are obtained on high temperature components. It may be preferable to obtain readings with probes less than 12.7 mm (0.5 inches) in diameter to provide greater assurance that pitting/localized corrosion is not present.

4.3.4.4 Radiographic Testing (RT) may also be used to determine metal loss; however, accurate thickness data may only be obtained by moving the component containing the metal loss or moving the source around the component to obtain multiple views. This type of manipulation may not be possible for all pressure-containing components. However, RT examination can be effectively used to qualify the existence, extent, and depth of a region of metal loss, and may be used in conjunction with UT to determine whether the metal loss on a component is general or local.

4.3.4.5 For components susceptible to brittle fracture (see Part 3, paragraph 3.2.2), supplemental inspection in accordance with paragraph 5.3.4.3 of Part 5 is required to confirm no crack-like flaws exist.

4.3.4.6 Special precautions shall be made to validate inspection results when measured thickness readings are 2.5 mm (0.100 inches) or less. Recommendations for consideration are listed below:

a) Confirm appropriate instrument calibration for the full range of measured thickness values.

b) Perform multiple forms of NDE or utilize multiple inspectors to validate inspection findings.

c) Validate inspection method accuracy with a mock-up sample representing the actual field conditions (considering operating temperature, measured thickness ranges, damage profile, etc.), insofar as possible.

d) Increase inspection frequency to confirm damage progression rate.

4.4 Assessment Techniques and Acceptance Criteria

4.4.1 Overview

4.4.1.1 If the metal loss is less than the specified corrosion/erosion allowance and adequate thickness is available for the future corrosion allowance, no further action is required other than to record the data; otherwise, an assessment is required.

4.4.1.2 An overview of the assessment levels is provided in Figure 4.1.

a) Level 1 Assessments are limited to Type A components subject to internal pressure or external pressure.

b) Level 2 Assessments may be used to evaluate Type A components that do not satisfy the Level 1 Assessment criteria and may be used to evaluate Type B Class 1 components and the following Type B Class 2 components subject to internal pressure or external pressure.

   - Pressure vessel nozzles, tank nozzles and piping branch connections.
   - The reinforcement zone of conical transitions.
   - Flanges.

c) Level 3 Assessments may be used to evaluate Type A and B components that do not satisfy the Level 1 or Level 2 Assessment criteria and may be used to evaluate Type C components using stress analysis methods (see Annex 2D).

4.4.1.3 If thickness readings indicate that the metal loss is localized and thickness profiles are obtained, the assessment procedures in this Part can still be used for the assessment. However, the results may be conservative, and the option for performing the analysis using the assessment procedures of Part 5 is provided.

4.4.1.4 FFS Assessments for the components listed below require special consideration because of the complexities associated with the design requirements of the original construction code. In each case, an Engineer knowledgeable and experienced in the design requirements of the applicable code should perform the assessment (see Part 1, paragraph 1.4.3). If the metal loss is in a component that was not subject to special design requirements per the original construction code (i.e., design requirements based on stress analysis), then the Level 1 or Level 2 Assessment procedures may be applied. If the corrosion/erosion damage is in a component subject to special design requirements, then the calculations required in the original design to qualify the component should be repeated considering a reduced wall thickness.

a) Pressure Vessels Designed to The ASME Code, Section VIII, Division 2 – A user design specification is required where the operational parameters for the original design were established. In addition, detailed heat transfer and stress calculations, and a fatigue analysis may have been performed to satisfy the design-by-analysis rules required in this code.

b) Low Pressure Storage Tanks Designed to API 620 – The design rules for low–pressure storage tanks contained in API 620 require a thorough knowledge of engineering mechanics in that the required thickness of a shell component is based upon the evaluation of free body diagrams, the development of equilibrium equations, and the consideration of a biaxial stress field to determine an allowable design stress.

c) Piping Designed to ASME B31.3 – Metal loss in piping systems can be evaluated using a Level 1 Assessment if the supplemental loads on the piping system are negligible (see Annex 2C, paragraph 2C.2.7). Supplemental loads on piping systems are negligible if the piping satisfies the requirements for a Type A component (see Table 4.2). If supplemental loads are not negligible, a piping stress analysis is required. The piping analysis should consider the relationship between the component thickness, piping flexibility, and the resulting stress (see paragraph 4.4.3.3).

4.4.2 Level 1 Assessment

4.4.2.1 The following assessment procedure shall be used to evaluate Type A Components (see paragraph 4.2.5) subject to internal or external pressure when Point Thickness Reading (PTR) data are used to characterize the metal loss (see paragraph 4.3.3.2).

a) STEP 1 – Take the point thickness reading data in accordance with paragraph 4.3.3.2. From these data determine the minimum measured thickness, t_{mm}, and the average measured thickness, t_{am}.

b) STEP 2 – If Equation (4.1) is satisfied, then proceed to STEP 3 to complete the assessment using the average thickness, t_{am}. If Equation (4.1) is not satisfied, then thickness profiles shall be used for the assessment (see paragraph 4.4.2.2).

c) STEP 3 – The acceptability of the component for continued operation can be established using the Level 1 criteria in Table 4.4, Table 4.5, Table 4.6 and Table 4.7. The averaged measured thickness or $MAWP$ acceptance criterion may be used. In either case, the minimum thickness criterion shall be satisfied. For $MAWP$ acceptance criterion, see Part 2, paragraph 2.4.2.2(e) to determine the acceptability of the equipment for continued operation.

4.4.2.2 The following assessment procedure shall be used to evaluate Type A Components (see paragraph 4.2.5) subject to internal or external pressure when Critical Thickness Profile (CTP) data are used to characterize the metal loss (see paragraph 4.3.3.3).

a) STEP 1 – Determine the thickness profile data in accordance with paragraph 4.3.3.3 and determine the minimum measured thickness, t_{mm}.

b) STEP 2 – Determine the wall thickness and diameter to be used in the assessment using Equation (4.3) and Equation (4.4) or Equation (4.5).

$$t_{ml} = t_{nom} - FCA_{ml} \tag{4.3}$$

$$D_{ml} = D + 2 \cdot FCA_{ml} \qquad (for\ Internal\ FCA) \tag{4.4}$$

$$D_{ml} = D \qquad (for\ External\ FCA) \tag{4.5}$$

c) STEP 3 – Compute the remaining thickness ratio, R_t.

$$R_t = \left(\frac{t_{mm} - FCA_{ml}}{t_{ml}} \right) \tag{4.6}$$

d) STEP 4 – Compute the length for thickness averaging, L where the parameter Q is evaluated using Table 4.8.

$$L = Q\sqrt{D_{ml} \cdot t_{ml}} \tag{4.7}$$

e) STEP 5 – Establish the Critical Thickness Profiles (CTP's) from the thickness profile data (see paragraph 4.3.3.3). Determine the average measured thickness t_{am}^{s} based on the longitudinal CTP and the average measured thickness t_{am}^{c} based on the circumferential CTP. The average measured thicknesses t_{am}^{s} and t_{am}^{c} shall be based on the length L determined in STEP 4 (see Figure 4.19). The length L shall be located on the respective CTP such that the resulting average thickness is a minimum.

f) STEP 6 – Based on the values of t_{am}^{s} and t_{am}^{c} from STEP 5, determine the acceptability of the component for continued operation using the Level 1 criteria in Table 4.4, Table 4.5, Table 4.6 and Table 4.7, as applicable. The averaged measured thickness or $MAWP$ acceptance criterion may be used. In either case, the minimum measured thickness, t_{mm}, shall satisfy the criterion in Table 4.4, Table 4.5, Table 4.6 and Table 4.7. For $MAWP$ acceptance criterion, see Part 2, paragraph 2.4.2.2(e) to determine the acceptability of the equipment for continued operation.

4.4.2.3 If the component does not meet the Level 1 Assessment requirements (see Part 2, paragraph 2.4.2.2(e)), then the following, or combinations thereof, shall be considered:

a) Rerate, repair, or replace the component.

b) Adjust the FCA_{ml} by applying remediation techniques (see paragraph 4.6).

c) Adjust the weld joint efficiency or quality factor, E, by conducting additional examination and repeat the assessment. Note: To raise the value of E from 0.7 to 0.85, or from 0.85 to 1.0, would require that the weld seams be spot or 100% radiographed, respectively, and these examinations may reveal additional flaws that will have to be evaluated.

d) Conduct a Level 2 or a Level 3 Assessment.

4.4.3 Level 2 Assessment

4.4.3.1 The assessment procedure in paragraph 4.4.2.1 may be used to evaluate Type A and Type B Class 1 Components (see paragraph 4.2.5) subject to internal pressure, external pressure, supplemental load or combined loads when Point Thickness Reading (PTR) data are used to characterize the metal loss (see paragraph 4.3.3.2). Note that the Level 2 Acceptance Criteria in Table 4.4, Table 4.5, Table 4.6 and Table 4.7 shall be used in conjunction with STEP 3.

4.4.3.2 The assessment procedure in paragraph 4.4.2.2 may be used to evaluate Type A and Type B Class 1 Components (see paragraph 4.2.5) subject to internal pressure, external pressure, supplemental load or combined loads when CTP data are used to characterize the metal loss (see paragraph 4.3.3.3). Note that the Level 2 Acceptance Criteria in Table 4.4, Table 4.5, Table 4.6 and Table 4.7 shall be used in conjunction with STEP 6.

4.4.3.3 The following assessment procedure can be used to evaluate Type B Class 2 Components (see paragraph 4.4.1.2(b)) subject to internal pressure or external pressure load.

a) STEP 1 – Compute the $MAWP_r$ based upon the average measured thickness minus the future corrosion allowance applied to the region of metal loss and the thickness required for supplemental loads (see Annex 2C, paragraph 2C.2.7), for each component using the equations in the original construction. The calculated $MAWP_r$ should be equal to or exceed the equipment design pressure or equipment $MAWP$. The average thickness of the region, t_{am}, shall be obtained as follows for components with a thickness interdependency:

   1) Nozzles and Branch Connections – Determine the average thickness within the nozzle reinforcement zone shown in Figure 4.13 (see paragraph 4.3.3.4). The assessment procedures in Annex 2C, paragraph 2C.3.4 or 2C.5.7, as applicable, can be utilized to evaluate metal loss at a nozzle or piping branch connection, respectively. The weld load path analysis in this paragraph should also be checked, particularly if the metal loss has occurred in the weldments of the connection.

   2) Axisymmetric Structural Discontinuities – Determine L using Equation (4.7) and L_v based on the type of structural discontinuity listed below. The average thickness is computed based on the smaller of these two distances. If $L < L_v$, then the midpoint of L should be located at t_{mm} to establish a length for thickness averaging unless the location of t_{mm} is within $L/2$ of the zone for thickness averaging. In this case, t_{mm} should be positioned so that it is entirely within L before the average thickness is computed.

      i) Conical shell transition (see Figure 4.14) for the zone for thickness averaging and L_v.

      ii) Flange connections (see Figure 4.15) for the zone for thickness averaging and L_v. If the flange has a hub, and the metal loss is uniform along the hub, then the average thickness may be proportioned in accordance with the original hub dimensions for the flange calculation. If the metal loss is non-uniform or the flange does not have a hub, then the flange calculation should be performed using a uniform hub section with a thickness equal to the average thickness.

      iii) Cylinder to flat head junctions (see Figure 4.16) for the zone for thickness averaging and L_v.

      iv) Integral tubesheet connections (see Figure 4.17) for the zone for thickness averaging and L_v.

      v) Stiffening or insulation support rings (see Figure 4.18) for the thickness zone, L_v.

   3) Piping Systems – Piping systems that are not classified as Type A components in Table 4.2 are classified as Type B Class 1 Components in Table 4.2 because of the relationship between the component thickness, piping flexibility, and the resulting stress. For straight sections of piping, determine L using Equation (4.7) and compute the average thickness based on L to represent the section of pipe with metal loss in the piping analysis. For elbows or bends, the thickness readings should be averaged within the bend and a single thickness used in the piping analysis (i.e., to compute the flexibility factor, system stiffness and stress intensification factor). For branch connections, the thickness should be averaged

within the reinforcement zones for the branch and header, and these thicknesses should be used in the piping model (to compute the stress intensification factor). An alternative assumption is to use the minimum measured thickness to represent the component thickness in the piping model. This approach may be warranted if the metal loss is localized; however, this may result in an overly conservative evaluation. In these cases, a Level 3 Assessment may be required to reduce the conservatism in the assessment (see paragraph 4.4.4.4).

b) STEP 2 – The minimum measured wall thickness, t_{mm}, shall satisfy the criterion in Table 4.4, Table 4.5, Table 4.6 and Table 4.7.

4.4.3.4 If the component does not meet the Level 2 Assessment requirements, then the following, or combinations thereof, can be considered:

a) Rerate, repair, or replace the component.

b) Adjust the FCA_{ml} by applying remediation techniques (see paragraph 4.6).

c) Adjust the weld joint efficiency factor, E, by conducting additional examination and repeat the assessment (see paragraph 4.4.2.3).

d) Conduct a Level 3 Assessment.

e) Evaluate the region of metal using the Part 5 Assessment procedures.

4.4.4 Level 3 Assessment

4.4.4.1 The stress analysis techniques discussed in Annex 2D can be utilized to evaluate regions of general or local metal loss in pressure vessels, piping, and tanks. The finite element method is typically used to compute the stresses in a component; however, other numerical methods such as the boundary element or finite difference method may also be used. Handbook solutions may also be used if the solution matches the component geometry and loading condition. The evaluation may be based on a linear stress analysis with acceptability determined using stress categorization, or a non-linear stress analysis with acceptability determined using a plastic collapse load. Non-linear stress analysis techniques are recommended to provide the best estimate of the acceptable load carrying capacity of the component. Guidelines for performing and processing results from a finite element analysis for an FFS analysis are provided in Annex 2D.

4.4.4.2 If a component is subject to external pressure and/or other loads that result in compressive stresses, a structural stability analysis should be performed using the methods in Annex 2D to determine suitability for continued service. In addition, methods to evaluate fatigue are also included in Part 14 if a component is subject to cyclic loading.

4.4.4.3 Thickness data per paragraph 4.3.3 as well as the component geometry, material properties and loading conditions are required for a Level 3 Assessment. The thickness data can be used directly in finite element model of the component. If thickness profile data are available, the thickness grid can be directly mapped into a three-dimensional finite element model using two or three dimensional continuum elements, as applicable. This information can also be used if the component is modeled using shell elements.

4.4.4.4 If the region of local metal loss is close to or at a major structural discontinuity, details of the component geometry, material properties, and imposed supplemental loads (see Annex 2C, paragraph 2C.2.7) at this location are required for the assessment. Special consideration is required if there are significant supplemental loads at a nozzle, piping branch connection, or pipe bend. The location and distribution of the metal loss in these components may significantly affect both the flexibility and stress distribution in a manner that cannot be evaluated using the approaches employed in the design. In addition, the localized metal loss may significantly reduce the plastic collapse load capability depending on the nozzle geometry, piping system configuration, and/or applied supplemental loads.

4.5 Remaining Life Assessment

4.5.1 Thickness Approach

4.5.1.1 The remaining life of a component can be determined based upon computation of a minimum required thickness for the intended service conditions according to Table 4.4, Table 4.5, Table 4.6 and Table 4.7, thickness measurements from an inspection, and an estimate of the anticipated corrosion rate. This method is suitable for determination of the remaining life for Type A and Type B Class 1 Components (see paragraph 4.2.5).

$$R_{life} = \frac{t_{am} - t_{min}}{C_{rate}} \tag{4.8}$$

4.5.1.2 The remaining life determined using the Thickness Approach may produce non-conservative results when applied to Type B Class 2 or Type C Components (see paragraph 4.2.5). For these cases, the remaining life should be established using the $MAWP$ approach.

4.5.2 MAWP Approach

4.5.2.1 The $MAWP$ approach provides a systematic method for determining the remaining life of Type A, B, and C components (see Annex 4A, reference [2]). This method is also the only method suitable for determining the remaining life of Type B and C components. In addition, the $MAWP$ approach ensures that the design pressure is not exceeded during normal operation if the future corrosion rate is accurately established.

4.5.2.2 The following procedure can be used to determine the remaining life of a component using the $MAWP$ approach.

a) STEP 1 – Determine the metal loss of the component, t_{loss}.

$$t_{loss} = t_{nom} - t_{am} \tag{4.9}$$

b) STEP 2 – Determine the $MAWP_r$ for a series of increasing time increments using an effective corrosion allowance and the nominal thickness in the computation. The effective corrosion allowance is determined as follows:

$$CA_e = t_{loss} + C_{rate} \cdot time \tag{4.10}$$

c) STEP 3 – Using the results from STEP 2, determine the remaining life from a plot of the $MAWP$ versus time. The time at which the $MAWP_r$ curve intersects the equipment design pressure or equipment $MAWP$ is the remaining life of the component.

d) STEP 4 – Repeat the STEPS 1 through 3 for each component. The equipment remaining life is taken as the smallest value of the remaining life computed for each of the individual components.

4.5.2.3 This approach may also be applied to tanks using the maximum fill height, MFH, instead of the $MAWP$.