3 ft/s for CS ≤5 ft/s for SS ≤7 ft/s for higher alloys	20	10	2
High velocity >3 ft/s for CS >5 ft/s for SS >7 ft/s for higher alloys	10 (20 if in conjunction with probes)	10	1
Hydrofluoric acid (HF) corrosion	10	1	1
Sour water corrosion Low velocity ≤20 ft/s	20	10	2
High velocity >20 ft/s	10	2	2
Amine Low velocity	20	10	2
High velocity	10	10	1
Other corrosion mechanism	1	1	1

[a] The adjustment factors shown above are estimates providing a measure of the relative effectiveness of various on-line monitoring methods. Factors based on the user's experience can be used as a substitute for the values presented in this table.

[b] Factors shall not be added unless noted. This table assumes that an organized on-line monitoring plan is in place that recognizes the potential corrosion mechanism. Key process variables are, for example, oxygen, pH, water content, velocity, Fe content, temperature, pressure, H_2S content, CN levels, etc. The applicable variable(s) should be monitored at an appropriate interval, as determined by a knowledgeable specialist. For example, coupons may be monitored quarterly, while pH, chlorides, etc. may be monitored weekly.

[c] The effectivness of other on-line corrosion monitoring methods (e.g. hydrogen flux, FSM, LP probe) shall be evaluated by a corrosion engineer or other knowledgeable specialist.