10.1 General

10.1.1 FFS Procedures and Temperature Limits

Fitness-For-Service (FFS) assessment procedures for pressurized components operating in the creep range are provided in this Part. The temperature above which creep needs to be evaluated can be established using a Level 1 Assessment. The procedures in this Part can be used to qualify a component for continued operation or for re-rating. A flow chart for the assessment procedures for components operating in the creep range is shown in Figure 10.1.

10.1.2 Remaining Life of Components with and without Crack-Like Flaws

The FFS assessment procedure for components operating in the creep range requires an estimate of remaining life. Assessment procedures for determining a remaining life are provided for components with and without a crack-like flaw subject to steady-state and cyclic operating conditions. If the component contains a crack-like flaw, and is not operating in the creep range, then Part 9 can be used for the FFS assessment.

10.2 Applicability and Limitations of the Procedure

10.2.1 Suitability for Service and Remaining Life

The assessment procedures in this Part can be used to determine the suitability for continued operation and the remaining life of a component operating in the creep range. The use of these procedures is not normally required for equipment designed to a recognized code or standard that is operating within the original design parameters. Conditions that may warrant a FFS evaluation for components operating in the creep range include:

a) Operational upsets that result in an operating temperature and pressure, or other loading conditions that may result in creep damage and were not included in the original design.

b) Metal loss in the component beyond that provided for in the original design; metal loss in this category will result in component stress above those originally considered in the original design.

c) Component weldments that have significantly different properties in the weld metal, Heat Affected Zone (HAZ), and base metal. Examples include 1.25Cr-0.5Mo, 2.25Cr-1Mo and 9Cr-1Mo-V.

d) Stress concentration regions in the components that were not accounted for in the original design. Examples include out-of-roundness or peaking in longitudinal seam welds, notch-like locations such as transition regions with a slope greater than 1:3, and bulges that have occurred in service.

e) Fire damage that can result in a short time heating event.

f) The discovery of a crack-like flaw; both initial fabrication and service induced crack-like flaws should be evaluated.

g) The discovery of an LTA, pitting damage, weld misalignment, out-of-roundness, bulge, dent, or dent-gouge combination that can result in localized creep strain accumulation and subsequent cracking. Both initial fabrication and service-induced flaws should be evaluated.

10.2.2 Applicability and Limitations

Specific details pertaining to the applicability and limitations of each of the assessment procedures are discussed below.

10.2.2.1 The Level 1 assessment procedures apply only if all of the following conditions are satisfied:

a) The original design criteria were in accordance with Part 2, paragraph 2.2.2.

b) The component has not been subject to fire damage or another overheating event that has resulted in a significant change in shape such as sagging or bulging, or excessive metal loss from scaling.

c) The material meets or exceeds the respective minimum hardness and carbon content shown in Table 10.1.

d) The component does not contain:

   1) An LTA or groove-like flaw,

   2) Pitting damage,

   3) Blister, HIC, or SOHIC damage,

   4) Weld misalignment, out-of-roundness, or bulge that exceed the original design code tolerances,

   5) A dent or dent-gouge combination,

   6) A crack-like flaw, or

   7) Microstructural abnormality such as graphitization, sigma phase formation, carburization or hydrogen attack.

10.2.2.2 The Level 2 assessment procedures apply only if all of the following conditions are satisfied:

a) The original design criteria were in accordance with Part 2, paragraph 2.2.2.

b) A history of the operating conditions and documentation of future operating conditions for the component are available.

c) The component has been subject to less than or equal to 50 cycles of operation including startup and shutdown conditions, or less than that specified in the original design.

d) The component does not contain any of the flaws listed in paragraph 10.2.2.1.d.

10.2.2.3 A Level 3 Assessment should be performed when the Level 1 and 2 methods cannot be applied due to applicability and limitations of the procedure or when the results obtained indicate that the component is not suitable for continued service.

a) Conditions that typically require a Level 3 Assessment include the following.

   1) Advanced stress analysis techniques are required to define the state of stress because of complicated geometry and/or loading conditions.

   2) The component is subject to cyclic operation (see paragraph 10.2.2.2.c).

   3) The component contains a flaw listed in paragraph 10.2.2.1.d. A detailed assessment procedure is provided for a crack-like flaw; however, this procedure cannot be used to evaluate crack-like flaws that are caused by stress corrosion, oxide wedging, or similar environmental phenomena.

b) The Level 3 Assessment procedures, with the exception of the procedure for the evaluation of dissimilar metal welds, can be used to evaluate components that contain the flaw types in paragraph 10.2.2.1.d. A separate procedure is provided to evaluate components with crack-like flaws.

c) The assessment procedure provided for dissimilar metal welds is only applicable to 2.25Cr - 1Mo to austenitic stainless steel welds made with stainless steel or nickel-based filler metals. An alternative assessment procedure for this material and other materials that are not currently covered may be used.

10.2.2.4 To perform an evaluation to any of the assessment levels, the material properties for the temperature and stress conditions the component is subject to must be available. For a Level 1 Assessment, the required material properties are included in the material screening curves (see paragraph 10.4.2). For the Level 2 and Level 3 assessments, the required material properties are included for many commonly used materials in Annex 10B.

10.3 Data Requirements

10.3.1 General

10.3.1.1 The Level 1 Assessment is a screening criterion based on the original design of the component, the past and future planned operating conditions. This assessment can be performed based on the following information.

a) Original Equipment Design Data (see paragraph 10.3.2).

b) Maintenance and Operating History (see paragraph 10.3.3).

10.3.1.2 Significant input data are required to perform a Level 2 or Level 3 Assessment. Details regarding the required data are discussed in paragraphs 10.3.2 through 10.3.6. The accuracy of these data and stress conditions will determine the accuracy of the assessment in this Part.

10.3.2 Original Equipment Design Data

An overview of the original equipment data required for an assessment is provided in Part 2, paragraph 2.3.1.

10.3.3 Maintenance and Operational History

10.3.3.1 An overview of the maintenance and operational history required for an assessment is provided in Part 2, paragraph 2.3.2.

10.3.3.2 The definition of the operating history is required in order to perform a FFS assessment of a component operating in the creep range.

a) The component operating history and future operational conditions are required to perform a remaining life assessment. This information should include an accurate description of operating temperatures, pressures, supplemental loads, and the corresponding time period for all significant events. These events include start-ups, normal operation, upset conditions, and shutdowns. Past operating history may not be required as described in paragraph 10.3.5.2.

b) If an accurate histogram cannot be generated, then an approximate histogram shall be developed based on information obtained from plant personnel. This information shall include a description of all assumptions made, and include a discussion of the accuracy in establishing points on the histogram. A sensitivity analysis (see paragraph 10.5.1.4) shall be included in the FFS assessment to determine and evaluate the effects of the assumptions made to develop the operating history.

c) If past operating conditions are not known or estimated operating conditions have a significant amount of uncertainty, a material test can be performed whereby the creep damage associated with past operation can be evaluated in terms of a material parameter (see paragraph 10.3.5.2).

d) When creating the histogram, the history to be used in the assessment shall be based on the actual sequence of operation.

10.3.4 Required Data for a FFS Assessment – Loads and Stresses

10.3.4.1 A stress analysis is required for a Level 2 or Level 3 Assessment.

a) Level 1 Assessment – Nominal stresses are required. The nominal stresses may be computed using code equations (see Annex 2C).

b) Level 2 and Level 3 Assessments – stress analysis may be performed using the following methods.

   1) Handbook solutions may be used if these solutions accurately represent the component geometry and loading condition.

   2) Reference stress solutions that include the effects of stress re-distribution during creep may be used in the assessment if these solutions accurately represent the material creep response, component geometry, and loading conditions.

   3) Numerical analysis techniques such as the finite element method can be used to determine the stress state at major structural discontinuities or at the location of a flaw (e.g. crack-like flaw or LTA) where creep damage or creep crack growth is normally manifested. In these cases, it is recommended that this analysis includes the effects of plasticity and creep to account for the redistribution of stresses that occurs in the creep range. This is particularly important because the stresses at major structural discontinuities relax to magnitudes that are significantly less than those computed using an elastic stress calculation. Since the stress results are used directly in the assessment procedure and the remaining life from this procedure is sensitive to the magnitude of stress, the results from an elastic analysis will typically over-estimate the creep damage and result in a conservative estimate of remaining life.

   4) Guidelines for computing stresses for a tube or elbow in a Level 2 Assessment are provided in paragraph 10.5.2.5.

10.3.4.2 Stress calculations shall be performed for all points included in the load histogram (see paragraph 10.3.3.2) that will be used in the assessment.

10.3.4.3 The stress analysis performed for all assessment levels shall include the effects of service-induced wall thinning (e.g. oxidation).

10.3.4.4 Additional information regarding stress analysis for a component containing a crack-like flaw is provided in Part 9, paragraph 9.3.4.2.

10.3.4.5 Component temperatures used in an assessment should be based on the operating temperatures considering the following.

a) Heat transfer analysis considering thermal conductivity, fluid film coefficients, and transient effects.

b) Insulating effects of scale, other corrosion products, or process products left on the component surfaces.

c) The influence of the process environment on local overheating or cooling.

10.3.5 Required Data for a FFS Assessment – Material Properties

10.3.5.1 An overview of the material data required to perform a remaining life assessment is provided in Annex 10B and summarized below. The material data presented in Annex 10B are from the MPC Project Omega data that are based on a strain-rate approach, and the creep rupture life data from API Std 530. Both types of data can be used in the Level 2 or Level 3 Assessment procedures to determine a remaining life. The Project Omega data is required in a Level 3 creep buckling analysis. Material data applicable to service exposed materials from other sources may be used in a Level 3 Assessment.

a) MPC Project Omega Data – data are provided in terms of a damage parameter and strain-rate parameter, a method is suggested to account for minimum and average properties.

b) Creep Rupture Data – data are provided for minimum and average properties in terms of the Larson-Miller Parameter.

10.3.5.2 As previously described, a precise description of the component operating history and future operational conditions is required to perform a remaining life assessment. The future planned operating conditions can be readily defined; however, many times an adequate description of the past operating history cannot be made. To address this problem, the MPC Project Omega Program has developed a testing protocol to evaluate material parameters required for a remaining life assessment. The required tests necessitate removal of a material sample from a location in the component subject to the highest creep damage. This location is typically associated with the highest temperature and/or stress location. When an Omega Test is performed on a material sample from the component, the Omega material parameters are determined, and these parameters include the effects of creep damage associated with past operation. Therefore, by performing an Omega test, the remaining life problem is “shifted” such that the operating conditions up to the time of the test do not need to be evaluated to determine a remaining life (see Figure 10.2). This feature of the MPC Omega Method provides a means to accurately account for creep damage from past operation without having to know how the component was operated.

10.3.5.3 The material data from the MPC Project Omega Program (see Annex 10B) can be used directly to model creep behavior in an inelastic finite element analysis by implementing the equation shown below. This equation provides a strain-hardening relationship for the creep strain rate, i.e. the current creep strain rate is a function of the current stress, and temperature, and accumulated creep strain, and can be used with finite element computer programs that utilize either an explicit or implicit time integration algorithm for solution of the creep problem. Note that this creep constitutive relationship will need to be implemented in a customized user-subroutine. However, most of the finite element programs that have creep analysis capability provide this option.

$$\dot{\varepsilon}_c = \dot{\varepsilon}_{co} \exp\left[\Omega_m \varepsilon_c\right] \qquad (10.1)$$

10.3.5.4 If the component contains a crack-like flaw, parameters for the creep-crack growth equation is required (see Annex 10B). In addition, the fracture toughness is also required because an evaluation of the flaw using the Failure Assessment Diagram (FAD) based assessment procedures of Part 9 is required. It should be noted that although unstable crack growth is unlikely at elevated temperature, it may be a possibility during the start-up or shutdown phase of the cycle. In addition, the FAD assessment is required to place a limit on the plastic collapse of a component containing a crack-like flaw.

10.3.6 Required Data for a FFS Assessment – Damage Characterization

10.3.6.1 General requirements for all components

a) It shall be verified that the component material conformed to the original specification for the material of construction, or does so now.

b) The remaining sound wall thickness and the extent of corrosion/erosion shall be determined on all surfaces of the component.

c) The existence of flaws or damage described in paragraph 10.2.2.1.d shall be determined. If a flaw is found, the extent of the damage shall be documented in accordance with the applicable Parts of this Standard.

d) Local variations in the operating conditions shall be identified. These may result from hot spots, coolant flow patterns, furnace or heater firing condition, etc. Local variations in operating conditions may result in a localized increased rate of wall thinning.

e) Any unusual loading conditions resulting from missing or damaged supports, dead weight loads, etc., shall be noted, and considered in the stress analysis (see paragraph 10.3.4).

f) The allowable creep damage D_c^{allow} shall be specified. If information is not available for the specific material being evaluated, then use $D_c^{allow} = 1.0$.

g) Environmental interaction such as carburization, decarburization, hydrogen attack, etc., shall be considered and noted accordingly.

h) Where appropriate, and based on the observed metal loss or known reaction rates and the time-temperature history, future reaction rates shall be appropriately accounted for in the assessment.

   1) Where rates of future reactions are not reaction-product thickness limited, the reaction rate may be fit to a form shown in Equation (10.2) based on measurements or literature.

   $$R_r = Ae^{-Q/RT} \tag{10.2}$$

   2) Where the rate of material thickness change is dependent on the thickness of the reaction product, the reaction rate may be fit to a form shown in Equation (10.3) based on measurements or literature.

   $$R_r = B \cdot t^{1/2} \cdot e^{-Q/RT} \tag{10.3}$$

i) If a Level 2 or 3 Assessment is performed, then the grain size, carbon content, and heat treatment conditions should be considered.

j) If a Level 2 or 3 Assessment is performed for a weldment, then the following information should be considered.

   1) The weld joint geometry.

   2) Composition of the deposit, especially carbon and oxygen contents, and tramp elements and possible resulting embrittlement.

   3) Welding process used during fabrication.

   4) The effect of creep rate mismatch between the base metal and weld metal or HAZ on the remaining life.

   5) The stress concentration at the toe of the weld.

   6) The effect of radial (offset) and angular (peaking) misalignment at the weld joint, shell out-of-roundness, and other geometrical imperfections on the remaining life (see Part 8).

   7) Inspection records.

   8) Post weld heat treatment originally used at the time of construction.

   9) Repair history including subsequent PWHT information.

   10) Residual stress effects.

   11) The effects of precipitates in welds or inclusions on void formation that may result in a reduction in the remaining life.

10.3.6.2 Supplemental requirements for a component with a crack-like flaw

a) A determination should be made whether the crack-like indication is an original fabrication flaw or service damage induced. If the origin of the crack-like indication cannot be established, then it shall be classified as a service-induced flaw.

b) If a crack-like flaw is in the vicinity of a weld, the location of the flaw, in the heat affected zone, at the fusion line, or in the deposit shall be recorded. In addition, the crack-like flaw length and depth, and location from the surface for an embedded flaw shall be established in accordance with Part 9.

10.3.7 Recommendation for Inspection Technique and Sizing Requirements

10.3.7.1 General requirements for all components

Inspection should be performed to establish the component condition and any detectable damage.

a) Wall Thinning – straight beam ultrasonic thickness examination (UT).

b) Crack-Like Flaws (see Part 9, paragraph 9.3.7 for additional information).

   1) Surface Cracks – The crack length, angle relative to the principal stress direction (see Part 9, Figure 9.2) and distance to other surface cracks may be determined using Magnetic Particle (MT) or Dye Penetrant (PT) examination technique. The depth and angle of the flaw relative to the surface (see Part 9, Figure 9.4) is typically determined using angle beam ultrasonic thickness (UT) examination technique.

   2) Embedded Cracks – The crack depth, length, angle, and distance to other surface breaking or embedded cracks are typically determined using angle beam ultrasonic thickness (UT) examination technique (e.g., time-of-flight-diffraction (TOFD) or pulse echo techniques). The calibration settings may need to be more sensitive than are used for new construction weld quality inspections.

c) Bulging – the extent of the bulge shall be measured from a reference plane.

d) Hardness Measurements – may be taken in the field, although measurements made in the laboratory on samples of material in service are more reliable. For measurements in the field, the removal of about 0.5mm (0.02-inch) of material from the surface is recommended. All evidence of oxidation, sulfidation, carburization, nitriding, and decarburization must be removed. All measurements shall be performed in conjunction with the use of calibration blocks in the range of hardness expected.

e) Tube Diameter or Circumference Measurements – Calipers can be used to determine the diameter of a fired heater or boiler tube at orthogonal directions; however, a better method is to measure the circumference of the tube with a strap (flexible measuring tape).

   1) Strap measurements should be taken at the highest heat flux areas of tubes. This type of measurement can be related to the swelling and creep in the tube, although complexities arise when there is external oxidation on the tube surface or the tube has ovalized in service due to non-uniform circumferential heating. Therefore, in certain cases, strap measurements are not considered to be a quantitative measure of strain, but are instead performed to provide an indication of overheating or a qualitative measure of creep damage.

   2) Strap measurements taken at defined locations on new tubes (baseline measurements) and subsequently at different points in time can provide an indication of creep damage if ovalization or other damage has not occurred.

   3) Another way to determine that severe bulging and creep damage has not occurred is to use a set of no-go gauges preset at a given percent (%) strain (for example 2%) that can easily be slipped over

the tube and slid along the tube length. The location and extent of uneven bulging should be recorded.

4) The level of acceptable strain varies greatly amongst the tube materials and the operating conditions. For heater tubes made of HK alloys, the amount of strain at failure can be as low as 0.5%, so there are limitations to using strapping as a stand-alone method for deciding on when tube replacement is warranted.

10.3.7.2 Nondestructive material examination by means of replication is a metallographic examination method that exposes and replicates the microstructure of the surface material.

a) Method – Portable equipment is typically used for the examination. Surface preparation is conducted by progressive grinding to remove scale, surface carburization, and other surface material. After final grinding, the surface must be polished in the following ways; electrolytic polishing or mechanical polishing using polishing discs and diamond paste (i.e. particle size of 1μ to 7μ). After polishing, the surface must be cleaned thoroughly and dried. It is particularly important to thoroughly clean the surface after electro-polishing to prevent corrosion on the newly polished surface by the aggressive electrolyte. A strip of acetate tape is softened in a solvent and pressed against the polished surface. Once the tape dries it is removed and can be viewed under the optical or electron microscope when vapor deposit coated with carbon or gold.

b) Application – The replication method can be used for the examination of all metallic materials. Replication is typically used to establish microstructure of the materials and to determine if cavities or cracks are present. This method is restricted to relatively small areas for examination; however, many replicas can be taken to ensure coverage of a large area. Replication can be used as a follow-up to other detection methods such as magnetic particle or eddy current. Surface cracks can be identified at a much earlier stage using the replication method than with other NDE methods. This early detection allows time to plan repairs and/or replacements thus avoiding unscheduled repairs.

c) Flaw Detection – Because each type of crack has specific characteristics, a damage type determination is usually possible with this method. If further evaluation is desired for metallurgical and microstructural components, such as carbides, cavities, etc., replicas can be coated with a reflective, conductive material and studied in a scanning electron microscope.

d) Limitations – The replication method can only be used on surfaces that are readily accessible. The surface conditions must be exposed, dry, and at ambient temperature, between about -18°C to 32°C (0°F to 90°F).

10.3.7.3 As an alternative to replication, small samples can be removed from the component to determine composition as well as microstructure. However, it should be noted that repair of this area may be required unless the region can be qualified for continued operation with a Level 3 Assessment.

10.3.7.4 Supplemental requirements for a component with a crack-like flaw

a) Detection and sizing of crack-like flaws originating in creep service requires validation and qualification of procedures and personnel. Service-induced cracks may not be good planar reflectors, and they may not be located in regions easily accessed by shear wave.

b) Surface cracks may be characterized by magnetic particle, dye penetrant, eddy current, or ultrasonic examination, or by replication. Subsurface cracks may be characterized using UT. If crack-like indications are found, the location, length, position relative to surface, and extent must be determined. Position relative to a weld or discontinuity must be recorded.

c) Automated TOFD can be effectively used for rapid screening of aligned clusters of small cavities. High frequency composite transducers may be used for detection of low levels of aligned cavitation. Focus beam transducers may be used for early stage damage characterization, provided the signal responses have been characterized and validated.

10.4 Assessment Techniques and Acceptance Criteria

10.4.1 Overview

The FFS assessment procedures used to evaluate the remaining life of a component operating in the creep range are described below. The three assessment levels used to evaluate creep damage are based on the data and details required for the analysis, whether the component contains a crack-like flaw, the degree of complexity required for a given situation, and the perceived risk (see API RP 580 or API RP 581).

a) Level 1 Assessments are based on a comparison with specified time-temperature-stress limits and a simplified creep damage calculation for components subject to multiple operating conditions, i.e. temperature and applied stress combinations. In addition, a check on material properties in terms of hardness or carbon content and a visual examination of the component is made in order to evaluate the potential for creep damage based on component distortion and material characteristics such as discoloration or scaling.

b) Level 2 Assessments can be used for components operating in the creep regime that satisfy the requirements of paragraph 10.2.2.2. The stress analysis for the assessment may be based on closed form stress solutions, reference stress solutions, or solutions obtained from finite element analysis.

c) Level 3 Assessments can be used to evaluate those cases that do not meet the requirements of Level 1 or Level 2 assessments. A detailed stress analysis is required to evaluate creep damage, creep-fatigue damage, creep crack growth, and creep buckling. In addition, a separate procedure is provided to perform a creep-fatigue assessment of a dissimilar-weld joint.

10.4.2 Level 1 Assessment

10.4.2.1 The Level 1 assessment for a component subject to a single design or operating condition in the creep range is provided below.

a) STEP 1 – Determine the maximum operating temperature, pressure, and service time the component is subject to. If the component contains a weld joint that is loaded in the stress direction that governs the minimum required wall thickness calculation, then 14ºC (25ºF) shall be added to the maximum operating temperature to determine the assessment temperature. Otherwise, the assessment temperature is the maximum operating temperature. The service time shall include past and future planned operation.

b) STEP 2 – Determine the nominal stress of the component for the operating condition defined in STEP 1 using Annex 2C. The computed nominal stress shall include the effects of service-induced wall thinning.

c) STEP 3 – Determine the material of construction for the component and find the figure with the screening and damage curves to be used for the Level 1 assessment from Figures 10.3 through 10.26.

d) STEP 4 – Determine the maximum permissible time for operation based on the screening curve obtained from STEP 3, the nominal stress from STEP 2, and the assessment temperature from STEP 1. If the time determined from the screening curve exceeds the service time for the component from STEP 1, then the component is acceptable per the Level 1 Assessment procedure. Otherwise, go to STEP 5.

e) STEP 5 – Determine the creep damage rate, R_c and associated creep damage D_c for the operating condition defined in STEP 1 using the damage curve obtained from STEP 3, the nominal stress from STEP 2, and the assessment temperature from STEP 1. The creep damage for this operating condition shall be computed using Equation (10.4) where the service exposure time is determined from STEP 1.

$$D_c^{total} = R_c \cdot t_{se} \tag{10.4}$$

f) STEP 6 – If the total creep damage determined from STEP 5 satisfies Equation (10.5), then the component is acceptable per the Level 1 Assessment procedure. Otherwise, the component is not acceptable and the requirements of paragraph 10.4.2.3 shall be followed.

$$D_c^{total} \le 0.25 \tag{10.5}$$

10.4.2.2 The Level 1 assessment for a component subject to a multiple design or operating conditions in the creep range is shown below.

a) STEP 1 – Determine the maximum temperature, pressure, and service time for each operating condition the component is subject to. Define j as the operating condition number and J as the total number of operating conditions. If the component contains a weld joint that is loaded in the stress direction that governs the minimum required wall thickness calculation, then 14ºC (25ºF) shall be added to the operating temperature to determine the assessment temperature. Otherwise, the operating temperature is the assessment temperature. The service exposure time for each design or operating condition, t_{se}^j, shall include past and future planned operation.

b) STEP 2 – Determine the nominal stress of the component for each of the operating conditions defined in STEP 1 using Annex 2C. The computed nominal stress shall include the effects of service-induced wall thinning.

c) STEP 3 – Determine the material of construction for the component and find the figure with the damage curves to be used for the Level 1 assessment from Figures 10.3 through 10.25.

d) STEP 4 – Determine the creep damage rate, R_c^j and associated creep damage D_c^j for each of the j operating conditions defined in STEP 1 using the damage curve obtained from STEP 3, the nominal stress from STEP 2, and the assessment temperature from STEP 1. The creep damage for each operating condition, j, can be computed using Equation (10.6) where the service exposure time is determined from STEP 1.

$$D_c^j = R_c^j \cdot t_{se}^j \tag{10.6}$$

e) STEP 5 – Determine the creep damage for total number of operating conditions, J, using Equation (10.7).

$$D_c^{total} = \sum_{j=1}^{J} D_c^j \tag{10.7}$$

f) STEP 6 – If the total creep damage determined from STEP 5 satisfies Equation (10.8), then the component is acceptable per the Level 1 Assessment procedure. Otherwise, the component is not acceptable and the requirements of paragraph 10.4.2.3 shall be followed.

$$D_c^{total} \le 0.25 \tag{10.8}$$

10.4.2.3 If the component does not meet the Level 1 Assessment requirements, then the following, or combinations thereof, can be considered:

a) Rerate, repair, replace, or retire the component.

b) Adjust the future operating conditions, the corrosion allowance, or both; note that this does not apply if $D_c^{total} > 0.25$ based on the current operating time.

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

10.4.3 Level 2 Assessment

10.4.3.1 The Level 2 assessment procedure shall be performed in accordance with paragraph 10.5.2.3. The temperature of the component used in the assessment is assumed to be uniform for each specific time step.

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

a) Rerate, repair, replace, or retire the component.

b) Adjust the future operating conditions, the corrosion allowance, or both; note that this does not apply if $D_c^{total} > D_c^{allow}$ based on the current operating time.

c) Conduct a Level 3 Assessment.

10.4.4 Level 3 Assessment

10.4.4.1 The Level 3 Assessment procedures are covered in paragraph 10.5. With the exception of the procedure for the evaluation of dissimilar metal welds, these procedures can also be used to evaluate a component containing one or more of the flaws listed in paragraph 10.2.2.1.d. If the flaw is volumetric (i.e. LTA, pitting damage, weld misalignment, out-of-roundness, bulge, dent, or dent-gouge combination), then the stress analysis model used to evaluate the remaining life shall include the flaw so that localized stresses and strains are accounted for. These stress results are then directly used in the assessment. If the component contains a crack-like flaw, then the stress analysis used for remaining life can be based on an uncracked body analysis. The effects of the crack are accounted for in the assessment procedure.

10.4.4.2 If the component does not meet the Level 3 Assessment requirements, then the following, or combinations thereof, can be considered:

a) Rerate, repair, replace, or retire the component.

b) Adjust the future operating conditions, the corrosion allowance, or both; note that this does not apply if $D_c^{total} > D_c^{allow}$ based on the current operating time.

10.5 Remaining Life Assessment

10.5.1 Overview

10.5.1.1 A remaining life calculation is required for all components operating in the creep range. The assessment procedures in paragraph 10.4 are limited to components that are not subject to significant cyclic operation and/or components that do not contain crack-like flaws.

10.5.1.2 The assessment procedures described in this paragraph provide the best estimate of the structural integrity of a component operating at elevated temperature. Five assessment procedures are provided.

a) *Creep Rupture Life* – The assessment procedure is given in paragraph 10.5.2, and is applicable to components that are subject to steady-state operation in the creep range which do not have crack-like flaws.