PART 2, ANNEX D CONTENTS

Risk-Based Inspection Methodology
Part 2—Probability of Failure Methodology
Annex 2.D—Determination of External Damage Susceptibilities

2.D.1 Overview

2.D.1.1 Determination of External Damage Susceptibilities

External damage susceptibilities should be based on assignments for each potential mechanism using this document or as estimated by a corrosion specialist.

Screening questions are used to determine which of the external damage mechanism sections may apply. The applicable sections are used to determine conservative estimated corrosion rates or cracking susceptibilities for potential external damage mechanisms. The screening questions listed in Table 2.D.1.1 are used to select the applicable external damage mechanism.

2.D.1.2 Tables

Table 2.D.1.1—Screening Questions for External Damage

Screening Questions	Action
External Corrosion – Ferritic Component 1. Carbon or low alloy steel? 2. Is the operating temperature between 10 and 2~~3~~50 °F (-12 to 121~~177~~ °C)? 3. Is component uninsulated?	If Yes to all, proceed to Section 2.D.2
Corrosion Under Insulation (CUI) – Ferritic Component 1. Carbon or low alloy steel? 2. Is the operating temperature between 10 and 350 °F (-12 to 177 °C)? 3. Is component insulated?	If Yes to both, proceed to Section 2.D.3
External Chloride SCC (EXTClSCC) – Austenitic Component 1. Austenitic stainless steel? 2. Is component uninsulated? 3. Is the operating temperature between 120 and 300 °F (50 to 150 °C)?	If Yes to both, proceed to Section 2.D.4
External CUI Chloride SCC (CUIClSCC) – Austenitic Component 1. Austenitic stainless steel? 2. Is component insulated? 3. Is the operating temperature between 120 and 300 °F (50 to 150 °C)?	If Yes, proceed to Section 2.D.5

Table 2.D.1.2— Severity Index, SVI—External SCC Mechanisms

Susceptibility	External CISCC	CUI CISCC
High	50	50
Medium	10	10
Low	1	1
None	0	0

2.D.2 External Corrosion DF—Ferritic Component

2.D.2.1 Scope

The DF calculation for ferritic components subject to external corrosion is covered in this section.

2.D.2.2 Description of Damage

As a general rule, plants located in areas with high annual rainfalls, in warm humid climates, and in marine locations are more prone to external corrosion than plants located in cooler, drier, mid-continent locations. Variables that can affect external corrosion rates include annual rainfall, humidity, chloride levels in rainfall, proximity to ocean spray, and levels of various industrial pollutants. Corrosion rates can also vary by location within a facility. For example, units located near cooling towers and steam vents are highly susceptible to external corrosion, as are units whose operating temperatures cycle through the dew point on a regular basis.

Mitigation of external corrosion is accomplished through proper painting. A regular program of inspection for paint deterioration and repainting will prevent most occurrences of external corrosion.

2.D.2.3 Screening Criteria

If the component is un-insulated and subject to any of the following, then the component should be evaluated for external damage from corrosion.

a) Areas exposed to mist overspray from cooling towers.

b) Areas exposed to steam vents.

c) Areas exposed to deluge systems.

d) Areas subject to process spills, ingress of moisture, or acid vapors.

e) Carbon steel systems, operating between 10 °F and ~~3~~250 °F (−12 °C and 121~~77~~ °C). External corrosion is particularly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture.

f) Systems that do not normally operate between 10 °F and ~~3~~250 °F (−12 °C and 121~~77~~ °C) but cool or heat into this range intermittently or are subjected to frequent outages.

g) Systems with deteriorated coating and/or wrappings.

h) Cold service equipment consistently operating below the atmospheric dew point.

i) Un-insulated nozzles or other protrusions components of insulated equipment in cold service conditions.

2.D.2.4 Required Data

The basic component data required for analysis are given in Part 2, Table 4.1, and the specific data required for determination of the DF for external corrosion are provided in Table 2.C.2.1.

2.D.2.5 Basic Assumption

The DF for external corrosion is based on the method for general thinning covered in Part 2, Section 4.

2.D.2.6 Determination of the DF

2.D.2.6.1 Overview

A flow chart of the steps required to determine the DF for external corrosion is shown in Figure 2.C.2.1. The following sections provide additional information and the calculation procedure.

2.D.2.6.2 Drivers

External corrosion rates are affected by the operating temperature, weather conditions based on the equipment location (such as coastal conditions and proximity to cooling water towers or steam vents), and the equipment surface condition (external coating or paint, insulation type and condition, and weatherproofing). The driver selected for the base corrosion rate, C_{rB}, should be the best match of the external corrosion rates experienced at that location. The following are examples of conditions that may give corrosion rates similar to the respective categories.

a) Severe—High wetting (e.g. >60 % of time); very high rainfall [e.g. > 100 in./year (2250 mm/year)]; frequent deluge testing; highly corrosive industrial atmosphere; in a coastal zone with very high atmospheric chloride content (e.g. >1500 mg/m^2/day).

b) Moderate—Frequently wet (e.g. 30 % to 60 % of time); downwind of a cooling tower; high rainfall (e.g. 60 to 100 in./year (1524 to 2250 mm/year)); corrosive industrial atmosphere; near the coast with high chloride content in rainwater (e.g. 300 to 1500 mg/m^2/day).

c) Mild—Occasionally wet (e.g. < 30 % of time); moderate rainfall (e.g. 20 to 60 in./year (762 to 1524 mm/year)); low chloride content in rainwater (e.g. 60 to 300 mg/m^2/day).

d) Dry—Very dry or cold zone with very low pollution and time of wetness; low rainfall (e.g. < 20 in./year (508 mm/year)); inside building (operating above dew point); low chloride content in rainwater (e.g. < 60 mg/m^2/day).

2.D.2.6.3 Inspection Effectiveness

Inspections are ranked according to their expected effectiveness at detecting the specific damage mechanism. Examples of inspection activities that are both intrusive (requires entry into the equipment) and nonintrusive (can be performed externally) are provided in Annex 2.F~~C~~, Table 2.F~~C~~.9~~10~~.1.

The number and effectiveness categories for inspection history will be used to determine the DF.

2.D.2.6.4 Calculation of the DF

The following procedure may be used to determine the DF for external corrosion; see Figure 2.C.2.1.

a) STEP 1—Determine the furnished thickness, t, and age, age, for the component from the installation date.

b) STEP 2—If the corrosion rate is determined based on inspection history or assigned by a knowledgeable specialist, use the assigned corrosion rate and go to STEP 5.

c) STEP 3—Determine the base corrosion rate, C_{rB}, based on the driver and operating temperature using Table 2.C.2.2.

   Corrosion rates can be higher than predicted in cyclic or intermittent service. Table 2.C.2.2 can be used to help estimate a more representative corrosion rate; with adjustments made for factors such as:

   - The complete temperature range the equipment will see, including idle or out of service
   - Time spent at each temperature range
   - Wet/dry cycling if going through the dew point range
   - Potential for higher concentration of contaminants

- Frequency of temperature cycles

d) STEP 4—Calculate the final corrosion rate, C_r, using Equation (2.D.1).

$$C_r = C_{rB} \cdot \max\left[F_{EQ},\ F_{IF}\right] \tag{2.D.1}$$

The adjustment factors are determined as follows.

1) Adjustment for Equipment Design or Fabrication, F_{EQ}—If the equipment has a design that allows water to pool and increase metal loss rates, such as piping supported directly on beams, vessel stiffening rings or insulation supports, or other such configuration that does not allow water egress and/or does not allow for proper coating maintenance, then FEQ = 2; otherwise, FEQ = 1.

2) Adjustment for Interface, FIF—If the piping has an interface where it enters either soil or water, then FIF = 2; otherwise, FIF = 1.

e) STEP 5—Determine the time in service, age_{tke}, since the last known inspection thickness, t_{rde} (see Part 2, Section 4.5.5. The t_{rde} is the starting thickness with respect to wall loss associated with external corrosion. If no measured thickness is available, set t_{rde} = t and age_{tke} = age. The measured wall loss due to external corrosion, L_e, may be used to calculate t_{rde} using Equation (2.D.2).

$$t_{rde} = t - L_e \tag{2.D.2}$$

NOTE When using Equation (2.D.2), age_{tke}, is the time in service since L_e was measured.

f) STEP 6—Determine the in-service time, age_{coat}, since the coating has been installed using Equation (2.D.3).

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date \tag{2.D.3}$$

g) STEP 7—Determine the expected coating age, C_{age}, based on coating type, quality of application and service conditions. C_{age} should be 0 years for no coating or poorly applied coatings. Lower quality coatings will typically have a C_{age} of 5 years or less. High quality coatings or coatings in less harsh external environments may have a C_{age} of 15 or more years. C_{age} may be adjusted based on an evaluation of the coating condition during a high quality inspection.

h) STEP 8—Determine coating adjustment, $Coat_{adj}$, using Equations (2.D.4) through (2.D.5).

If $age_{tke} \geq age_{coat}$:

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right)$$

If $age_{tke} < age_{coat}$:

1. If the coating has failed at the time of inspection when age_{tke} was established, then

$$Coat_{adj} = 0$$

2. If the coating has not failed at the time of inspection when age_{tke} was established, use Equation (2.36) to calculate $Coat_{adj}$

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) - min\left(C_{age}, age_{coat} - age_{tke}\right) \quad (2.D.4)$$

i) STEP 9—Determine the in-service time, age, over which external corrosion may have occurred using Equation (2.D.5).

$$age = age_{tke} - Coat_{adj} \quad (2.D.5)$$

j) STEP 10—Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or API 579-1/ASME FFS-1 [10]. 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} where pressure does not govern the minimum required thickness criteria.

k) STEP 11—Determine the A_{rt} parameter using Equation (2.D.6) based on the age and t_{rde} from STEP 5 and C_r from STEP 4.

$$A_{rt} = \frac{C_r \cdot age}{t_{rde}} \quad (2.D.6)$$

l) STEP 12—Calculate the flow stress, $FS^{extcorr}$, using S from STEP 9 and Equation (2.D.7).

$$FS^{extcorr} = \frac{(YS + TS)}{2} \cdot E \cdot 1.1 \quad (2.D.7)$$

NOTE Use flow stress (FS^{Thin}) at design temperature for conservative results, using the appropriate Equation (2.40) or Equation (2.41).

m) STEP 13—Calculate the strength ratio parameter, $SR_P^{extcorr}$, using Equation (2.D.8) or (2.D.9).

1) Use Equation (2.D.8) with t_{rde} from STEP 4, t_{min} or t_c (Section 4.5.6, Step 5), S, and E from STEP 10, and $FS^{extcorr}$ from STEP 12.

$$SR_P^{extcorr} = \frac{S \cdot E}{FS^{extcorr}} \cdot \frac{max(t_{min}, t_c)}{t_{rde}} \quad (2.D.8)$$

NOTE 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. 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 5 may be used when appropriate.

2) Using Equation (2.D.9) with t_{rde} from STEP 5 and $FS^{extcorr}$ from STEP 12.

$$SR_P^{extcorr} = \frac{P \cdot D}{\alpha \cdot FS^{extcorr} \cdot t_{rde}} \quad (2.D.9)$$

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 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.D.8) should be used.

n) STEP 14—Determine the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, and $N_D^{extcorr}$, and the corresponding inspection effectiveness category using Section 2.D.2.6.2 for past inspections performed during the in-service time (see Part 2, Section 4.5.5).

o) STEP 15—Determine the inspection effectiveness factors, $I_1^{extcorr}$, $I_2^{extcorr}$, and $I_3^{extcorr}$, using Equation (2.D.10), prior probabilities, $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$, and $Pr_{p3}^{extcorr}$, from Part 2, Table 4.5, conditional probabilities (for each inspection effectiveness level), $Co_{p1}^{extcorr}$, $Co_{p2}^{extcorr}$, and $Co_{p3}^{extcorr}$, from Part 2, Table 4.6, and the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$, and $N_D^{extcorr}$, in each effectiveness level obtained from STEP 14.

$$\begin{aligned}
I_1^{extcorr} &= Pr_{p1}^{extcorr}\left(Co_{p1}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{p1}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{p1}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{p1}^{extcorrD}\right)^{N_D^{extcorr}}\\
I_2^{extcorr} &= Pr_{p2}^{extcorr}\left(Co_{p2}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{p2}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{p2}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{p2}^{extcorrD}\right)^{N_D^{extcorr}}\\
I_3^{extcorr} &= Pr_{p3}^{extcorr}\left(Co_{p3}^{extcorrA}\right)^{N_A^{extcorr}}\left(Co_{p3}^{extcorrB}\right)^{N_B^{extcorr}}\left(Co_{p3}^{extcorrC}\right)^{N_C^{extcorr}}\left(Co_{p3}^{extcorrD}\right)^{N_D^{extcorr}}
\end{aligned} \tag{2.D.10}$$

p) STEP 16—Calculate the posterior probabilities, $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$, and $Po_{p3}^{extcorr}$, using Equation (2.D.11) with $I_1^{extcorr}$, $I_2^{extcorr}$, and $I_3^{extcorr}$ in STEP 14.

$$\begin{aligned}
Po_{p1}^{extcorr} &= \frac{I_1^{extcorr}}{I_1^{extcorr}+I_2^{extcorr}+I_3^{extcorr}}\\
Po_{p2}^{extcorr} &= \frac{I_2^{extcorr}}{I_1^{extcorr}+I_2^{extcorr}+I_3^{extcorr}}\\
Po_{p3}^{extcorr} &= \frac{I_3^{extcorr}}{I_1^{extcorr}+I_2^{extcorr}+I_3^{extcorr}}
\end{aligned} \tag{2.D.11}$$

q) STEP 17—Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$, and $\beta_3^{extcorr}$, using Equation (2.D.12) and assigning $COV_{\Delta t} = 0.20$, $COV_{S_f} = 0.20$, and $COV_P = 0.05$.

$$\begin{aligned}
\beta_1^{extcorr} &= \frac{1-D_{S_1}\cdot A_{rt}-SR_p^{extcorr}}{\sqrt{D_{S_1}{}^2\cdot A_{rt}{}^2\cdot COV_{\Delta t}{}^2+\left(1-D_{S_1}\cdot A_{rt}\right)^2\cdot COV_{S_f}{}^2+(SR_p^{extcorr})^2\cdot COV_P{}^2}},\\
\beta_2^{extcorr} &= \frac{1-D_{S_2}\cdot A_{rt}-SR_p^{extcorr}}{\sqrt{D_{S_2}{}^2\cdot A_{rt}{}^2\cdot COV_{\Delta t}{}^2+\left(1-D_{S_2}\cdot A_{rt}\right)^2\cdot COV_{S_f}{}^2+(SR_p^{extcorr})^2\cdot COV_P{}^2}},\\
\beta_3^{extcorr} &= \frac{1-D_{S_3}\cdot A_{rt}-SR_p^{extcorr}}{\sqrt{D_{S_3}{}^2\cdot A_{rt}{}^2\cdot COV_{\Delta t}{}^2+\left(1-D_{S_3}\cdot A_{rt}\right)^2\cdot COV_{S_f}{}^2+(SR_p^{extcorr})^2\cdot COV_P{}^2}}.
\end{aligned} \tag{2.D.12}$$

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 Part 2, Section 4.5.3 [17].

NOTE 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 $0.10 \le COV_{\Delta t} \le 0.20$, with a recommended conservative value of $COV_{\Delta t} = 0.20$.

r) STEP 18—Calculate $D_f^{extcorr}$ using Equation (2.D.13).

$$D_f^{extcorr} = \left[\frac{\left(Po_{p1}^{extcorr}\Phi\left(-\beta_1^{extcorr}\right)\right) + \left(Po_{p2}^{extcorr}\Phi\left(-\beta_2^{extcorr}\right)\right) + \left(Po_{p3}^{extcorr}\Phi\left(-\beta_3^{extcorr}\right)\right)}{1.56\text{E-}04} \right] \tag{2.D.13}$$

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

2.D.2.7 Nomenclature

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

age_{coat} is the in-service time since the coating installation, years

age_{tke} is the component in-service time since the last inspection thickness measurement with respect to wall loss associated with external corrosion or service start date, years

A_{rt} is the expected metal loss fraction since last inspection

C_{age} is the total anticipated coating life from the time of installation

$Coat_{adj}$ is the coating adjustment, years

C_r is the corrosion rate, in/year (mm/year)

C_{rB} is the base value of the corrosion rate, in/year (mm/year)

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

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

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

COV_P is the pressure variance

COV_{S_f} is the flow stress variance

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

D is the component inside diameter, inch (mm)

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

$D_f^{extcorr}$	is the DF for external corrosion
$DF_p^{extcorr}$	is the DF for external corrosion
E	is the weld joint efficiency or quality code from the original construction code
F_{EQ}	is the adjustment factor for equipment design/fabrication detail
F_{IF}	is the corrosion rate adjustment factor for interface for soil and water
$FS^{extcorr}$	is the flow stress
$I_1^{extcorr}$	is the first order inspection effectiveness factor
$I_2^{extcorr}$	is the second order inspection effectiveness factor
$I_3^{extcorr}$	is the third order inspection effectiveness factor
L_e	is the measured wall loss from external corrosion, in (mm)
$N_A^{extcorr}$	is the number of A level inspections
$N_B^{extcorr}$	is the number of B level inspections
$N_C^{extcorr}$	is the number of C level inspections
$N_D^{extcorr}$	is the number of D level inspections
P	is the pressure (operating, design, PRD overpressure, etc.), psi (MPa)
$Po_{p1}^{extcorr}$	is the posterior probability for damage state 1
$Po_{p2}^{extcorr}$	is the posterior probability for damage state 2
$Po_{p3}^{extcorr}$	is the posterior probability for damage state 3
$Pr_{p1}^{extcorr}$	is the prior probability of corrosion rate data reliability for damage state 1
$Pr_{p2}^{extcorr}$	is the prior probability of corrosion rate data reliability for damage state 2
$Pr_{p3}^{extcorr}$	is the prior probability of corrosion rate data reliability for damage state 3
S	is the allowable stress, psi (MPa)

$SR_P^{extcorr}$ 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/weld overlay thickness, as applicable, mm (inch)

t_c is the minimum structural thickness of the component base material, in (mm)

t_{min} is the minimum required thickness, in (mm)

t_{rde} is the measured thickness reading from previous inspection with respect to wall loss associated with external corrosion, in (mm)

TS is the tensile strength, psi (MPa)

YS is the yield strength, psi (MPa)

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

2.D.2.8 References

2.D.2.9 Tables

Table 2.D.2.1—Data Required for Determination of the DF—External Corrosion

Required Data	Comments
Driver	The drivers for external corrosion. See Section 15.6.2 for driver descriptions and selection.
Corrosion rate (mpy:mm/yr)	Corrosion rate for external corrosion. Based on temperature, and driver, or user input.
Coating installation date	The date the coating was installed.
Coating quality	Relates to the type of coating applied, for example: None—no coating or primer only; Medium—single coat epoxy; High—multi-coat epoxy or filled epoxy.
If equipment has a design or fabrication detail that allows water to pool and increase metal loss rates, such as piping supported directly on beams, vessel external stiffening rings or insulation supports or other such configuration that does not allow for water egress and/or does not allow for proper coating maintenance, external metal loss can be more severe.	If equipment has a design or fabrication detail that allows water to pool and increase metal loss rates, such as piping supported directly on beams, vessel external stiffening rings or insulation supports, or other such configuration that does not allow for water egress and/or does not allow for proper coating maintenance, external metal loss can be more severe.
Interface penalty (Yes/No)	If the piping has an interface where it enters either soil or water, this area is subject to increased corrosion.
Inspection effectiveness category	The effectiveness category that has been performed on the component.
Number of inspections	The number of inspections in each effectiveness category that have been performed.
Thickness reading	The thickness used for the DF calculation is either the furnished thickness or the measured thickness (see Section 4.5.5).
Thickness reading date	The date at which the thickness measurement used in the calculation was obtained. If no acceptable inspection has been conducted, the installation date should be used.

Table 2.D.2.2—Corrosion Rates for Calculation of the DF—External Corrosion

Operating Temperature (°F)	Corrosion Rate As a Function of Driver [1] (mpy)			
	Severe	Moderate	Mild	Dry
10	0	0	0	0
18	3	1	0	0
43	10	5	3	1
90	10	5	3	1
160	10	5	2	1
225	2	1	0	0
250	0	0	0	0

NOTE 1 Driver is defined as the atmospheric condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

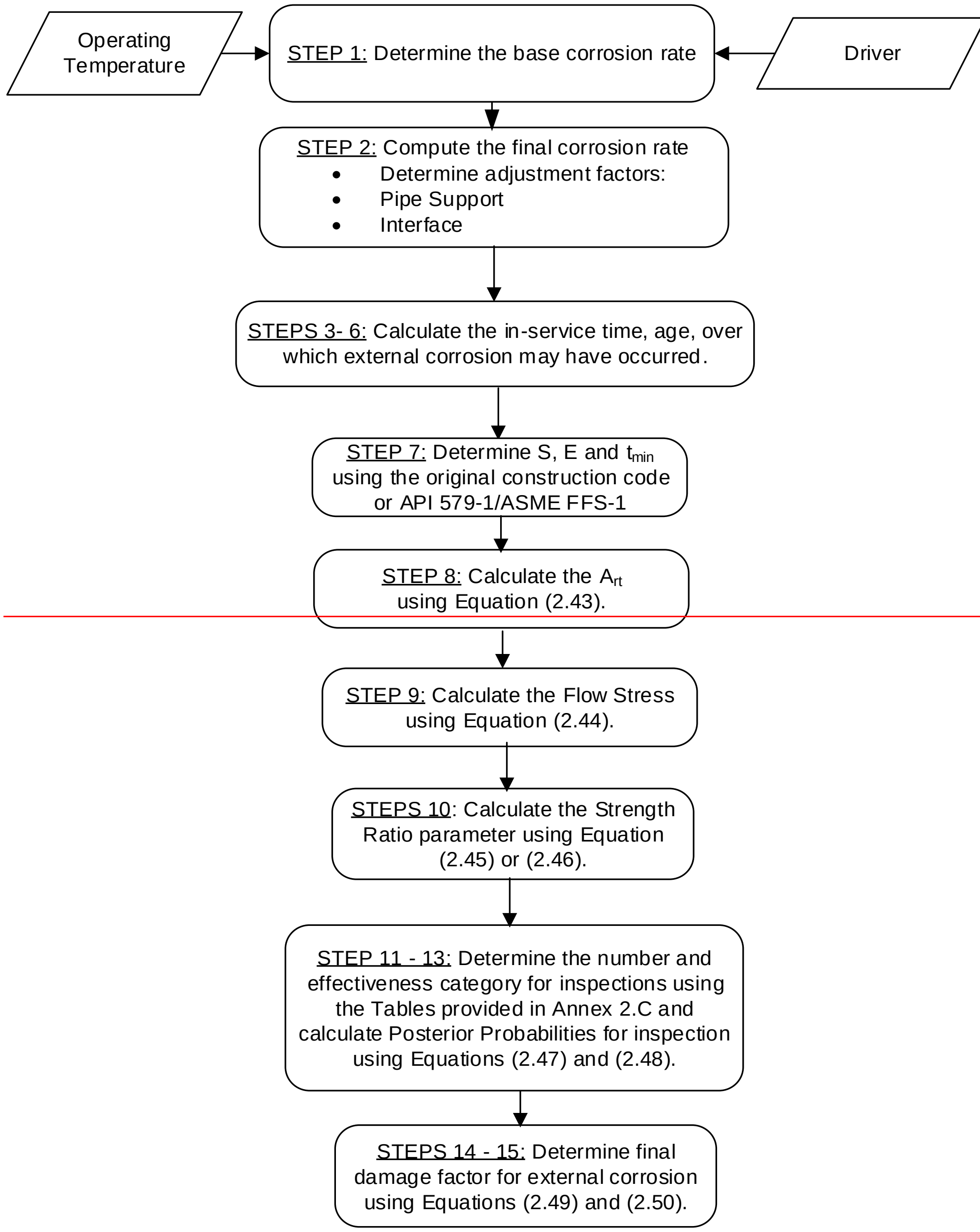
Table 2.D.2.2M—Corrosion Rates for Calculation of the DF—External Corrosion

Operating Temperature (°C)	Corrosion Rate As a Function of Driver [1] (mm/y)			
	Severe	Moderate	Mild	Dry
−12	0	0	0	0
−8	0.076	0.025	0	0
6	0.254	0.127	0.076	0.025
32	0.254	0.127	0.076	0.025
71	0.254	0.127	0.051	0.025
107	0.051	0.025	0	0
121	0	0	0	0

NOTE 1 Driver is defined as the atmospheric condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

2.D.2.10 Figures



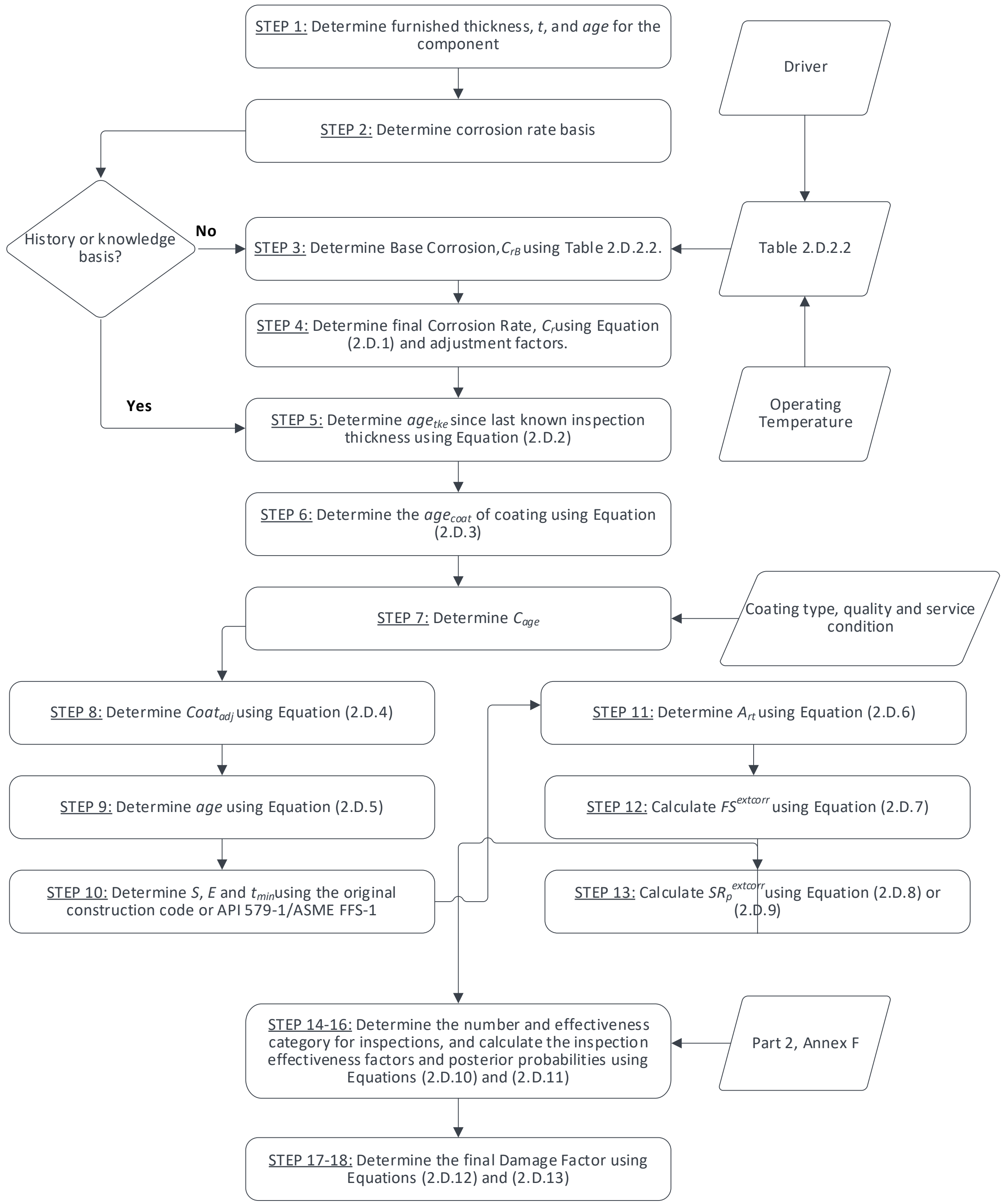


Figure 2.D.2.1—Determination of the External Corrosion DF

2.D.3 Corrosion Under Insulation (CUI) DF—Ferritic Component

2.D.3.1 Scope

The DF calculation for ferritic components subject to CUI is covered in this section.

2.D.3.2 Description of Damage

CUI results from the collection of water in the vapor space (or annulus space) between the insulation and the metal surface. Sources of water may include rain, water leaks, condensation, cooling water tower drift, deluge systems, and steam tracing leaks. CUI causes wall loss in the form of localized corrosion. CUI generally occurs in the temperature range between 10 °F and 350 °F (−12 °C and 175 °C), with the temperature range of 170 °F to 230 °F (77 °C to 110 °C) being the most severe environment.

As a general rule, plants located in areas with high annual rainfall, in warm humid climates, or in marine locations are more prone to CUI than plants located in cooler, drier, mid-continent locations. Variables that can affect CUI corrosion rates include annual rainfall, humidity, chloride levels in rainfall, proximity to ocean spray, and levels of various industrial pollutants. Corrosion rates can also vary by location within the facility. For example, units located near cooling towers and steam vents are highly susceptible to CUI, as are units whose operating temperatures cycle through the dew point on a regular basis. External inspection of insulated systems should include a review of the integrity of the insulation system for conditions that could lead to CUI and for signs of ongoing CUI, i.e. rust stains or bulging. However, external indicators of CUI are not always present.

Mitigation of CUI is accomplished through good insulation practices and proper coatings. Proper installation and maintenance of insulation simply prevents ingress of large quantities of water. In recent years, a coating system is frequently specified for component operating in the CUI temperature range and where CUI has been a problem. A high-quality immersion grade coating, like those used in hot water tanks, is recommended. For guidance, refer to NACE 6H189. A good coating system should last a minimum of 15 years.

2.D.3.3 Screening Criteria

Specific locations and/or systems, such as penetrations and visually damaged insulation areas, are highly suspect and should be considered during inspection program development. Examples of highly suspect areas include, but are not limited to, the following.

a) Penetrations

   1) All penetrations or breaches in the insulation jacketing systems, such as dead-legs (vents, drains, and other similar items), hangers and other supports, valves and fittings, bolted-on pipe shoes, ladders, and platforms.

   2) Steam tracer tubing penetrations.

   3) Termination of insulation at flanges and other components.

   4) Poorly designed insulation support rings.

   5) Stiffener rings.

b) Damaged Insulation Areas

   1) Damaged or missing insulation jacketing.

   2) Termination of insulation in a vertical pipe or piece of equipment.

3) Caulking that has hardened, has separated, or is missing.

4) Bulges, staining of the jacketing system, or missing bands (bulges may indicate corrosion product buildup).

5) Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs.

6) Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.

The following are some examples of other suspect areas that should be considered when performing inspection for CUI.

1) Areas exposed to mist overspray from cooling towers.

2) Areas exposed to steam vents.

3) Areas exposed to deluge systems.

4) Areas subject to process spills, ingress of moisture, or acid vapors.

5) Insulation jacketing seams located on top of horizontal vessels or improperly lapped or sealed insulation systems,

6) Carbon steel systems, including those insulated for personnel protection, operating between −12 °C and 175 °C (10 °F and 350 °F). CUI is particularly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture.

7) Carbon steel systems that normally operate in services above 350 °F (175 °C) but are in intermittent service or are subjected to frequent outages.

8) Dead-legs and attachments that protrude from the insulation and operate at a different temperature than the operating temperature of the active line, i.e. insulation support rings, piping/platform attachments.

9) Systems in which vibration has a tendency to inflict damage to insulation jacketing providing paths for water ingress.

10) Steam traced systems experiencing tracing leaks, especially at tubing fittings beneath the insulation.

11) Systems with deteriorated coating and/or wrappings.

12) Cold service equipment consistently operating below the atmospheric dew point.

13) Inspection ports or plugs that are removed to permit thickness measurements on insulated systems represent a major contributor to possible leaks in insulated systems. Special attention should be paid to these locations. Promptly replacing and resealing of these plugs is imperative.

2.D.3.4 Required Data

The basic component data required for analysis are given in Part 2, Table 4.1, and the specific data required for determination of the DF for CUI are provided in Table 2.D.3.1.

2.D.3.5 Basic Assumption

The DF for CUI is based on the method for general thinning covered in Part 2, Section 4.

2.D.3.6 Determination of the DF

2.D.3.6.1 Overview

A flow chart of the steps required to determine the DF for CUI is shown in Figure 2.D.3.1. The following sections provide additional information and the calculation procedure.

2.D.3.6.2 Inspection Effectiveness

Inspections are ranked according to their expected effectiveness at detecting the specific damage mechanism. Examples of inspection activities that are both intrusive (requires entry into the equipment) and nonintrusive (can be performed externally) are provided in Annex 2.F~~C~~, Table 2.F~~C~~.9~~10~~.3.

The number and category of the highest effective inspection will be used to determine the DF**.**

2.D.3.6.3 Calculation of the DF

The following procedure may be used to determine the DF for CUI; see Figure 2.D.3.1.

a) STEP 1—Determine the furnished thickness, t, and age, age, for the component from the installation date.

b) STEP 2—If the corrosion rate determined based on inspection history or assigned by a knowledgeable specialist use the assigned value and skip to STEP 5.

c) STEP 3—Determine the base corrosion rate, C_{rB}, based on the driver and operating temperature using Table 2.D.3.2.

   Corrosion rates can be higher than predicted in cyclic or intermittent service. Table 2.D.3.2 can be used to help estimate a more representative corrosion rate; with adjustments made for factors such as:
   1) The complete temperature range the equipment will see, including idle or out of service
   2) Time spent at each temperature range
   3) Wet/dry cycling if going through the dew point range
   4) Potential for higher concentration of contaminants
   5) Frequency of temperature cycles

d) STEP 4—Calculate the final corrosion rate using Equation (2.D.14).

$$C_r = C_{rB} \cdot F_{INS} \cdot F_{CM} \cdot F_{IC} \cdot \max\left[F_{EQ},\ F_{IF}\right] \tag{2.D.14}$$

   The adjustment factors are determined as follows.

   1) Adjustment for insulation type; F_{INS}, based on Table 2.D.3.3.

   2) Adjustment for Complexity, F_{CM}—Established based on the following criteria.

      — If the complexity is Below Average, then F_{CM} = 0.75.

      — If the complexity is Average, then F_{CM} = 1.0.

      — If the complexity is Above Average, then F_{CM} = 1.25.

   3) Adjustment for Insulation Condition, F_{IC}—Established based on the following criteria.

      — If the insulation condition is Below Average, then F_{IC} = 1.25.

— If the insulation condition is Average, then F_{IC} = 1.0.

— If the insulation condition is Above Average, then F_{IC} = 0.75.

4) Adjustment for Equipment Design or Fabrication, F_{EQ}—If equipment has a design that allows water to pool and increase metal loss rates, such as piping supported directly on beams, vessel external stiffening rings or insulation supports, or other such configuration that does not allow water egress and/or does not allow for proper coating maintenance, then F_{EQ} = 2; otherwise, F_{EQ} = 1.

5) Adjustment for Interface, F_{IF}—If the piping has an interface where it enters either soil or water, then F_{IF} = 2; otherwise, F_{IF} = 1.

e) STEP 5—Determine the time in service, age_{tke}, since the last known thickness, t_{rde} (see Part 2, Section 4.5.5). The t_{rde} is the starting thickness with respect to wall loss associated with external corrosion (see Section 4.5.5). If no measured thickness is available, set t_{rde} = t and age_{tke} = age. The measured wall loss from CUI, L_e, may be used to calculate t_{rde} using Equation (2.D.15).

$$t_{rde} = t - L_e \tag{2.D.15}$$

NOTE 1 When using Equation (2.D.15), age_{tke} is the time in service since L_e was measured.

f) STEP 6—Determine the in-service time, age_{coat}, since the coating has been installed using Equation (2.D.16).

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date \tag{2.D.16}$$

g) STEP 7— Determine the expected coating age, C_{age}, based on coating type, quality of application and service conditions. C_{age} should be 0 years for no coating or poorly applied coatings. Lower quality coatings will typically have a C_{age} of 5 years or less. High quality coatings or coatings in less harsh external environments may have a C_{age} of 15 or more years. C_{age} may be adjusted based on an evaluation of the coating condition during a high quality inspection.

h) STEP 8—Determine the coating adjustment, $Coat_{adj}$, using Equations (2.D.17) and (2.D.18).

If $age_{tke} \geq age_{coat}$:

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) \tag{2.D.17}$$

If $age_{tke} < age_{coat}$:

1. If the coating has failed at the time of inspection when age_{tke} was established, then

$$Coat_{adj} = 0$$

2. If the coating has not failed at the time of inspection when age_{tke} was established, use Equation (2.D.18) to calculate $Coat_{adj}$

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) - min\left(C_{age}, age_{coat} - age_{tke}\right) \tag{2.D.18}$$

i) STEP 9—Determine the in-service time, age, over which CUI may have occurred using Equation (2.D.19).

$$age = age_{tke} - Coat_{adj} \tag{2.D.19}$$

j) STEP 10—Determine the allowable stress, S, weld joint efficiency, E, and minimum required thickness, t_{min}, per the original construction code or API 579-1/ASME FFS-1 [10]. 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} where pressure does not govern the minimum required thickness criteria.

k) STEP 11—Determine the A_{rt} parameter using Equation (2.D.20) based on the age and t_{rde} from STEP 5, C_r from STEP 3.

$$A_{rt} = \frac{C_r \cdot age}{t_{rde}} \tag{2.D.20}$$

l) STEP 12—Calculate the flow stress, FS^{CUIF}, using E from STEP 10 and Equation (2.D.21).

$$FS^{CUIF} == \frac{(YS + TS)}{2} \cdot E \cdot 1.1 \tag{2.D.21}$$

NOTE 2 Use flow stress (FS^{Thin}) at design temperature for conservative results, using the appropriate Equation (2.D.20) or Equation (2.D.21).

m) STEP 13—Calculate strength ratio parameter, SR_P^{Thin}, using Equation (2.D.22) or Equation (2.D.23).

1) Use Equation (2.D.22) with t_{rde} from STEP 5, S, E, and t_{min} or t_c (Part 2, Section 4.5.6, Step 5), from STEP 10, and flow stress FS^{CUIF} from STEP 11.

$$SR_P^{CUIF} = \frac{S \cdot E}{FS^{CUIF}} \cdot \frac{max(t_{min}, t_c)}{t_{rde}} \tag{2.D.22}$$

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. 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 5 may be used when appropriate.

2) Use Equation (2.D.23) with t_{rde} from STEP 4 and flow stress FS^{CUIF} from STEP 12.

$$SR_P^{CUIF} = \frac{P \cdot D}{\alpha \cdot FS^{CUIF} \cdot t_{rde}} \tag{2.D.23}$$

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 4 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.D.22) should be used.

n) STEP 14—Determine the number of inspections, $N_A^{CUIF}, N_B^{CUIF}, N_C^{CUIF}$, and N_D^{CUIF}, and the corresponding inspection effectiveness category using Section 2.D.3.6.2 for all past inspections.

o) STEP 15—Determine the inspection effectiveness factors, I_1^{CUIF}, I_2^{CUIF}, and I_3^{CUIF}, using Equation (2.D.24), prior probabilities, Pr_{p1}^{CUIF}, Pr_{p2}^{CUIF}, and Pr_{p3}^{CUIF}, from Part 2, Table 4.5, conditional probabilities (for each inspection effectiveness level), $Co_{p1}^{CUIF}, Co_{p2}^{CUIF}$ and Co_{p3}^{CUIF}, from Part 2, Table 4.6, and the number of inspections, $N_A^{CUIF}, N_B^{CUIF}, N_C^{CUIF}$, and N_D^{CUIF}, in each effectiveness level obtained from STEP 13.

$$
\begin{aligned}
I_1^{CUIF} &= Pr_{p1}^{CUIF}\left(Co_{p1}^{CUIFA}\right)^{N_A^{CUIF}}\left(Co_{p1}^{CUIFB}\right)^{N_B^{CUIF}}\left(Co_{p1}^{CUIFC}\right)^{N_C^{CUIF}}\left(Co_{p1}^{CUIFD}\right)^{N_D^{CUIF}} \\
I_2^{CUIF} &= Pr_{p2}^{CUIF}\left(Co_{p2}^{CUIFA}\right)^{N_A^{CUIF}}\left(Co_{p2}^{CUIFB}\right)^{N_B^{CUIF}}\left(Co_{p2}^{CUIFC}\right)^{N_C^{CUIF}}\left(Co_{p2}^{CUIFD}\right)^{N_D^{CUIF}} \\
I_3^{CUIF} &= Pr_{p3}^{CUIF}\left(Co_{p3}^{CUIFA}\right)^{N_A^{CUIF}}\left(Co_{p3}^{CUIFB}\right)^{N_B^{CUIF}}\left(Co_{p3}^{CUIFC}\right)^{N_C^{CUIF}}\left(Co_{p3}^{CUIFD}\right)^{N_D^{CUIF}}
\end{aligned}
\tag{2.D.24}
$$

n) STEP 16—Calculate the posterior probabilities, Po_{p1}^{CUIF}, Po_{p2}^{CUIF}, and Po_{p3}^{CUIF}, using Equation (2.D.25) with I_1^{CUIF}, I_2^{CUIF} and I_3^{CUIF} in STEP 13.

$$
\begin{aligned}
Po_{p1}^{CUIF} &= \frac{I_1^{CUIF}}{I_1^{CUIF}+I_2^{CUIF}+I_3^{CUIF}} \\
Po_{p2}^{CUIF} &= \frac{I_2^{CUIF}}{I_1^{CUIF}+I_2^{CUIF}+I_3^{CUIF}} \\
Po_{p3}^{CUIF} &= \frac{I_3^{CUIF}}{I_1^{CUIF}+I_2^{CUIF}+I_3^{CUIF}}
\end{aligned}
\tag{2.D.25}
$$

o) STEP 17—Calculate the parameters, β_1^{CUIF}, β_2^{CUIF}, and β_3^{CUIF}, using Equation (2.D.26) and assigning $COV_{\Delta t}$ = 0.20, COV_{S_f} = 0.20, and COV_p = 0.05.

$$
\begin{aligned}
\beta_1^{CUIF} &= \frac{1-D_{S_1}\cdot A_{rt}-SR_p^{CUIF}}{\sqrt{D_{S_1}{}^2\cdot A_{rt}{}^2\cdot COV_{\Delta t}{}^2+\left(1-D_{S_1}\cdot A_{rt}\right)^2\cdot COV_{S_f}{}^2+(SR_p^{CUIF})^2\cdot COV_P{}^2}}, \\
\beta_2^{CUIF} &= \frac{1-D_{S_2}\cdot A_{rt}-SR_p^{CUIF}}{\sqrt{D_{S_2}{}^2\cdot A_{rt}{}^2\cdot COV_{\Delta t}{}^2+\left(1-D_{S_2}\cdot A_{rt}\right)^2\cdot COV_{S_f}{}^2+(SR_p^{CUIF})^2\cdot COV_P{}^2}}, \\
\beta_3^{CUIF} &= \frac{1-D_{S_3}\cdot A_{rt}-SR_p^{CUIF}}{\sqrt{D_{S_3}{}^2\cdot A_{rt}{}^2\cdot COV_{\Delta t}{}^2+\left(1-D_{S_3}\cdot A_{rt}\right)^2\cdot COV_{S_f}{}^2+(SR_p^{CUIF})^2\cdot COV_P{}^2}}.
\end{aligned}
\tag{2.D.26}
$$

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 Part 2, Section 4.5.3 [17].

NOTE 5 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.

p) STEP 18—Calculate D_f^{CUIF} using Equation (2.D.27).

$$D_f^{CUIF} = \left[\frac{\left(Po_{p1}^{CUIF}\,\Phi\left(-\beta_1^{CUIF}\right)\right) + \left(Po_{p2}^{CUIF}\,\Phi\left(-\beta_2^{CUIF}\right)\right) + \left(Po_{p3}^{CUIF}\,\Phi\left(-\beta_3^{CUIF}\right)\right)}{1.56\text{E-}04} \right] \tag{2.D.27}$$

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

2.D.3.7 Nomenclature

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

age_{coat} is the in-service time since the coating installation, years

age_{tke} is the component in-service time since the last inspection thickness measurement with respect to wall loss associated with CUI or service start date, years

A_{rt} is the expected metal loss fraction since last inspection

C_{age} is the total anticipated coating life from the time of installation, years

$Coat_{adj}$ is the coating adjustment, year

C_r is the corrosion rate, mpy (mm/year)

C_{rB} is the base value of the corrosion rate, mpy (mm/year)

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

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

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

COV_P is the pressure variance

COV_{S_f} is the flow stress variance

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

D is the component inside diameter, in (mm)

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^{CUIF} is the DF for CUI for ferritic components

E	is the weld joint efficiency or quality code from the original construction code
F_{CM}	is the corrosion rate adjustment factor for insulation complexity
F_{EQ}	is an adjustment factor for equipment design detail
F_{IC}	is the corrosion rate adjustment factor for insulation condition
F_{IF}	is the corrosion rate adjustment factor for interface for soil and water
F_{INS}	the corrosion rate adjustment factor for insulation type
FS^{CUIF}	is the flow stress, psi (MPa)
I_1^{CUIF}	is the first order inspection effectiveness factor
I_2^{CUIF}	is the second order inspection effectiveness factor
I_3^{CUIF}	is the third order inspection effectiveness factor
L_e	is the measured wall loss due to CUI, in (mm)
N_A^{CUIF}	is the number of A level inspections
N_B^{CUIF}	is the number of B level inspections
N_C^{CUIF}	is the number of C level inspections
N_D^{CUIF}	is the number of D level inspections
P	is the pressure (operating, design, PRD overpressure, etc.) used to calculate the limit state function for POF
Po_{p1}^{CUIF}	is the posterior probability posterior for damage state 1
Po_{p2}^{CUIF}	is the posterior probability posterior for damage state 2
Po_{p3}^{CUIF}	is the posterior probability posterior for damage state 3
Pr_{p1}^{CUIF}	is the prior probability of corrosion rate data reliability for damage state 1
Pr_{p2}^{CUIF}	is the prior probability of corrosion rate data reliability for damage state 2
Pr_{p3}^{CUIF}	is the prior probability of corrosion rate data reliability for damage state 3
S	is the allowable stress
SR_P^{CUIF}	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/weld overlay thickness, as applicable

t_c	is the minimum structural thickness of the component base material
t_{min}	is the minimum required thickness based on the applicable construction code
t_{rde}	is the measured thickness reading from previous inspection with respect to wall loss associated with CUI
TS	is the tensile strength
YS	is the yield strength
α	is the component geometry shape factor
β_1^{CUIF}	is the β reliability indices for damage state 1
β_2^{CUIF}	is the β reliability indices for damage state 2
β_3^{CUIF}	is the β reliability indices for damage state 3
Φ	is the standard normal cumulative distribution function

2.D.3.8 References

See Reference [83] in Section 2.2.

2.D.3.9 Tables

Table 2.D.3.1—Data Required for Determination of the DF—CUI

Required Data	Comments
Insulation type	Type of insulation per Table 17.3.
Driver	The drivers for external CUI corrosion. See Section 15.6.2 for driver descriptions and selection.
Corrosion rate (mpy:mm/yr)	Corrosion rate for external CUI corrosion. Based on temperature, and driver (see below), or user input.
Coating installation date	The date the coating was installed.
Coating quality	Relates to the type of coating applied under the insulation, for example: None—no coating or primer only; Medium—single coat epoxy; High—multi-coat epoxy or filled epoxy.
Equipment design/fabrication penalty (Yes/No)	If the equipment has a design or fabrication detail that allows water to pool and increase metal loss rates, such as piping supported directly on beams, vessel external stiffener rings or insulation supports, or other such configuration that does not allow water egress and/or does not allow for proper coating maintenance, external metal loss can be more severe.
Complexity	The number of protrusions such as branch connections, nozzles, pipe supports, poorly designed insulation support rings, etc., and any design feature that would promote the retention and/or collection of moisture. The complexity is defined as follows: Below Average—penetrations in the insulation system do not exist; Average—some penetrations in the insulation systems, or the insulation system is slightly complex do to some appurtenances or multiple branches in a piping system; Above Average—many penetrations in the insulation systems, or the insulation system is very complex do to many appurtenances or multiple branches in a piping system.
Insulation condition? (Above Average, Average, or Below Average)	Determine the insulation condition based on external visual inspection of jacketing condition. Above Average insulation will show no signs of damage (i.e. punctured, torn, or missing waterproofing, and missing caulking) or standing water (i.e. brown, green, or black stains). Take careful note of areas where water can enter into the insulation system, such as inspection ports and areas where the insulation is penetrated (i.e. nozzles, ring supports and clips). Horizontal areas also accumulate water. Average insulation condition will have good jacketing with some areas of failed weatherproofing or small damaged areas. NOTE the corrosion rates for CUI represent average/typical insulation systems found in most plants. This should be considered when determining if any adjustment or penalty multipliers apply.

Table 2.D.3.1—Data Required for Determination of the DF—CUI (Continued)

Required Data	Comments
Pipe support penalty? (Yes/No)	If piping is supported directly on beams or other such configuration that does not allow for proper coating maintenance, CUI can be more severe.
Interface penalty? (Yes/No)	If the piping has an interface where it enters either soil or water, this area is subject to increased corrosion.
Inspection effectiveness category	The effectiveness category that has been performed on the component.
Number of inspections	The number of inspections in each effectiveness category that have been performed.
Thickness reading	The thickness used for the DF calculation is either the furnished thickness or the measured thickness (see Section 4.5.5).
Thickness reading date	The date at which the thickness measurement used in the calculation was obtained. If no acceptable inspection has been conducted, the installation date should be used.

Table 2.D.3.2—Corrosion Rates for Calculation of the DF—CUI

Operating Temperature (°F)	Corrosion Rate As a Function of Driver [1] (mpy)			
	Severe	Moderate	Mild	Dry
10	0	0	0	0
18	3	1	0	0
43	10	5	3	1
90	10	5	3	1
160	20	10	5	2
225	10	5	1	1
275	10	2	1	0
325	5	1	0	0
350	0	0	0	0

NOTE 1 Driver is defined as the CUI condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

Table 2.D.3.2M—Corrosion Rates for Calculation of the DF—CUI

Operating Temperature (°C)	Corrosion Rate as a Function of Driver [1] (mm/y)			
	Severe	Moderate	Mild	Dry
−12	0	0	0	0
−8	0.076	0.025	0	0
6	0.254	0.127	0.076	0.025
32	0.254	0.127	0.076	0.025
71	0.508	0.254	0.127	0.051
107	0.254	0.127	0.025	0.025
135	0.254	0.051	0.025	0
162	0.127	0.025	0	0
176	0	0	0	0

NOTE 1 Driver is defined as the CUI condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

Table 2.D.3.3—Corrosion Rate Adjustment Factor for Insulation Type

Insulation Type	Adjustment Factor, F_{INS}
Unknown/unspecified	1.25
Asbestos	1.5
Cellular Glass	0.75
Expanded Perlite	1.0
Fiberglass	1.25
Type E Fiberglass	1.25
Mineral ~~w~~Wool	1.~~2~~5
Mineral Wool (water resistant)	1.25
Calcium silicate*	1.25
Flexible Aerogel*	1.25
Microporous Blanket	1.0
Intumescent Coating	0.75
Cementitious Coating	1.0

NOTE 1 The values in this table are suggested values

NOTE 2 * Use "0.75" for any insulation complying with Mass Loss Corrosion Rate (MLCR) less than deionized (DI) water values calculated as per ASTM C1617

2.D.3.10 Figures

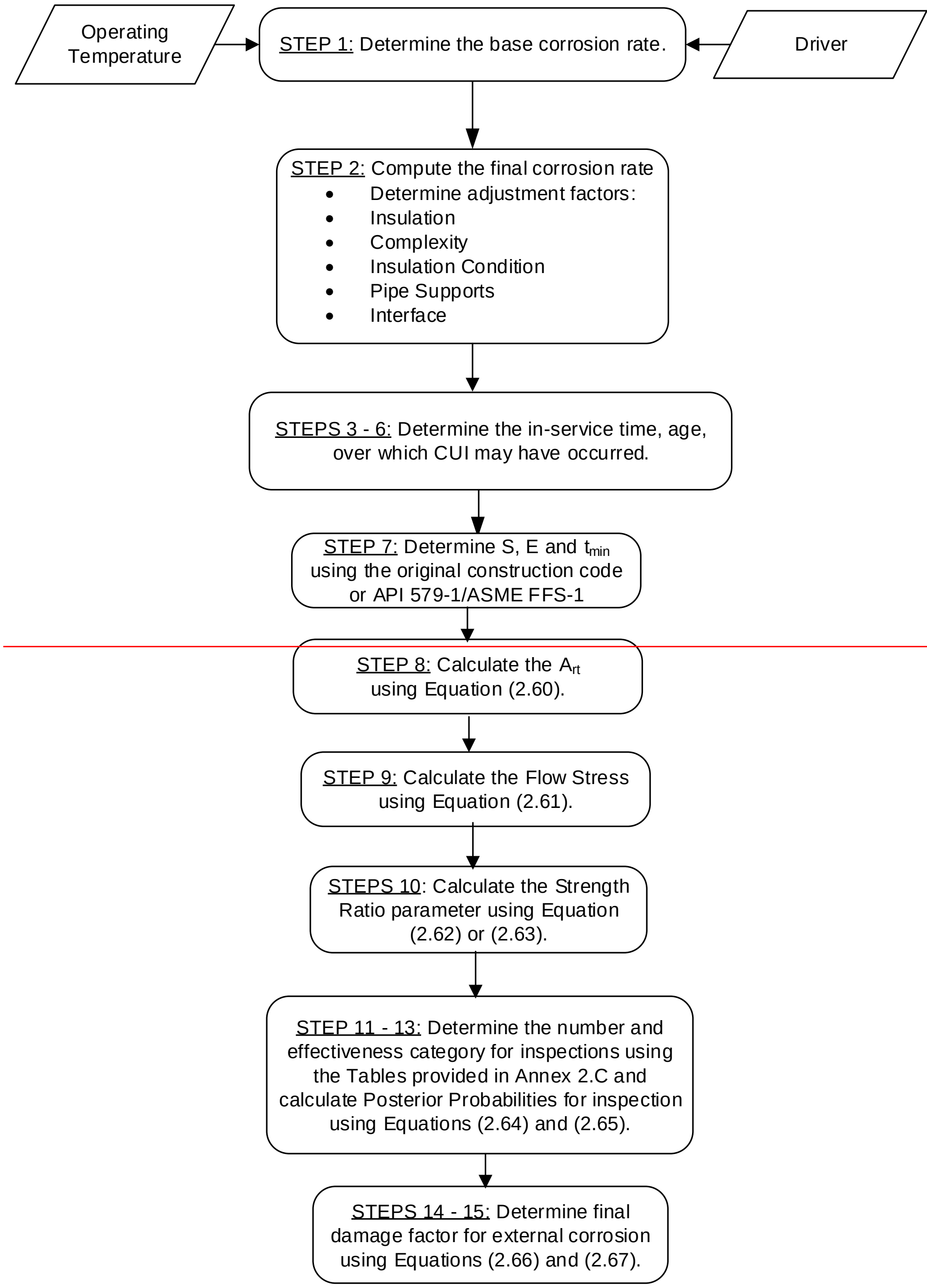


Figure 2.D.3.1—Determination of the CUI DF

2.D.4 External Chloride Stress Corrosion Cracking (ExtClSCC) DF—Austenitic Component

2.D.4.1 Scope

The DF calculation for un-insulated austenitic stainless steel components subject to ExtClSCC is covered in this section.

2.D.4.2 Description of Damage

Uninsulated austenitic stainless steel components located in process plants may be subject to ExtClSCC as a result chloride accumulation resulting from local atmospheric conditions that include chlorides. Cracking generally occurs at metal temperatures above about 140 °F (60 °C), although exceptions can be found at lower temperatures. The operating range where damage may occur is between 120 °F to 300 °F (50 °C to 150 °C). Heating and/or cooling intermittently into this range will present an opportunity for ClSCC to occur.

Mitigation of ExtClSCC is best accomplished by preventing chloride accumulation on the stainless steel surface. On un-insulated surfaces, chloride-containing fluids, mists, or solids should be prevented from contacting the surface. Markers, dyes, tape, etc. used on stainless steels should be certified suitable for such applications. In rare cases, un-insulated stainless steels could be protected externally by a coating. If intermittent conditions exist, then both normal operating and intermittent temperatures should be considered.

2.D.4.3 Screening Criteria

If all of the following are true, then the component should be evaluated for susceptibility to ExtClSCC.

a) The component's material of construction is an austenitic stainless steel.

b) The component external surface is exposed to chloride-containing fluids, mists, or solids.

c) The operating temperature is between 120 °F and 300 °F (50 °C and 150 °C) or the system heats or cools into this range intermittently.

2.D.4.4 Required Data

The basic component data required for analysis are given in Part 2, Table 4.1, and the specific data required for determination of the DF for ExtClSCC are provided in Table 2.D.4.1.

2.D.4.5 Basic Assumption

The DF for ExtClSCC is based on the method in Section 2.C.2.5.

2.D.4.6 Determination of the DF

2.D.4.6.1 Overview

A flow chart of the steps required to determine the DF for ExtClSCC is shown in Figure 2.D.4.1. The following sections provide additional information and the calculation procedure.

2.D.4.6.2 Inspection Effectiveness

Inspections are ranked according to their expected effectiveness at detecting the specific damage mechanism. Examples of inspection activities that are both intrusive (requires entry into the equipment) and nonintrusive (can be performed externally) are provided in Annex 2.F~~C~~, Table 2.F~~C~~.9~~10~~.2.

If multiple inspections of a lower effectiveness have been conducted during the designated time period, they can be equated to an equivalent higher effectiveness inspection in accordance with Part 2, Section 3.4.3.

2.D.4.6.3 Calculation of the DF

The following procedure may be used to determine the DF for ExtClSCC; see Figure 2.D.4.1.

a) STEP 1—Determine the susceptibility using Table 2.D.4.2 based on the driver and the operating temperature.

NOTE a High susceptibility should be used if cracking is confirmed to be present.

b) STEP 2—Determine the Severity Index, S_{VI}, using Table 2.D.1.2 based on the susceptibility from STEP 1.

c) STEP 3—Determine the in-service time, age_{crack}, since the last Level A, B, or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation.

d) STEP 4—Determine the in-service time, age_{coat}, since the coating has been installed using Equation (2.D.28).

$$age_{coat} = Calculation\ Date - Coating\ Installation\ Date \tag{2.D.28}$$

e) STEP 5—Determine the expected coating age, C_{age}, based on coating type, quality of application and service conditions. C_{age} should be 0 years for no coating or poorly applied coating. Lower quality coatings will typically have a C_{age} of 5 years or less. High quality coatings or coatings in less harsh external environments may have a C_{age} of 15 or more years. C_{age} may be adjusted based on an evaluation of the coating condition during a high-quality inspection.

f) STEP 6—Determine the coating adjustment, $Coat_{adj}$, using Equations (2.D.29) through (2.D.30).

If $age_{crack} \geq age_{coat}$:

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) \tag{2.D.29}$$

If $age_{crack} < age_{coat}$:

1. If the coating has failed at the time of inspection when age_{tke} was established, then

   $$Coat_{adj} = 0$$

2. If the coating has not failed at the time of inspection when age_{tke} was established, use Equation (2.36) to calculate $Coat_{adj}$

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) - min\left(C_{age}, age_{coat} - age_{tke}\right) \tag{2.D.30}$$

g) STEP 7—Determine the in-service time, age, over which ExtClSCC may have occurred using Equation (2.D.31).

$$age = age_{crack} - Coat_{adj} \tag{2.D.31}$$

h) STEP 8—Determine the number of inspections performed with no cracking detected or cracking was repaired and the corresponding inspection effectiveness category using Section 2.D.6.2 for past inspections performed during the in-service time. Combine the inspections to the highest effectiveness performed using Part 2, Section 3.4.3. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation.

i) STEP 9—Determine the base DF for ExtClSCC, $D_{fB}^{ext-ClSCC}$, using Table 2.C.1.3 based on the number of inspections and the highest inspection effectiveness determined in STEP 8 and the Severity Index, S_{VI}, from STEP 2.

j) STEP 10—Calculate the escalation in the DF based on the time in service since the last inspection using the age from STEP 7 and Equation (2.D.32). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

$$D_f^{ext-ClSCC} = min\left(D_{fB}^{ext-ClSCC} \cdot \left(max\left(age, 1.0 \right) \right)^{1.1}, \ 5000 \right) \tag{2.D.32}$$

2.D.4.7 Nomenclature

age is the component in-service time since the last cracking inspection or service start date

age_{coat} is the in-service time since the coating installation

age_{crack} is the in-service time since the last ClSCC inspection

C_{age} is the total anticipated coating life from the time of installation

$Coat_{adj}$ is the coating adjustment

$D_f^{ext-ClSCC}$ is the DF for ExtClSCC

$D_{fB}^{ext-ClSCC}$ is the base value of the DF for ExtClSCC

S_{VI} is the Severity Index

2.D.4.8 References

2.D.4.9 Tables

Table 2.D.4.1—Data Required for Determination of the DF—External ClSCC

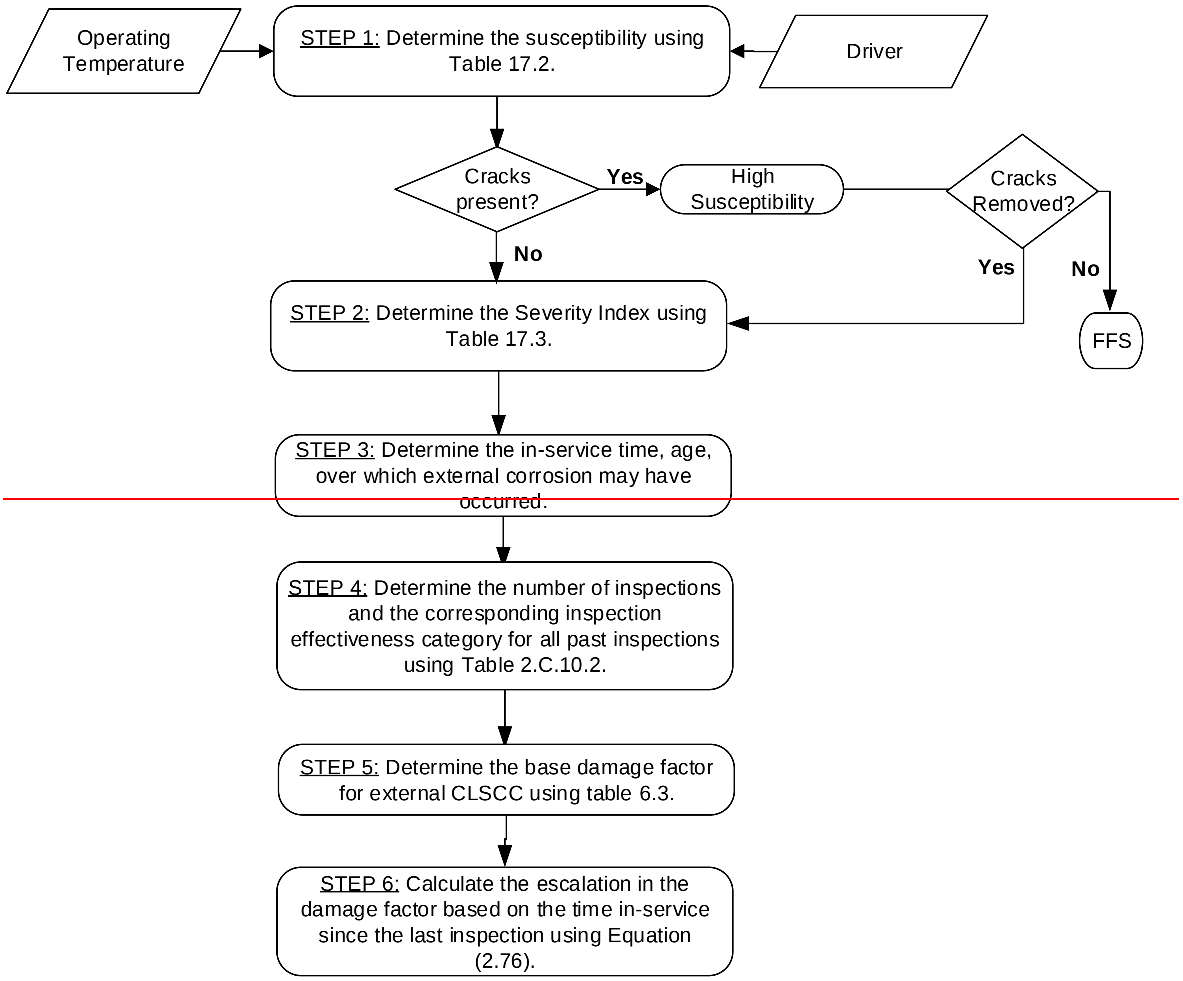
Required Data	Comments
Driver	The drivers for ExtClSCC. See Section 15.6.2 for driver descriptions and selection.
Crack severity	Crack severity based on susceptibility (temperature and weather; see below).
Date	The date the component was installed or the date of the last inspection where no damage was found.
Coating quality	Relates to the type of coating applied, for example: None—no coating or primer only; Medium—single coat epoxy; High—multi-coat epoxy or filled epoxy.
Coating date	Determine the age of the coating.
Inspection effectiveness category	The effectiveness category that has been performed on the component.
Number of inspections	The number of inspections in each effectiveness category that have been performed.
Operating temperature, °F (°C)	Determine the expected operating temperature (consider normal and non-normal operating conditions).

Table 2.D.4.2—SCC Susceptibility—External ClSCC

Operating Temperature		SCC Susceptibility As a Function of Driver [1]			
°C	°F	Severe	Moderate	Mild	Dry
<49	120	None	None	None	None
49 to 93	120 to 200	High	Medium	Low	None
93 to 149	200 to 300	Medium	Low	Low	None
>149	>300	None	None	None	None

NOTE 1 Driver is defined as the atmospheric condition causing the SCC.

2.D.4.10 Figures



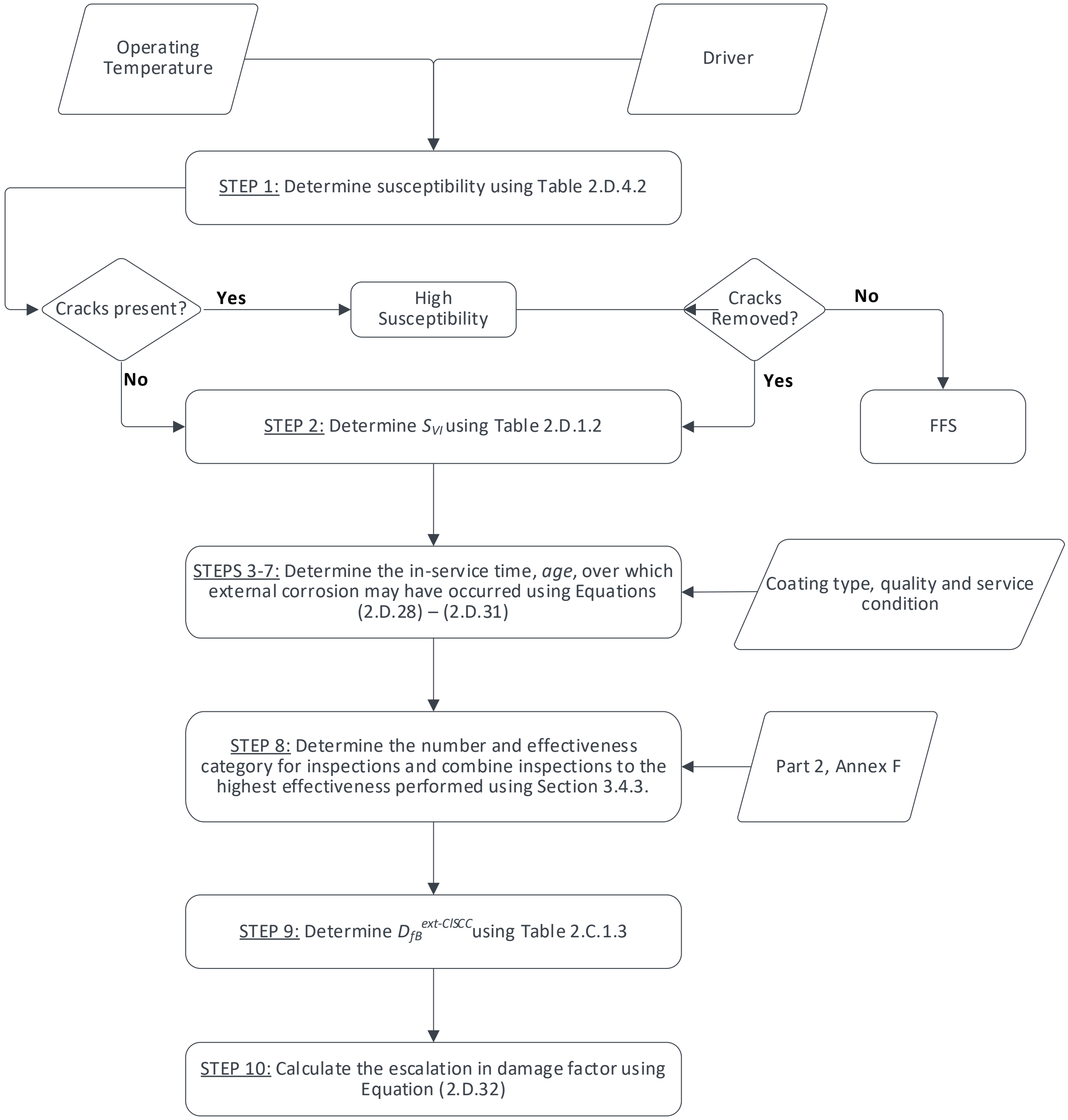


Figure 2.D.4.1—Determination of the External ClSCC DF

2.D.5 External CUI ClSCC DF—Austenitic Component

2.D.5.1 Scope

The DF calculation for insulated austenitic stainless steel components subject to CUI ClSCC is covered in this section.

2.D.5.2 Description of Damage

Insulation can be a source of chlorides and/or cause the retention of water and chloride concentrating under the insulation. CUI ClSCC can be caused by the spray from sea water and cooling water towers carried by the prevailing winds. The spray soaks the insulation over the austenitic stainless steel components, the chloride concentrates by evaporation, and cracking occurs in the areas with residual stresses (e.g. weld and bends). Other cases of cracking under insulation have resulted from water dripping on insulated pipe and leaching chlorides from insulation. Mitigation of CUI ClSCC is best accomplished by preventing chloride accumulation on the stainless steel surface. This is best accomplished by maintaining the integrity of the insulation and by preventing chloride ions from contacting the stainless steel surface with a protective coating. An immersion grade coating suitable for stainless steel is the most practical and proven method of protection. However, wrapping of the stainless steel with aluminum foil that serves as both a barrier coating and a cathodic protection (CP) anode has also proven to be effective.

CUI damage in austenitic stainless steels occurs at temperatures between 120 °F and 350 °F (50 °C and 175 °C) although exceptions have been reported at lower temperatures.

a) Below 120 °F (50 °C), it is difficult to concentrate significant amounts of chlorides.

b) Above 350 °F (175 °C), water is normally not present and CUI damage is infrequent.

c) Austenitic stainless steel piping that normally operates above 500 °F (260 °C) can also suffer severe ExtClSCC during start-up if the insulation is soaked from deluge system testing or rain during downtime.

Heating and/or cooling intermittently into this range creates the conditions for CUI ClSCC to occur.

2.D.5.3 Screening Criteria

If all of the following are true, then the component should be evaluated for susceptibility to CUI ClSCC.

a) The component’s material of construction is an austenitic stainless steel.

b) The component is insulated.

c) The component’s external surface is exposed to chloride-containing fluids, mists, or solids.

d) The operating temperature is between 120 °F and 300 °F (50 °C and 150 °C) or intermittently operated in this range.

2.D.5.4 Required Data

The basic component data required for analysis are given in Part 2, Table 4.1, and the specific data required for determination of the DF for CUI ClSCC are provided in Table 2.D.5.1.

2.D.5.5 Basic Assumption

The DF for external CUI ClSCC is based on the method in Section 2.C.2.5.

2.D.5.6 Determination of the DF

2.D.5.6.1 Overview

A flow chart of the steps required to determine the DF for external CUI ClSCC is shown in Figure 2.D.5.1. The following sections provide additional information and the calculation procedure.

2.D.5.6.2 Inspection Effectiveness

Inspections are ranked according to their expected effectiveness at detecting the specific damage mechanism. Examples of inspection activities that are both intrusive (requires entry into the equipment) and nonintrusive (can be performed externally) are provided in Annex 2.F~~C~~, Table 2.F~~C~~.9~~10~~.4.

If multiple inspections of a lower effectiveness have been conducted during the designated time period, they can be equated to an equivalent higher effectiveness inspection in accordance with Part 2, Section 3.4.3.

2.D.5.6.3 Calculation of the DF

The following procedure may be used to determine the DF for CUI ClSCC; see Figure 2.D.5.1. NOTE a high susceptibility should be used if cracking is known to be present.

a) STEP 1—Determine the susceptibility using Table 2.D.5.2 based on the driver and the operating temperature and the following adjustment factors.

   1) Adjustments for Piping Complexity—If the piping complexity is Below Average, then decrease susceptibility one level (e.g. Medium to Low). If the piping complexity is Above Average, then increase susceptibility one level (e.g. Medium to High). If the piping complexity is Average, then there is no change in the susceptibility.

   2) Adjustments for Insulation Condition—If the insulation condition is Above Average, then decrease susceptibility one level (e.g. Medium to Low). If the insulation condition is Below Average, then increase susceptibility one level (e.g. Medium to High). If the insulation condition is Average, then there is no change in the susceptibility.

   3) Adjustments for Chloride-free Insulation—If the insulation contains chlorides, then there is no change in the susceptibility. If the insulation is chloride free, then decrease the susceptibility one level (e.g. Medium to Low).

   NOTE a high susceptibility should be used if cracking is confirmed to be present.

b) STEP 2—Determine the Severity Index, S_{VI}, using Table 2.D.1.2, based on the susceptibility from STEP 1.

c) STEP 3—Determine the in-service time, age_{crack}, since the last Level A, B, or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation.

d) STEP 4—Determine the in-service time, age_{coat}, since the coating has been installed using Equation (2.D.33).

$$age = Calculation\ Date - Coating\ Installation\ Date \tag{2.D.33}$$

e) STEP 5—Determine the expected coating age, C_{age}, based on coating type, quality of application and service conditions. C_{age} should be 0 years for no coating or poorly applied coating. Lower quality coatings will typically have a C_{age} of 5 years or less. High quality coatings or coatings in less harsh external environments may have a C_{age} of 15 or more years. C_{age} may be adjusted based on an evaluation of the coating condition during a high-quality inspection.

f) STEP 6—Determine the coating adjustment, $Coat_{adj}$, using Equations (2.D.34) and (2.D.35).

If $age_{crack} \geq age_{coat}$:

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) \tag{2.D.34}$$

If $age_{crack} < age_{coat}$:

1. If the coating has failed at the time of inspection when age_{tke} was established, then

   $$Coat_{adj} = 0$$

2. If the coating has not failed at the time of inspection when age_{tke} was established, use Equation (2.36) to calculate $Coat_{adj}$

$$Coat_{adj} = min\left(C_{age}, age_{coat}\right) - min\left(C_{age}, age_{coat} - age_{tke}\right) \tag{2.D.35}$$

g) STEP 7—Determine the in-service time, age, over which external CUI ClSCC may have occurred using Equation (2.D.36).

$$age = age_{crack} - Coat_{adj} \tag{2.D.36}$$

h) STEP 8—Determine the number of inspections performed with no cracking detected or cracking was repaired and the corresponding inspection effectiveness category using Section 18.6.2 for past inspections performed during the in-service time. Combine the inspections to the highest effectiveness performed using Part 2, Section 3.4.3. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation.

i) STEP 9—Determine the base DF for CUI ClSCC, $D_{fB}^{CUI-ClSCC}$, using Table 2.C.1.3 based on the number of inspections and the highest inspection effectiveness determined in STEP 8 and the Severity Index, S_{VI}, from STEP 2.

j) STEP 10—Calculate the escalation in the DF based on the time in service since the last inspection using the age from STEP 7 and Equation (2.D.37). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions.

$$D_f^{CUI-ClSCC} = \min\left(D_{fB}^{CUI-ClSCC} \cdot \left(\max[age, 1.0]\right)^{1.1}, 5000\right) \tag{2.D.37}$$

2.D.5.7 Nomenclature

age is the component in-service time since the last cracking inspection or service start date

age_{coat} is the in-service time since the coating installation

age_{crack} is the in-service time since the last ClSCC inspection

C_{age} is the total anticipated coating life from the time of installation

$Coat_{adj}$ is the coating adjustment

$D_f^{CUI-ClSCC}$ is the DF for CUI ClSCC

$D_{fB}^{CUI-ClSCC}$ is the base value of the DF for CUI ClSCC

S_{VI} is the Severity Index

2.D.5.8 References

See Reference [83] in Part 2, Section 2.2.

2.D.5.9 Tables

Table 2.D.5.1—Data Required for Determination of the DF—CUI ClSCC

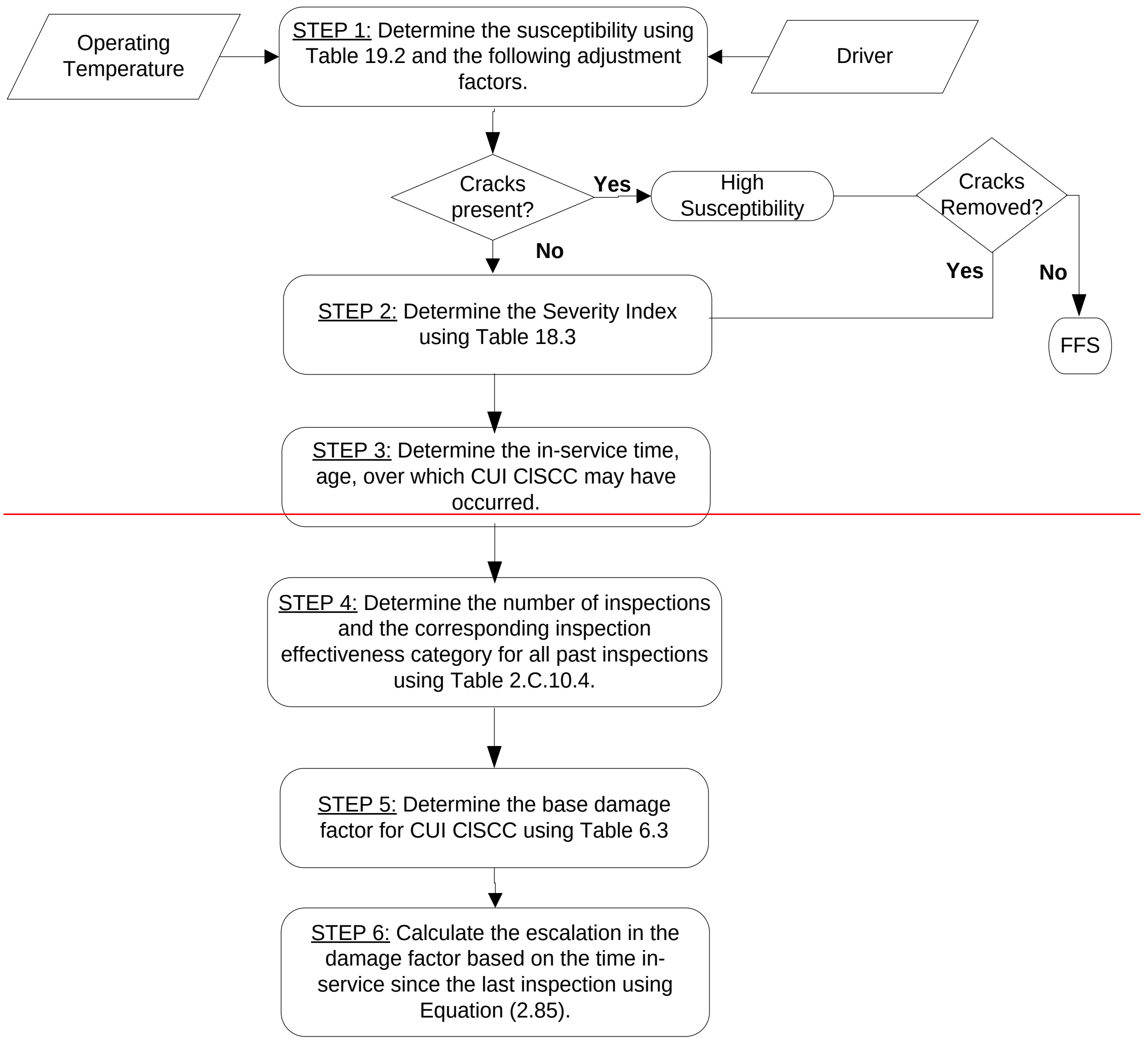
Required Data	Comments
Driver	The drivers for CUI ClSCC. See Section 15.6.2 for driver descriptions and selection.
Crack severity	Crack severity based on susceptibility (temperature and weather; see below).
Date	The date the insulation was installed or the date of the last inspection where no damage was found.
Coating quality	Relates to the type of coating applied under the insulation, for example: None—no coating or primer only; Medium—single coat epoxy; High—multi-coat epoxy or filled epoxy.
Coating date	Determine the age of the coating.
Inspection effectiveness category	The effectiveness category that has been performed on the component.
Insulation condition (Above Average, Average, or Below Average)	Determine insulation condition (Below Average, Average, or Above Average) based on external visual inspection of jacketing condition. Above average insulation will show no signs of damage (i.e. punctured, torn, or missing waterproofing, and missing caulking) or standing water (i.e. brown, green, or black stains). Take careful note of areas where water can enter into the insulation system, such as inspection ports and areas where the insulation is penetrated (i.e. nozzles, ring supports and clips). Horizontal areas also accumulate water. Average insulation condition will have good jacketing with some areas of failed weatherproofing or small damaged areas. NOTE the susceptibilities represent susceptibilities for CUI for average/typical insulation systems found in most plants. This should be considered when determining if any adjustments apply.
Complexity	The number of protrusions such as branch connections, nozzles, pipe supports, poorly designed insulation support rings, etc., and any design feature that would promote the retention and/or collection of moisture. The complexity is defined as follows: Below Average—penetrations in the insulation system do not exist; Average—some penetrations in the insulation systems, or the insulation system is slightly complex do to some appurtenances or multiple branches in a piping system; Above Average—many penetrations in the insulation systems, or the insulation system is very complex do to many appurtenances or multiple branches in a piping system.
Number of inspections	The number of inspections in each effectiveness category that have been performed.
Operating Temperature, °F (°C)	Determine the highest operating temperature expected during operation (consider normal and non-normal operating conditions).

Table 2.D.5.2—SCC Susceptibility—CUI ClSCC

Operating Temperature		SCC Susceptibility As a Function of Driver [1]			
°C	°F	Severe	Moderate	Mild	Dry
<49	<120	None	None	None	None
49 to 93	120 to 200	High	High	Medium	Low
93 to 149	200 to 300	High	Medium	Low	None
>149	>300	None	None	None	None

NOTE Driver is defined as the atmospheric condition causing the SCC.

2.D.5.10 Figures



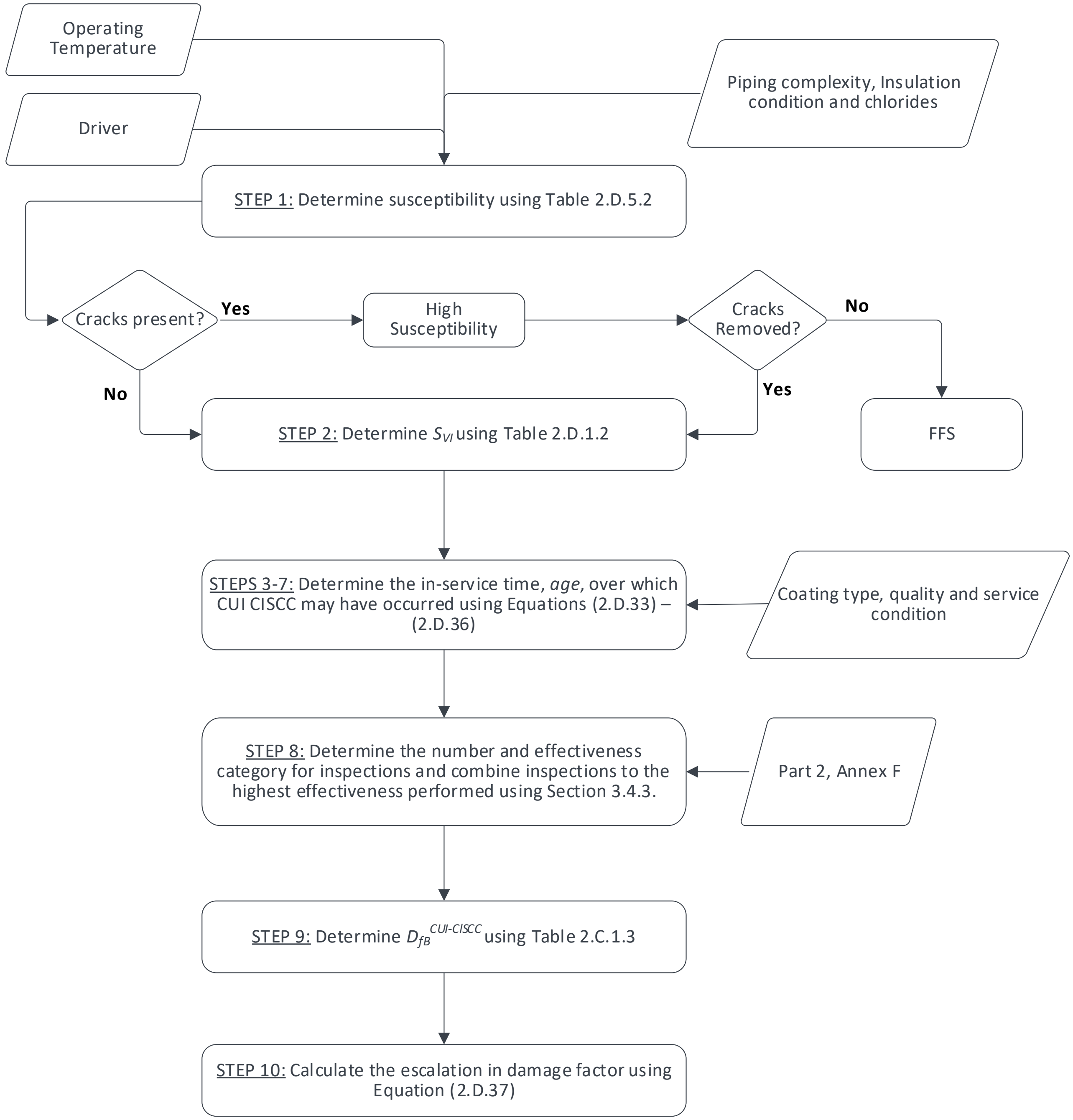


Figure 2.D.5.1—Determination of the CUI ClSCC DF