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The Occupational Safety
& Health Standards Board

The Equity Engineering Group, Inc.

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July 28, 2021

California Occupational Safety and Health Standards Board
2520 Venture Oaks Way, Suite 350
Sacramento, California

SUBJECT: PETITION FOR MODIFICATIONS TO TITLE 8, CHAPTER 4, SUBCHAPTER 15, ARTICLE 18, SECTION 6857 REFERENCES TO FITNESS-FOR-SERVICE ASSESSMENTS

To Whom It May Concern,

This letter is a formal petition for modification to the applicable Fitness-For-Service (FFS) procedures referenced in California Code of Regulations Title 8, Chapter 4 *Division of Industrial Safety*, Subchapter 15 *Petroleum Safety Orders –Refining, Transportation and Handling*, Article 18 *Unfired Pressure Vessels, Boilers, and Fired Pressure Vessels and Pressure Relief Valves*, Section 6857 *Vessels, Boilers, and Pressure Relief Devices*.

INTRODUCTION AND BACKGROUND

E²G | The Equity Engineering Group, Inc. is an employee-owned engineering firm whose focus is on providing specialized engineering consulting services and products for new and aging infrastructure in the refining and petrochemical industries. We develop technologies to solve challenging industry problems, promote safety, and reduce risk to people and the environment. E²G was the lead investigator for the landmark API 579 *Recommended Practice for Fitness-For-Service* (API RP579) published in 2000. E²G's president and CEO, Mr. David Osage, ASME Fellow, P.E., has served as Chair and Vice-Chair of the ASME/API Joint FFS Committee (FFSJC). Mr. Osage continues to serve as the technical editor for the API 579-1/ASME FFS-1 (API 579) FFS Standard. E²G has two (2) additional members on the API 579 FFSJC and several additional contributing members.

California Code of Regulations Title 8, Chapter 4, Subchapter 15, Article 18, Section 6857, paragraph (c)(1) states "Maintenance, inspection, and repair procedures of unfired pressure vessels shall comply with API 510, Pressure Vessel Inspection Code, Eighth Edition, June 1997, Addendum 4, August 2003; API 580, Risk-based Inspection, Recommended Practice, First Edition, May 2002; **API 579, Fitness-for-Service, Recommended Practice, First Edition, January 2000**; or the National Board Inspection Code/American National Standard ANSI/NB-23, 2004 Edition; which are hereby incorporated by reference." There are several subsequent references to the 2000 edition of API RP579 within Section 6857. The 2000 edition of API RP579 was replaced in 2007 with the first edition of the ASME/API jointly approved API 579 FFS Standard. In 2016, the second edition of API 579 was published. The ASME/API FFSJC is targeting publication of the third edition of API 579 by the end of 2021.

SUBSTANCE OR NATURE OF THE STANDARD, AMENDMENT, OR REPEAL REQUESTED

It is proposed that all references in California Code of Regulations Title 8, Chapter 4, Subchapter 15, Article 18, Section 6857 related to the execution of FFS assessments shall refer to "the latest edition of the API 579-1/ASME FFS-1 *Fitness-For-Service* Standard" as opposed to the 2000 edition of API RP579.

REASON FOR THE REQUEST

The 2000 edition of API RP579 was the first publication of an API document dedicated solely to providing guidance on FFS assessment procedures for equipment found to have damage or defects. The document was published as a Recommended Practice and was intended to supplement and augment the requirements in API 510, API 570 and API 653: "*(i) to ensure safety of plant personnel and the public while older equipment continues to operate; (ii) to provide technically sound Fitness-For-Service assessment procedures to ensure that different service providers furnish consistent life predictions; and (iii) to help optimize maintenance and operation of existing facilities, maintain availability of older plants, and enhance long-term economic viability*."

In addition to leveraging advances in FFS technology, there have been numerous corrections to procedures that were found to be insufficient since the initial edition of API RP579 was published in 2000. API RP579 was replaced in 2007 with the first edition of the ASME/API jointly approved API 579 FFS standard. Corrections, modifications, and enhancements included in the 2007 edition of API 579 are summarized in PVP2008-61796 [1]. The second edition to API 579 was published in 2016. Again, numerous corrections, modifications, and enhancements were included. A summary of changes is provided in PVP2014-28451 [2]. The ASME/API FFSJC is targeting publication of the third edition of API 579 by the end of 2021. A summary of changes is provided in [3].

There are currently numerous instances where results obtained using the 2000 edition of API RP579 would no longer be found to be acceptable per the current procedures and acceptance criterion in the 2016 edition of API 579. In the up-coming publication of the third edition of API 579 (targeted for 2021), there will be several additional instances where results obtained from an assessment completed per the 2000 edition of API RP579 will no longer be considered acceptable. Some examples are listed below for general reference:

- The ability to utilize allowable stress values from ASME Section VIII, Division 2 (ASME VIII-2) for evaluation of equipment built to ASME Section VIII, Division 1 will no longer be permitted. Since the allowable stress criterion in ASME VIII-2 was reduced in 2007, the ASME/API FFSJC determined that the resultant factor of safety obtained after employing both the post-2007 ASME VIII-2 allowable stress criteria and API 579 FFS procedures would be inappropriate for pressure vessels designed and constructed to ASME VIII-1.
- The brittle fracture screening procedures for establishing minimum permissible temperature limits will be more restrictive for some components (e.g. ASME B16.5 flanges, pressure vessel nozzle reinforcement zones, etc.). The ASME/API FFSJC determined that the current procedures were inadequate in qualifying for protection from potential brittle fracture failures.

- The coefficient of variation (COV) criteria employed to justify use of point thickness readings in a general metal loss assessment will be replaced with a more conservative qualification on the minimum measured thickness. The ASME/API FFSJC determined that the COV was insufficient in classifying damage as general metal loss compared to local metal loss and there was opportunity for misapplication of the current assessment procedures.
- The thickness averaging procedure for evaluation of wall loss near a pressure vessel nozzle junction will be more stringent. The ASME/API FFSJC determined that the current published procedure could, under certain circumstances, permit more extensive wall loss near the nozzle junction as opposed to away from the nozzle junction and thus not in alignment with the intent of the FFS procedures.
- Numerous changes have been made to the procedures and critical input parameters associated with the evaluation of crack-like flaws. The ASME/API FFSJC identified errors in the current published procedures that in some instances may provide non-conservative results.

Lastly, there is currently no guidance in the California Code of Regulations on how to evaluate damage mechanisms not addressed in the 2000 edition of API RP579. For example, the following damage mechanisms are addressed in the 2016 edition of API 579 (and will be included in the next release of API 579), but these damage mechanisms are not addressed in the 2000 edition of API RP579:

- Creep due to high temperature operation
- Hydrogen Induced Cracking (HIC) and Stress Oriented Hydrogen Induced Cracking (SOHIC) due to low temperature hydrogen damage
- Fatigue due to cyclic operation
- Dents, gouges, and dent-gouge combinations due to mechanical damage

Changing the language in the California Code of Regulations to reference the latest edition of API 579-1/ASME FFS-1, *Fitness-For-Service* will ensure that fitness-for-service assessments are performed in accordance with state-of-the-art technology and best engineering practice, as agreed upon by the ASME/API FFSJC.

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Thank you in advance for your consideration. If there is any additional information needed, or if there is anything additional that we can do to help, please do not hesitate to contact the undersigned at bmacejko@e2g.com or 216.658.4765.

Sincerely,

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Consulting Engineer

Phillip E. Prueter, P.E. (CA-Mechanical)
Principal Engineer

David A. Osage, ASME Fellow, P.E. (OH)
Corporate Principal Engineer

REFERENCES

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API 579-1/ASME FFS-1 2007 – A JOINT API/ASME FITNESS FOR SERVICE STANDARD FOR PRESSURIZED EQUIPMENT

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ABSTRACT

The first edition of API 579 *Recommended Practice for Fitness-For-Service* was published in 2000. Work on the second edition of API 579 was initiated the same year with many planned technical improvements. In addition to technical improvements, API and ASME agreed to form a joint committee to produce a joint API/ASME FFS Standard that can be used for pressure-containing equipment. This new standard designated as API 579-1/ASME FFS-1 2007 *Fitness-For-Service* is based on the first edition of API 579, incorporates all planned technical enhancements originally slated for the second edition, and also includes modifications to address the special needs of other industries such as the fossil electric power industry, and the pulp and paper industry. Insights into the driving force to create API 579 and an overview of the technical enhancements that will be incorporated into API 579-1/ASME FFS-1 are presented in this paper. The use of the API 579-1/ASME FFS-1 fitness-for-service assessment procedure models to establish a probability of failure for use with the API Risk Based Inspection Planning Technology is also provided.

INTRODUCTION

The ASME and API design codes and standards for pressurized equipment provide rules for the design, fabrication, inspection, and testing of new pressure vessels, piping systems, and storage tanks. These codes typically do not provide assessment procedures to evaluate degradation due to in-service environmentally-induced damage, or flaws from original fabrication that may be found during subsequent inspections. Fitness-For-Service (FFS) assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. The first edition of API 579 *Recommended Practice for Fitness-For-Service* [1] published in 2000 (API 579 2000) was developed to provide guidance for conducting FFS assessments of flaws commonly encountered in the refining and petrochemical industry that occur in pressure vessels, piping, and tankage. However, the assessment procedures have been used to evaluate flaws encountered in other industries such as the pulp and paper industry, fossil electric power industry, and nuclear industry. The results from a FFS assessment may be used to make run, rerate, repair, or replace decisions to ensure that pressurized equipment containing flaws that have been identified during an inspection can continue to be operated safely.

API 579 2000 produced by API Committee on Refinery Equipment (CRE) Fitness-For-Service (FFS) Task Group has become the de facto international FFS Standard for pressure containing equipment in the refining and petrochemical industries. Based on advances in technology and User feedback, the API CRE FFS Task Group initiated an effort to produce the second edition of API 579 in 2001. The work to produce an updated version continued within this Task Group until 2002 when a joint API and ASME FFS Standard committee was formed to complete this task.

NEW JOINT API AND ASME FFS STANDARD

In 1995, the ASME Board on Pressure Technology Codes and Standards (BPTCS) formed the Post Construction Committee

(PCC). The scope of this committee is to develop and maintain standards addressing common issues and technologies related to post-construction activities and to work with other consensus committees in the development of separate, product-specific codes and standards addressing issues encountered after initial construction for equipment and piping covered by BPTCS.

A new FFS standards committee was started under PCC with membership from ASME and the API CRE FFS Task Group. With two FFS standards development activities in place, many members found themselves working on two separate committees. Subsequently, coordination, utilization of committee member time, funding, and the overall development process to produce a new FFS standard became ineffective. In order to streamline development efforts, pool resources, and promote widespread regulatory acceptance, API and ASME agreed to form a joint committee to produce a single FFS standard that can be used for pressure-containing equipment for all industries.

The first meeting of the Joint API/ASME FFS Committee (FFSJC) took place in February, 2002. Oversight of the FFSJC is undertaken by the API CRE and ASME Board on Pressure Technology Codes and Standards. This oversight includes approval of committee membership and all standards actions.

The FFSJC has produced a new FFS standard entitled API 579-1/ASME FFS-1 2007 *Fitness-For-Service* [2]. API 579 2000 was the basis of this new standard. The API 579-1/ASME FFS-1 2007 standard will include all topics currently contained in the first edition of API 579 and will also include new parts covering FFS assessment procedures that address unique damage mechanisms experienced by other industries. API 579-1/ASME FFS-1 was released in June 2007. API 579-1/ASME FFS-1 2007 superseded API 579-2000.

The agreement to produce a joint standard on FFS technology is a landmark decision that will focus resources to develop a single document that can be used in all industries. This agreement will help avoid jurisdictional conflicts and promote uniform acceptance of FFS technology. It will also provide an opportunity for pooling of resources of API, ASME, the Pressure Vessel Research Council (PVRC), and the Materials Property Council (MPC) to develop new FFS technology as required by the new joint committee.

OVERVIEW OF API 579-1/ASME FFS-1

Applicable Codes

API 579-1/ASME FFS-1 provides guidelines for performing FFS assessments that can be used in conjunction with the applicable in-service inspection code to determine the suitability for continued operation. The assessment procedures in this recommended practice can be used for FFS assessments and/or rerating of components designed and constructed to the design codes shown below.

- ASME B&PV Code, Section VIII, Division 1
- ASME B&PV Code, Section VIII, Division 2
- ASME B&PV Code, Section I
- ASME B31.3 Piping Code
- ASME B31.1 Piping Code
- API 650
- API 620

The assessment procedures in API 579-1/ASME FFS-1 may also be applied to pressure-containing equipment constructed to other recognized codes and standards including international and internal corporate standards. API 579-1/ASME FFS-1 has broad application since the assessment procedures are based on allowable stress based methods or plastic collapse analysis for non-crack-like flaws, and FAD-based assessment procedures for crack-like flaws.

Organization

API 579-1/ASME FFS-1 is a highly structured document designed to facilitate use by practitioners and to facilitate future enhancements and modifications by the FFSJC. Part 1 of the document covers: introduction and scope; responsibilities of the Owner-User, Inspector, and Engineer; qualification requirements for the Inspector and Engineer; and references to other codes and standards. An outline of the overall FFS assessment methodology that is common to all assessment procedures included in API 579-1/ASME FFS-1 is provided in Part 2 of the document. The organization of Part 2 is shown in Table 1. This same organization is utilized in all subsequent parts that contain FFS assessment procedures.

Starting with Part 3, a catalogue of FFS assessment procedures organized by damage mechanism is provided in API 579-1/ASME FFS-1. A complete listing of the flaw and damage assessment procedures currently covered is shown in Table 2. When assessment procedures are developed for a new damage mechanism, they will be added as a self-contained part to maintain the structure of document. Annexes are provided with technical information that can be used with the parts of API 579-1/ASME FFS-1 that provide FFS assessment procedures. The majority of the information in the appendices covers stress analysis techniques, material property data, and other pertinent information that is required when performing a FFS assessment. An overview of the appendices is provided in Table 3.

Assessment Levels

Three levels of assessment are provided in API 579-1/ASME FFS-1 for each flaw and damage type. In general, each assessment level provides a balance between conservatism, the amount of information required for the evaluation, the skill of the practitioner performing the assessment, and the complexity of analysis being performed. Level 1 is the most conservative and the easiest to use. Practitioners usually proceed sequentially from a Level 1 to a Level 3 assessment (unless otherwise directed by the assessment techniques) if the current assessment level does not provide an acceptable result or a clear course of action cannot be determined.

It should be noted that the definitions of assessment levels in API 579-1/ASME FFS-1 are significantly different than those used in other standards. A general overview of each assessment level and its intended use is described below.

- Level 1 – The assessment procedures included in this level are intended to provide conservative screening criteria that can be utilized with a minimum amount of inspection or component information. The Level 1 assessment procedures may be used by either plant inspection or engineering personnel.
- Level 2 – The assessment procedures included in this level are intended to provide a more detailed evaluation that produces results that are less conservative than those from a Level 1 assessment. In a Level 2 assessment, inspection information similar to that required for a Level 1 assessment is required; however, more detailed calculations are used in the evaluation. Level 2 assessments are typically conducted by plant engineers or engineering specialists' experienced and knowledgeable in performing FFS assessments.
- Level 3 – The assessment procedures included in this level are intended to provide the most detailed evaluation and produce results that are less conservative than those from a Level 2 assessment. In a Level 3 assessment, the most detailed inspection and component information is typically required. The recommended analysis is based on numerical techniques such as the finite element method. The Level 3 assessment procedures are primarily intended to be used by engineering specialists experienced and knowledgeable in performing FFS evaluations.

Remaining Life and Rerating

The FFS assessment procedures in API 579-1/ASME FFS-1 cover both the present integrity of the component given a current state of damage and the projected remaining life. If the results of a FFS assessment indicate that the equipment is suitable for the current operating conditions, the equipment can continue to be operated at these conditions if a suitable inspection program is established. If the results of the FFS assessment indicate that the equipment is not suitable for the current operating conditions, calculation methods are provided in API 579-1/ASME FFS-1 to rerate the component. For pressurized components (e.g. pressure vessels and piping) these calculation methods can be used to find a reduced maximum allowable working pressure and/or coincident temperature. For tank components (i.e., shell courses) the calculation methods can be used to determine a reduced maximum fill height.

In API 579-1/ASME FFS-1, the remaining life calculation is used to establish an appropriate inspection interval in conjunction with the applicable in-service inspection code, provide information for an in-service monitoring plan, or to establish the need for remediation. API 579-1/ASME FFS-1 emphasizes the need for remediation where the remaining life cannot be established. Remediation can be in the form of altering the process stream, or isolating the process stream from the pressurized component by installation of a coating or lining, or application of weld overlay. API 579-1/ASME FFS-1 also emphasizes the need for monitoring and inspection to validate the assumptions made about continuing damage.

Relationship to Other FFS Standards

The FFSJC members agreed that alternate FFS approaches may be appropriate for use by more advanced practitioners. Therefore, the Level 3 assessment in API 579-1/ASME FFS-1 permits the use of alternative FFS assessment methodologies. For example, the Level 3 assessment in Part 9 covering crack-like flaws provides references to Nuclear Electric R-6 [4], BS 7910 [5], SAQ/FoU-Report 96/08 [6], WES 2805 [7], EPRI J-Integral Methodology [8], and A16 [9].

The European Community sponsored a project known as FITNET to review the existing FFS procedures and develop an updated, unified and verified European FITNET FFS Procedure [10] to cover structural integrity analysis to avoid failures due to fracture, fatigue, creep and corrosion. After final approval and publication of the FITNET FFS Procedure, the FFSJC will undertake an effort to review the procedure and make a recommendation on whether to reference the procedure under a Level 3 Assessment, as applicable, in the next edition of API 579-1/ASME FFS-1.

NEW DEVELOPMENTS FOR API 579-1/ASME FFS-1

Many new developments are being incorporated into API 579-1/ASME FFS-1, and are summarized in Table 2 and Table 3. Many of these new developments were made based on a technical gap analysis performed by the API CRE FFS Committee with feedback from the API 579 User community and input from the FFSJC. The most significant changes will be the introduction of four new parts in the document covering assessment procedures for:

- Assessment of HIC/SOHIC damage,
- Assessment of creep damage,
- Assessment of dents, gouges, and dent-gouge combinations, and
- Assessment of laminations.

Sections in API 579 2000 have been renamed as Parts in API 579-1/ASME FFS-1 to avoid confusion when referring to ASME B&PV Codes, and Appendices in API 579 2000 have been renamed as Annexes in API 579-1/ASME FFS-1.

In addition to technical changes, the example problems currently provided in each part of API 579 2000 have not been included in API 579-1/ASME FFS-1. Alternatively, a comprehensive set of example problems will be published as a separate document. This change is being made because of the space the example problems occupy and the request by the User community for additional example problems. A complete set of example problems is crucial to the deployment of any standard because these problems not only demonstrate proper use of the rules in the document but also provide a means to benchmark computer programs developed to automate assessment procedures.

TECHNICAL BASIS AND VALIDATION OF API 579 FFS ASSESSMENT METHODS

The technical basis and experimental validation of the FFS assessment procedures are summarized in Annex H of API 579-1/ASME FFS-1 and are published in a series of WRC Bulletins, see Table 4. The API CRE FFS Committee is committed to publishing in the public domain the technical background to all FFS assessment procedures utilized in API 579-1/ASME FFS-1. It is hoped that other FFS standards writing committees adopt the same policy as it is crucial that FFS knowledge remains at the forefront of technology on an international basis to facilitate adoption by jurisdictional authorities.

UNDERSTANDING OF DAMAGE MECHANISMS

The first step in a FFS assessment performed in accordance with API 579-1/ASME FFS-1 is to identify the flaw type and cause of damage. When conducting a FFS assessment it is important to determine the cause(s) of the damage or deterioration observed and the likelihood and degree of further damage that might occur in the future. In order to assist the practitioner in this step, WRC Bulletins 488 [11], 489 [12], and 490 [13] have been published to cover damage mechanisms in the pulp and paper industry, the refining and petrochemical industry, and the fossil electric power industry, respectively, to provide guidance to the practitioner for the combined considerations of:

- Practical information on damage mechanisms that can affect process equipment,
- Assistance regarding the type, extent, and time-dependency of damage that can be expected, and
- How this knowledge can be applied to the selection of effective inspection methods to detect, size, and characterize the damage.

WRC Bulletin 489 has also been published as API 571 *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry* [14]. This document is currently being updated to provide guidelines for NDE, both detection and flaw sizing, for each damage mechanism. These guidelines are intended to supplement the NDE provisions in API 579-1/ASME FFS-1.

IN-SERVICE INSPECTION CODES AND FITNESS-FOR-SERVICE

API 579-1/ASME FFS-1, like its predecessor API 579 2000, is intended to supplement the requirements in API 510 *Pressure Vessel Inspection Code: Maintenance Inspection, Rerating, Repair and Alteration* [15], API 570 *Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems* [16], API 653 *Tank Inspection, Repair, Alteration, and Reconstruction* [17], and ANSI/NB-23 *National Board Inspection Code* [18] to ensure safety of plant personnel and the public while older equipment continues to operate; to provide technically sound FFS assessment procedures; to ensure that different service providers furnish consistent remaining life predictions; and to help optimize maintenance and operation of existing facilities to maintain availability of older plants and enhance long-term economic viability. The benefits of having a comprehensive FFS document that is tightly integrated with the in-service inspection codes are:

- Ease of use in assessing flaws and damage mechanisms including jurisdictional acceptance,
- Extended safe operation of damaged equipment based on industry accepted assessment methods,
- Flexibility in developing tactics for repair and/or replacement of damaged equipment,
- New basis for inspection planning, and
- Turnaround support decision making with a goal to minimize turnaround scope and length.

In addition, API 579-1/ASME FFS-1 will be used in conjunction with API 580 *Recommended Practice for Risk-Based Inspection* [19], and API 581 *API RBI Technology* [20] to provide guidelines for risk assessment and prioritization for inspection and maintenance planning for pressure-containing equipment.

FFS AND RBI – COMPLEMENTARY TECHNOLOGIES

Overview

The FFS and RBI relationship depends upon the type of RBI study. In a RBI study using a qualitative evaluation, FFS assessment procedures can be used to alter the risk-ranking of equipment based on the level of damage and the results of the assessment. In a RBI study using a quantitative evaluation, the FFS assessment procedures provide a damage model that can be used to establish a probability of failure. The probably of failure results can be combined with a consequence of failure model to produce risk, which can be utilized to develop an inspection plan as described by Osage and Henry [21]. Inspection planning involves determining the scope, method of inspection, and inspection interval for a piece of equipment.

Determination of Probability of Failure using FFS Damage Models

As described by Osage and Henry [21], the calculation of risk in API RBI is determined as a function of time in accordance with Equation (1). This equation combines the probability of failure and the consequence of failure as described elsewhere within this paper.

$$R(t) = P_f(t) \cdot C(t) \tag{1}$$

The consequence of failure, $C(t)$, is assumed to be invariant with time. Therefore, Equation (1) can be rewritten as shown in Equations (2) and (3) depending on whether the risk is expressed as an impact area or in financial terms.

$$R(t) = P_f(t) \cdot CA \quad for\ \ Area - Based\ \ Risk \tag{2}$$

$$R(t) = P_f(t) \cdot FC \quad for\ \ Financial - Based\ \ Risk \tag{3}$$

In these equations, CA is the consequence impact area expressed in units of area and FC is the financial consequence expressed in economic terms. Note that in Equations (2) and (3), the risk is varying with time since the probability of failure is a function of time.

In API RBI the probability of failure as a function of time is computed from Equation (4).

$$P_f(t) = gff \cdot D_f(t) \cdot F_{MS} \tag{4}$$

In this equation, the probability of failure, $P_f(t)$, is determined as the product of a generic failure frequency , gff , a damage factor, $D_f(t)$, and a management systems factor, F_{MS}.

As an alternate, probability of failure as a function of time may be calculated from a structural reliability model based on the damage mechanism present. The structural reliability model in general terms is formulated in terms of a limit state defined as a resistance term minus a driving force term as shown in Equation (5).

$$G(R, L) = R - L \tag{5}$$

The resistance term may be written as an arbitrary function of independent variables r_n, or $R(r_1, r_2, ..., r_n)$, and the driving force term may also be expressed as an arbitrary function of independent variables l_n, or $L(l_1, l_2, ..., l_n)$.

For a damaged component subject to applied loads, the independent variables in the resistance term typically consist of component geometry, material properties, and a measure of the damage (e.g. for general corrosion a measure of damage is the metal loss). The independent variables in the driving force term are typically the applied loads.

For general metal loss in a cylindrical shell, the resistance term and driving force term are given by Equations (6) and (7) , respectively.

$$R(R_o,\ t,\ d_G,\ n,\ \sigma_{uts}) = \left[\frac{0.25}{n+0.277}\right]\left[\frac{e}{n}\right]^n \cdot \ln\left[\frac{R_o}{R_o - t + d_G}\right] \cdot \sigma_{uts} \tag{6}$$

$$L(P_{applied}) = P_{applied} \tag{7}$$

Substituting Equations (6) and (7) into Equation (5), the limit state is given by Equation (8).

$$G(R, L) = \left(\left[\frac{0.25}{n+0.277}\right]\left[\frac{e}{n}\right]^n \cdot \ln\left[\frac{R_o}{R_o - t + d_G}\right] \cdot \sigma_{uts}\right) - P_{applied} \tag{8}$$

In this equation, the resistance term of the limit state is a function of the cylinder geometry and material properties, and the driving force term is a function of the applied pressure. The resistance term in Equation (8) represents a simplified version of the Svensson method to compute the burst pressure of a cylindrical shell [22].

For combined general and local metal loss in a cylindrical shell, the limit state can be expressed using Equation (9).

$$G(R,L) = \left(\left[\frac{0.25}{n+0.277} \right] \left[\frac{e}{n} \right]^n \cdot \ln \left[\frac{R_o}{R_o - t + d_G} \right] \cdot \sigma_{uts} \cdot RSF(d_L, s) \right) - P_{applied} \quad (9)$$

This equation has the same basic form as Equation (8) except that a remaining strength factor term, $RSF(d_L, s)$, is introduced as a damage parameter to decrease the resistance term because a local area of metal loss is present. The remaining strength factor may be evaluated using the methods described in API 579-1/ASME FFS-1.

In the limit state function for general and local metal loss, the independent variables with the most uncertainty are the applied pressure, $P_{applied}$, and the metal loss terms d_G and d_L. The uncertainty in the metal loss terms is based on the thickness measurement, the location of the thickness measurement (i.e. the location where the thickness is measured representative of all regions in the component under evaluation), and the ability to project the metal loss as a function of time using previous thickness readings and/or estimates of corrosion rates.

As a final example, the limit state for a crack-like flaw evaluated using Part 9 of API 579-1/ASME FFS-1 is given by Equation (10).

$$G(R,L) = \left(1 - 0.14\left(L_r^P\right)^2\right)\left(0.3 + 0.7e^{-0.65\left(L_r^P\right)^6}\right) - K_r = 0 \;\; if \;\; L_r^P \le L_{r\max}^P \quad (10)$$

In Equation (10), L_r^P is the primary load ratio defined in Equation (11) and K_r is the toughness ratio defined in Equation (12).

$$L_r^P = \frac{\sigma_{ref}^P}{\sigma_{ys}} \quad (11)$$

$$K_r = \frac{K_I^P + \Psi K_I^{SR}}{K_{mat}} \quad (12)$$

In the limit state function for a crack-like flaw, the independent variables with the most uncertainty are the applied loads (i.e. primary, secondary and residual stress), the flaw size, and the material fracture toughness, K_{mat}. The stress intensity factors K_I^P and K_I^{SR} in Equation (12) are functions of the applied loads and flaw size. The process environment in the component and the associated damage mechanism may have a significant effect on the material fracture toughness and the ability to determine the flaw size. In addition, significant uncertainty in the flaw size is encountered when an estimate of flaw size as a function of time or cyclic loading is estimated using a crack growth model.

The uncertainty in the independent variables described above is typically modeled using continuous distribution functions. The most typical functions used in structural reliability analysis are the Normal, Lognormal, and Weibull distributions. The parameters for these distributions may be established based on industry data or expert solicitation. Once the limit state is determined and the uncertainty of the independent variables is modeled with a distribution function, the probably of failure may be computed using standard reliability methods [23], [24], [25].

Inspection Effectiveness – The Value of Inspection

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

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

- Lack of coverage of an area subject to deterioration,
- Inherent limitations of some inspection methods to detect and quantify certain types of deterioration,
- Selection of inappropriate inspection methods and tools,
- Application of methods and tools by inadequately trained inspection personnel,
- Inadequate inspection procedures, and
- The damage rate under some conditions (e.g. start-up, shut-down, or process upsets) may be high that failure may occur within a very short time; even if damage is not found during an inspection, failure may still occur as a result of a change or upset in conditions.

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

- Equipment type,
- Active and credible damage mechanism(s),
- Susceptibility to and rate of damage,
- NDE methods, coverage and frequency, and
- Accessibility to expected deterioration areas.

Inspection effectiveness may be introduced into the probability of failure calculation by using Bayesian analysis or more directly by modifying the model for the independent variables, the distribution function, and/or the distribution function parameters. For example, if the model for metal loss is determined to be a lognormal distribution, the distribution parameters, mean and coefficient of variation, may be changed based on the NDE method and coverage used during an inspection. Extending this concept further, a series of standard inspection categories may be defined, and the distribution parameters adjusted based on the NDE method and coverage defined for each standard category.

By identifying credible damage mechanisms, determining the damage rate, and selecting an inspection effectiveness category based on a defined level of inspection, a probability of failure may be determined. The probability of failure may be determined for future time periods or conditions as well as current conditions by projecting the damage rate and associated flaw size into the future.

CONCLUSIONS

FFS assessments are quantitative engineering evaluations which are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. API 579 2000 was developed to provide guidance for conducting FFS assessments of equipment in the refining and petrochemical industry. The assessment procedures provided in this document can be used to make run, rerate, repair or replace decisions to ensure that pressurized equipment containing flaws which have been identified by inspection can continue to be operated safely. Based on advances in technology and User feedback, an effort to produce the second edition of API 579 was initiated in 2001.

API and ASME have formed a joint committee to produce a single FFS Standard that can be used for pressure-containing equipment. API 579 2000 formed the basis of the new joint API/ASME standard. The API/ASME joint committee has produced a new FFS standard entitled API 579-1/ASMEFFS-1 2007 *Fitness-For-Service* with a publication date of June 2007.

API 579-1/ASME FFS-1 is intended to supplement and augment the requirements in API 510, API 570, API 653, and NB-23. In addition, the FFS assessment procedures provide a damage model that can be used to establish a probability of failure. The probably of failure results can be combined with a consequence of failure model to produce risk, which can be utilized to develop an inspection plan using risk-based inspection principals.

FFS is a powerful technology that can be used to extend the useful life of aging equipment or allow new equipment with flaws and/or damage to enter service without repairs. In many cases, significant savings can be realized because FFS enables the Owner-User to operate equipment until the next scheduled downtime without compromising safety and minimizing unscheduled downtimes. In many cases repair or replacement can be avoided.

NOMENCLATURE

$C(t)$	is the consequence of failure as a function of time
CA	is the consequence of failure impact area
d_G	is the general metal loss
d_L	is the local metal loss within s
$D_f(t)$	is the damage factor as a function of time
e	is the base of the natural logarithm, 2.718281828
F_{MS}	is the management systems factor
FC	is the financial consequence of failure
gff	is the generic failure frequency
$G(R,L)$	is the limit state function
K_{mat}	is the material fracture toughness
K_r	is the toughness ratio
K_I^P	is the stress intensity factor derived from primary loads
K_I^{SR}	is the stress intensity factor derived from secondary loads and residual stresses
$L(l_1, l_2, ..., l_n)$	is the load or driving force term in the limit state function
L_r^P	is the primary load ratio

$L^{P}_{r\max}$ is the maximum value permitted for the primary load ratio

n is the strain hardening coefficient that is a function of the yield and ultimate tensile strength

$P_{applied}$ is the applied pressure

$P_f(t)$ is the probability of failure as a function of time

Ψ is the plasticity interaction factor

$R(r_1, r_2, ..., r_n)$ is the resistance term in the limit state function

$R(t)$ is the risk as a function of time

$RSF(d, s)$ is the remaining strength factor as a function of d and s

R_o is the outside radius

s is the length associated with the metal loss

σ_{ys} is the yield strength

σ_{uts} is the ultimate tensile strength

σ^{P}_{ref} is the reference stress derived from primary loads

t is the wall thickness

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Table 1 – Organization of Each Part in API 579-1/ASME FFS-1 2007 Fitness-For-Service

Part Number and Title	Overview
1 – General	The scope and overall requirements for an FFS assessment are provided.
2 – Applicability and Limitations of the FFS Assessment Procedures	The applicability and limitations for each FFS assessment procedure are indicated; these limitations are stated in the front of each part for quick reference.
3 – Data Requirements	The data requirements for the FFS assessment are outlined; these data requirements include: Original equipment design data Maintenance and operational history Data/measurements for a FFS assessment Recommendations for inspection technique and sizing requirements
4 – Assessment Techniques and Acceptance Criteria	Detailed assessment rules are provided for three levels of assessment: Level 1, Level 2, and Level 3. A discussion of these assessment levels is covered in the body of this paper.
5 – Remaining Life Evaluation	Guidelines for performing a remaining life estimate are provided for the purpose of establishing an inspection interval in conjunction with the governing inspection code.
6 – Remediation	Guidelines are presented on methods to mitigate and/or control future damage. In many cases, changes can be made to the component or to the operating conditions to mitigate the progression of damage.
7 – In-Service Monitoring	Guidelines for monitoring damage while the component is in-service are provided. These guidelines are useful if a future damage rate cannot be estimated easily or the estimated remaining life is short. In-service monitoring is one method whereby future damage or conditions leading to future damage can be assessed or confidence in the remaining life estimate can be increased.
8 – Documentation	Guidelines for documentation for an assessment are provided. The general rule is that a practitioner should be able to repeat the analysis from the documentation without consulting an individual originally involved in the FFS assessment.
9 – References	A comprehensive list of technical references used in the development of the FFS assessment procedures is provided. References to codes and standards are provided.
10 – Tables and Figures	Tables and figures including logic diagrams are used extensively in each part to clarify assessment rules and procedures.

Table 2 – Overview of Flaw and Damage Assessment Procedures in API 579-1/ASME FFS-1 2007 *Fitness-For-Service*

Part And Damage Mechanism Covered	Overview	New Developments
3 – Brittle Fracture	Assessment procedures are provided to evaluate the resistance to brittle fracture of in-service carbon and low alloy steel pressure vessels, piping, and storage tanks. Criteria are provided to evaluate normal operating, start-up, upset, and shutdown conditions.	Brittle fracture rules modified to be more consistent with the current ASME Section VIII material toughness rules, and a new screening procedure for shock chilling has been developed.
4 – General Metal Loss	Assessment procedures are provided to evaluate general corrosion. Thickness data used for the assessment can be either point thickness readings or detailed thickness profiles. A methodology is provided to guide the practitioner to the Local Metal Loss assessment procedures based on the type and variability of thickness data recorded during an inspection.	Basic assessment procedures are the same. Editorial changes made to clarify requirements for evaluation of metal loss at structural discontinuities.
5 – Local Metal Loss	Assessment techniques are provided to evaluate single and networks of Local Thin Areas (LTAs) and groove-like flaws in pressurized components. Detailed thickness profiles are required for the assessment. The assessment procedures can also be utilized to evaluate blisters.	LTA rules modified to permit assessments of long flaws. New assessment procedures introduced to evaluate LTAs in cylinders subject to external pressure and to evaluate the circumferential extent of an LTA in a cylinder subject to pressure and net-section loads.
6 – Pitting Corrosion	Assessment procedures are provided to evaluate widely scattered pitting, localized pitting, pitting which occurs within a region of local metal loss, and a region of localized metal loss located within a region of widely scattered pitting. The assessment procedures can also be utilized to evaluate a network of closely spaced blisters. The assessment procedures utilize Part 5 for Local Metal Loss.	New Level 1 Assessment procedure incorporated that utilizes standard pitting charts. These pitting charts can be used by practitioners to perform a visual comparison between damage in the equipment and damage indicated by the chart. An RSF is provided for each chart. Once a chart has been chosen, the RSF can be determined based on the depth of pitting damage.
7 – Assessment Of Hydrogen Blisters And Hydrogen Damage Associated With HIC And SOHIC	Assessment procedures are provided to evaluate damage resulting from blisters, HIC damage, and SOHIC damage. The assessment guidelines include provisions for damage located at weld joints and structural discontinuities such as shell transitions, stiffening rings, and nozzles.	Assessment procedures for laminations removed and placed in Part 13. New assessment procedures developed to evaluate HIC/SOHIC damage. HIC damage will be evaluated using a modified LTA methodology. SOHIC damage will be evaluated using the principals of Part 9.
8 – Weld Misalignment and Shell Distortions	Assessment procedures are provided to evaluate stresses resulting from geometric discontinuities in shell type structures including weld misalignment and shell distortions (e.g. out-of-roundness, bulges, and dents).	Assessment procedures for dents and dent-gouge combinations removed and placed in Part 12. Assessment procedures for misalignment and out-of-roundness updated. Level 2 assessment procedure for bulges removed.
9– Crack-Like Flaws	Assessment procedures are provided to evaluate crack-like flaws. Recommendations for evaluating crack growth including environmental concerns are also covered.	The overall assessment procedure will remain the same. Updates to the following areas are included in the Annexes. • Fracture toughness estimation • New residual stress solutions • New stress intensity factor solutions

Table 2 – Overview of Flaw and Damage Assessment Procedures in API 579-1/ASME FFS-1 2007 *Fitness-For-Service*

Part And Damage Mechanism Covered	Overview	New Developments
10 – High Temperature Operation and Creep	Assessment procedures are provided to determine the remaining life of components operating in the creep regime.	This part completed, includes assessment procedures for: • Creep damage • Creep-fatigue damage • Creep-crack growth • Creep-crack growth in combination with fatigue crack growth • Assessment of bimetallic welds operating in the creep regime • Creep buckling Material data for all assessment methods is provided.
11 – Fire Damage	Assessment procedures are provided to evaluate equipment subject to fire damage using a methodology to rank and screen components for evaluation based on the heat exposure experienced during the fire. The assessment procedures of the other parts of API 579 are utilized to evaluate component damage.	The overall assessment procedure will remain the same. Editorial changes have been made to clarify the assessment procedure.
12 – Dent And Dent-Gouge Combinations	New Part – Assessment procedures are provided to evaluate dent, gouges, and dent-gouge combinations in pressure containing components.	Current assessment procedures for dents in Part 8 have been removed. New assessment procedures developed for dents, gouges, and dent-gouge combinations.
13 – Laminations	New Part – Assessment procedures will be provided to evaluate laminations in pressure containing components.	Current lamination rules in Part 7 have been removed. Updated rules to evaluate laminations incorporated.

Table 3 – Annexes in API 579-1/ASME FFS-1 2007 Fitness-For-Service

Annex	Overview	New Developments
A – Thickness, MAWP And Membrane Stress Equations for a FFS Assessment	Equations for the thickness, MAWP, and membrane stress are given for most of the common pressurized components. These equations are provided to assist international practitioners who may not have access to the ASME Code and who need to determine if the local design code is similar to the ASME Code for which the FFS assessment procedures were primarily designed.	Updates implemented reflect many of the new advances developed by PVRC that have been incorporated in the new ASME B&PV Code, Section VIII, Division 2.
B1, B2, B3, B4 – Stress Analysis Overview for a FFS Assessment	Recommendations for stress analysis techniques that can be used to perform an FFS assessment are provided including guidelines for finite element analysis.	Updates implemented to reflect many of the new advances developed by PVRC that have been incorporated in the new ASME B&PV Code, Section VIII, Division 2. The analysis techniques in this annex are used to evaluate protection against: • Plastic collapse • Local failure (strain concentration) • Collapse from buckling • Cyclic loading, new fatigue method for welded joints • Creep damage
C – Compendium of Stress Intensity Factor Solutions	A compendium of stress intensity factor solutions for common pressurized components (i.e. cylinders, spheres, nozzle, etc.) is given. These solutions are used for the assessment of crack-like flaws. The solutions presented represent the latest technology and have been re-derived using the finite element method in conjunction with weight functions.	New stress intensity factor solutions introduced for thick-wall cylinders and through-thickness cracks in cylinders and spheres.
D – Compendium of Reference Stress Solutions	A compendium of reference stress solutions for common pressurized components (i.e. cylinders, spheres, nozzle, etc.) is given. These solutions are used for the assessment of crack-like flaws.	Updates made to reference stress solutions.
E – Residual Stresses in a Fitness-For-Service Evaluation	Procedures to estimate the through-wall residual stress fields for different weld geometries are provided; this information is required for the assessment of crack-like flaws.	All residual stress solutions updated based on the work being performed under a PVRC Joint Industry Project.
F – Material Properties for a FFS Assessment	Material properties required for all FFS assessments are provided including: • Strength parameters (yield and tensile stress) • Physical Properties (i.e. Young's Modulus, etc.) • Fracture Toughness • Data for Fatigue Crack Growth Calculations • Fatigue Curves (Initiation) • Material Data for Creep Analysis including remaining life and creep crack growth	Updates implemented including: • A new universal stress-strain curve model provided that can be used in elastic-plastic analysis and to generate a FAD • Inclusion of cyclic stress-strain curves • Updates to smooth bar fatigue data • Fatigue data for welded joints • New procedures for estimating the fracture toughness based on the ASME B&PV Code material toughness exemption curves
G – Deterioration and	An overview of the types of flaws and damage	Annex modified to reference WRC Bulletins 488

Table 3 – Annexes in API 579-1/ASME FFS-1 2007 Fitness-For-Service

Annex	Overview	New Developments
Failure Modes	mechanisms that can occur is provided, concentrating on service-induced degradation mechanisms. This annex provides an abridged overview on damage mechanisms.	[11], 489 [12], and 490 [13] and API 571 [14].
H – Validation	An overview of the research work used to validate the general and local metal loss, and the crack-like flaw assessment procedures are provided.	The results from research performed by the Materials Properties Council's FFS Joint Industry Project and other organizations are summarized.
I – Glossary of Terms and Definitions	Definitions for common terms used throughout the parts and annexes of API 579 are given.	Editorial changes made to clarify many of the current definitions.
J – Technical Inquiries	Currently not used	---
K – Crack Opening Areas	The equations for the Crack Opening Areas (COA) in this annex have been derived for both elastic and plastic conditions for cylinders and spheres with membrane and/or bending stresses.	Crack opening area solutions incorporated based on reference [29].

Table 4 – References Covering Validation Work for API 579-1/ASME FFS-1 2007 Fitness-For-Service

WRC Bulletin	Subject
WRC Bulletins Published	
WRC 430 [26]	Review of Existing Fitness-For-Service Criteria for Crack-Like Flaws
WRC 465 [27]	Technologies for the Evaluation of Non-Crack-Like Flaws in Pressurized Components - Erosion/Corrosion, Pitting, Blisters, Shell Out-of-Roundness, Weld Misalignment, Bulges, and Dents in Pressurized Components
WRC 471 [28]	Development of Stress Intensity Factor Solutions for Surface and Embedded Cracks in API 579
WRC 478 [29]	Stress Intensity and Crack Growth Opening Area Solutions for Through-wall Cracks in Cylinders and Spheres
WRC 455 [30]	Recent Progress in Analysis of Welding Residual Stresses
WRC 476 [31]	Recommendations for Determining Residual Stresses in Fitness-For-Service Assessments
WRC 474 [32]	Master S-N Curve Method for Fatigue Evaluation of Welded Components
WRC 505 [22]	An Overview and Validation of The Fitness-For-Service Assessment Procedures for Locally Thin Areas in API 579
WRC Bulletins in Preparation	
---	An Overview of The Fitness-For-Service Assessment Procedures for Pitting Damage in API 579-1/ASME FFS-1
---	Compendium of Temperature-Dependent Physical Properties for Pressure Vessel Materials
---	An Overview and validation of the Fitness-For-Service Rules for the Assessment of HIC/SOHIC Damage in API 579-1/ASME FFS-1
---	An Overview of the Fitness-For-Service Assessment Procedures for Weld Misalignment and Shell Distortions in API 579-1/ASME FFS-1
---	An Overview and Validation of the Fitness-For-Service Assessment Procedures for Crack-Like Flaws in API 579-1/ASME FFS-1
---	An Overview and Validation of Residual Stress Distributions for Use in the Assessment Procedures of Crack-Like Flaws in API 579-1/ASME FFS-1
---	MPC Project Omega and Procedures for Assessment of Creep Damage in API 579-1/ASME FFS-1
---	Development of a Local Strain Criteria Based on the MPC Universal Stress-Strain Equation
---	Update on the Master S-N Curve Method for Fatigue Evaluation of Welded Components
---	Development of Partial Safety Factors for Use in the Assessment of Crack-Like Flaws Using API 579-1/ASME FFS-1
---	Development of Fitness-For-Service Assessment procedures for HIC/SOHIC Damage in API 579-1/ASME FFS-1

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PROPOSED MODIFICATIONS TO API 579-1/ASME FFS-1 2007 FITNESS-FOR-SERVICE

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ABSTRACT

The first edition of API 579 *Recommended Practice for Fitness-For-Service* was published in 2000, and subsequently recognized as the de facto international fitness-for-Service standard in the refining and petrochemical industry. The second edition of this document, API 579-1/ASME FFS-1 *Fitness-For-Service*, was published in 2007 as a joint standard of the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME). The second edition included fitness-for-service assessment procedures applicable to other industries including fossil utility and pulp and paper. Work on the third edition of API 579-1/ASME FFS-1 has begun with many planned technical improvements to further address industry needs. These improvements include the edition of a new part on fatigue evaluation, updates to the assessment procedures for crack-like flaws and remaining life assessments for components operating at elevated temperatures, and a rewrite of residual stress solutions for use in the evaluation of crack-like flaws based on the latest state-of-the-art approaches. In addition, the third edition will be reorganized where by technical information currently placed in separate annexes that currently appear after all of the parts will be re-deployed as annexes to specific parts with a similar topic. This new organization will facilitate use and also simplify future updates to the document. An overview of proposed improvements to fitness-for-service technologies is provided along with a description of the new organization of API 579-1/ASME FFS-1.

INTRODUCTION

The ASME and API design codes and standards for pressurized equipment provide rules for the design, fabrication, inspection, and testing of new pressure vessels, piping systems, and storage tanks. These codes typically do not provide assessment procedures to evaluate degradation due to in-service environmentally-induced damage, or flaws from original fabrication that may be found during subsequent inspections. Fitness-For-Service (FFS) assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. The first edition of API 579 *Recommended Practice for Fitness-For-Service* [1] published in 2000 (API 579 2000) was developed to provide guidance for conducting FFS assessments of flaws commonly encountered in the refining and petrochemical industry that occur in pressure vessels, piping, and tankage.

In 1995, the ASME Board on Pressure Technology Codes and Standards (BPTCS) formed the Post Construction Committee (PCC) with the intent to extend FFS technology to flaws and damage encountered in other industries such as the pulp and paper industry, fossil electric power industry, and nuclear industry. In order to streamline development efforts, pool resources, and promote widespread regulatory acceptance, API and ASME agreed to form a joint API and ASME committee to produce a single FFS standard that can be used for pressure-containing equipment for all industries. Oversight of this committee is undertaken by the API Committee on Refinery Equipment (CRE) and ASME Board on Pressure Technology Codes and Standards. The first meeting of the Joint API/ASME FFS Committee (FFSJC) took place in February, 2002.

The FFSJC produced a new FFS standard entitled API 579-1/ASME FFS-1 2007 *Fitness-For-Service* [2] that was released in June 2007. This new standard was based on the technology in

API 579 2000 and also included new parts covering FFS assessment procedures that address unique damage mechanisms experienced by other industries.

OVERVIEW OF API 579-1/ASME FFS-1 2007 Edition

Applicable Codes

API 579-1/ASME FFS-1 2007 provides guidelines for performing FFS assessments that can be used in conjunction with the applicable in-service inspection code to determine the suitability for continued operation. The assessment procedures in this recommended practice can be used for FFS assessments and/or rerating of components designed and constructed to the design codes shown below.

- ASME B&PV Code, Section VIII, Division 1
- ASME B&PV Code, Section VIII, Division 2
- ASME B&PV Code, Section I
- ASME B31.3 Piping Code
- ASME B31.1 Piping Code
- API 650
- API 620

The assessment procedures in API 579-1/ASME FFS-1 2007 may also be applied to pressure-containing equipment constructed to other recognized codes and standards including international and internal corporate standards. API 579-1/ASME FFS-1 2007 has broad application since the assessment procedures are based on allowable stress based methods or plastic collapse analysis for non-crack-like flaws, and FAD-based assessment procedures for crack-like flaws.

Organization

API 579-1/ASME FFS-1 2007 is a highly structured document designed to facilitate use by practitioners and to facilitate future enhancements and modifications by the FFSJC. The standard contains 13 Parts and 11 Annexes that are summarized in Table 1. Part 1 of the document covers: introduction and scope; responsibilities of the Owner-User, Inspector, and Engineer; qualification requirements for the Inspector and Engineer; and references to other codes and standards. An outline of the overall FFS assessment methodology that is common to all assessment procedures included in API 579-1/ASME FFS-1 is provided in Part 2 of the document. The organization of Part 2 is shown in Table 2. This same organization is utilized in all subsequent parts that contain FFS assessment procedures. In addition, the eight step procedure introduced in Part 2 for performing a FFS assessment is summarized in Table 3.

Starting with Part 3, a catalogue of FFS assessment procedures organized by damage mechanism is provided in API 579-1/ASME FFS-1. When assessment procedures are developed for a new damage mechanism, they will be added as a self-contained part to maintain the structure of the document. Annexes are provided with technical information that can be used with the parts of API 579-1/ASME FFS-1 that provide FFS assessment procedures. The majority of the information in the appendices covers stress analysis techniques, material property data, and other pertinent information that is required when performing a FFS assessment.

Assessment Levels

Three levels of assessment are provided in API 579-1/ASME FFS-1 for each flaw and damage type. In general, each assessment level provides a balance between conservatism, the amount of information required for the evaluation, the skill of the practitioner performing the assessment, and the complexity of analysis being performed. Level 1 is the most conservative and the easiest to use. Practitioners usually proceed sequentially from a Level 1 to a Level 3 assessment (unless otherwise directed by the assessment techniques) if the current assessment level does not provide an acceptable result or a clear course of action cannot be determined.

It should be noted that the definitions of assessment levels in API 579-1/ASME FFS-1 are significantly different than those used in other standards. A general overview of each assessment level and its intended use is described below.

- Level 1 – The assessment procedures included in this level are intended to provide conservative screening criteria that can be utilized with a minimum amount of inspection or component information. The Level 1 assessment procedures may be used by either plant inspection or engineering personnel.
- Level 2 – The assessment procedures included in this level are intended to provide a more detailed evaluation that produces results that are less conservative than those from a Level 1 assessment. In a Level 2 assessment, inspection information similar to that required for a Level 1 assessment is required; however, more detailed calculations are used in the evaluation. Level 2 assessments are typically conducted by plant engineers or engineering specialists experienced and knowledgeable in performing FFS assessments.
- Level 3 – The assessment procedures included in this level are intended to provide the most detailed evaluation and produce results that are less conservative than those from a Level 2 assessment. In a Level 3 assessment, the most detailed inspection and component information is typically required. The recommended analysis is based on numerical techniques such as the finite element method. The Level 3 assessment procedures are primarily intended to be used by engineering specialists experienced and knowledgeable in performing FFS evaluations.

Remaining Life and Rerating

The FFS assessment procedures in API 579-1/ASME FFS-1 cover both the present integrity of the component given a current state of damage and the projected remaining life. If the results of a FFS assessment indicate that the equipment is suitable for the current operating conditions, the equipment can continue to be operated at these conditions if a suitable inspection program is established. If the results of the FFS assessment indicate that the equipment is not suitable for the current operating conditions, calculation methods are provided in API 579-1/ASME FFS-1 to rerate the component. For pressurized components (e.g. pressure vessels and piping) these calculation methods can be used to find a reduced maximum allowable working pressure and/or coincident temperature. For tank components (i.e., shell courses) the calculation methods can be used to determine a reduced maximum fill height.

In API 579-1/ASME FFS-1, the remaining life calculation is used to establish an appropriate inspection interval in conjunction with the applicable in-service inspection code, provide information for an in-service monitoring plan, or to establish the need for remediation. API 579-1/ASME FFS-1 emphasizes the need for remediation where the remaining life cannot be established. Remediation can be in the form of altering the process stream, or isolating the process stream from the pressurized component by installation of a coating or lining, or application of weld overlay. API 579-1/ASME FFS-1 also emphasizes the need for monitoring and inspection to validate the assumptions made about continuing damage.

Example Problem Manual

A comprehensive set of example problems to illustrate the use of the assessment procedures in API 579-1/ASME FFS-1 was published as API 579-2/ASME FFS-2 *Example Problem Manual, First Edition* [3] in 2009 as a separate document. Example problems are provided for all calculation procedures in both SI and US Customary units. A complete set of example problems is crucial to the deployment of any standard because these problems not only demonstrate proper use of the rules in the document but also provide a means to benchmark computer programs developed to automate assessment procedures.

Relationship to Other FFS Standards

The FFSJC members agreed that alternate FFS approaches may be appropriate for use by more advanced practitioners. Therefore, the Level 3 assessment in API 579-1/ASME FFS-1 permits the use of alternative FFS assessment methodologies. For example, the Level 3 assessment in Part 9 covering crack-like flaws provides references to Nuclear Electric R-6 [4], BS 7910 [5], SAQ/FoU-Report 96/08 [6], WES 2805 [7], EPRI J-Integral Methodology [8], and A16 [9]. The European Community sponsored a project known as FITNET to review the existing FFS procedures and develop an updated, unified and verified European FITNET FFS Procedure [10] to cover structural integrity analysis to avoid failures due to fracture, fatigue, creep and corrosion.

NEW DEVELOPMENTS FOR API 579-1/ASME FFS-1

The new developments being incorporated into API 579-1/ASME FFS-1 are summarized below. These new developments were made based on feedback from the API 579 User community and input from the FFSJC.

- Reorganization of the document to facilitate use and updates,
- Expanded code coverage introduced in Part 1,
- Recommendations for establishing an allowable Remaining Strength Factor (RSF),
- Updated Level 1 assessment method for local thin areas in Part 5,
- Re-write of residual stress solutions for use in the assessment of crack-like flaws,
- Updated assessment procedures for the assessment of creep damage, and
- Development of a new Part 14 covering the assessment of fatigue damage.

The current schedule for the release of the next edition of API 579-1/ASME FFS-1 is 2014. The new organization of API 579-1/ASME FFS-1 2014 Edition is shown in Table 4. Note that all annexes have been re-deployed as Annexs to Parts in with a similar topic. This further simplifies use and updates. Coverage of piping systems constructed to ASME B31.4 and ASME B31.8 has been added. Note that the last edition of ASME B31G published in 2010 now provides a direct reference to API 579-1/ASME FFS-1 2014.

In a new annex to Part 2, guidelines for establishing an allowable Remaining Strength Factor will be provided based on the design margins in the original construction code. The guidelines are based on recommendations presented by Janelle in WRC Bulletin 505 [11]. This will enable the user to effectively perform FFS assessments on equipment constructed to international codes and standards that have different design margins. The Level 1 criteria for evaluating the circumferential extent of a Local Thin Area (LTA) have been simplified. The new screening criteria is based on the assumptions that internal pressure is the only acting load and that supplemental loading from weight, wind, earthquake, thermal expansion, and support displacements, as applicable is negligible.

The flaw interaction criteria in Part 9 are updated to be in accordance with the ASME Section XI. This update will remove conservatism in the currently interaction criteria.The residual stress solutions used in the evaluation of crack-like flaws have been re-written. The residual stress distributions presented are based on a comprehensive review of past editions of API 579-1/ASME FFS-1, other relevant standards and practices such as

R6 [4], BS 7910 [5], and FITNET [10], and supplemental numerical analysis. The recommended stress distributions presented reflect the most accurate or defensible guidance from these sources at this time. Due to the scatter in the reported results and recommended guidance, and the uncertainty inherent to residual stresses due to welding, the residual stress distributions represent an upper bound solution. In addition, methods for weld simulation to determine residual stresses are provided using the guidance contained in AWS A9.5:2013 [12].

The creep damage assessment procedures have been updated to include methods for numerical computation and incorporate ASME Code Case 2605. This Section VIII, Division 2 Case permits the use of 2 1/4 Cr-1 Mo-V for operating temperatures greater than 371°C (700°F) and less than or equal to 454°C (850°F) using a new creep-fatigue interaction design criteria. In addition, the rules for creep buckling have been updated. Guidelines for carrying out the metallurgical investigations and mechanical testing to assess the degradation of materials exposed to elevated temperatures during a fire event are provided. The metallurgical investigations and mechanical testing are intended to cover metallic materials in process units, specifically carbon steel, low alloy steels, and stainless steels. Investigation techniques described in this Annex include replication or in-situ field metallography evaluation, laboratory metallographic evaluation, hardness test, tensile test, impact test, etc.

A new Part 14 pertaining to the assessment of fatigue damage from variable amplitude loading has been developed. The fatigue rules are taken from ASME Section VIII, Division 2. Assessment methods for fatigue and the associated fatigue curves are typically presented in two forms: fatigue assessment method and curves that are based on smooth bar test specimens and fatigue assessment method and curves that are based on test specimens that include weld details of the quality consistent with code construction. The assessment procedures for fatigue in Part 14 may be summarized as follows.

- Smooth bar fatigue assessment methods and curves may be used for components with or without welds. The welded joint fatigue assessment method and curves shall only be used for welded joints.
- The smooth bar fatigue assessment methods and curves are applicable up to the maximum number of cycles given on the curves. The welded joint fatigue assessment methods and curves do not exhibit an endurance limit and are acceptable for all cycles.
- If welded joint fatigue assessment methods and curves are used in the evaluation and thermal transients result in a through-thickness stress difference at any time that is greater than the steady state difference, then the number of design cycles shall be determined as the smaller of the number of cycles for the base metal established using smooth bar fatigue method and for the weld established using the welded joint fatigue method.

TECHNICAL BASIS AND VALIDATION OF API 579 FFS ASSESSMENT METHODS

The technical basis and experimental validation of the FFS assessment procedures are summarized in Annex H of API 579-1/ASME FFS-1 and are published in a series of WRC Bulletins, see Table 5. The FFSJC is committed to publishing in the public domain the technical background to all FFS assessment procedures utilized in API 579-1/ASME FFS-1. It is hoped that other FFS standards writing committees adopt the same policy as it is crucial that FFS knowledge remains at the forefront of technology on an international basis to facilitate adoption by jurisdictional authorities.

CONCLUSIONS

FFS assessments are quantitative engineering evaluations which are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. The API/ASME FFSJC is working to produce the next edition of the *de facto* International Standard FFS standard API 579-1/ASMEFFS-1 *Fitness-For-Service* with a planned publication date of 2014. The new edition has been re-organized to facilitate use and updates and contains many updates including new methods for determining residual stress distributions for use in the evaluation of crack-like flaws and a new Part 14 covering the assessment of fatigue damage.

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Table 1 – Organization of API 579-1/ASME FFS-1 2007 Fitness-For-Service, 2007 Edition

Part or Annex	Overview
Part 1 – Introduction	Provides an introduction and definition of Fitness-For-Service (FFS) and scope of coverage by direct listing of design codes for pressurized equipment. Defines the responsibilities and qualifications of the Owner-User, Inspector and Engineer for performance of an FFS Assessment. Provides definitions of terms and references to design codes and standards.
Part 2 – Fitness-For-Service Engineering Assessment Procedure	Provides an overview of the FFS Assessment procedures that are organized by flaw or damage type, which can be used to evaluate pressurized components containing flaws or damage. The results from the assessment procedure can be used to make run-repair or replace decisions. Defines the general Fitness-For-Service assessment procedure used for all flaw types and damage mechanisms see Table 2.
Part 3 – Brittle Fracture	Assessment procedures are provided to evaluate the resistance to brittle fracture of in-service carbon and low alloy steel pressure vessels, piping, and storage tanks. Criteria are provided to evaluate normal operating, start-up, upset, and shutdown conditions.
Part 4 – General Metal Loss	Assessment procedures are provided to evaluate general corrosion. Thickness data used for the assessment can be either point thickness readings or detailed thickness profiles. A methodology is provided to guide the practitioner to the Local Metal Loss assessment procedures based on the type and variability of thickness data recorded during an inspection.
Part 5 – Local Metal Loss	Assessment techniques are provided to evaluate single and networks of Local Thin Areas (LTAs) and groove-like flaws in pressurized components. Detailed thickness profiles are required for the assessment. The assessment procedures can also be utilized to evaluate blisters.
Part 6 – Pitting Corrosion	Assessment procedures are provided to evaluate widely scattered pitting, localized pitting, pitting which occurs within a region of local metal loss, and a region of localized metal loss located within a region of widely scattered pitting. The assessment procedures can also be utilized to evaluate a network of closely spaced blisters. The assessment procedures utilize Part 5 for Local Metal Loss.
Part 7 – Hydrogen Blisters, HIC and SOHIC Damage	Assessment procedures are provided to evaluate damage resulting from blisters, HIC damage, and SOHIC damage. The assessment guidelines include provisions for damage located at weld joints and structural discontinuities such as shell transitions, stiffening rings, and nozzles.
Part 8 – Weld Misalignment and Shell Distortions	Assessment procedures are provided to evaluate stresses resulting from geometric discontinuities in shell type structures including weld misalignment and shell distortions (e.g. out-of-roundness, bulges, and dents).
Part 9 – Crack-Like Flaws	Assessment procedures are provided to evaluate crack-like flaws. Recommendations for evaluating crack growth including environmental concerns are also covered.
Part 10 – High Temperature Operation and Creep	Assessment procedures are provided to determine the remaining life of components operating in the creep regime.
Part 11 – Fire Damage	Assessment procedures are provided to evaluate equipment subject to fire damage using a methodology to rank and screen components for evaluation based on the heat exposure experienced during the fire. The assessment procedures of the other parts of API 579 are utilized to evaluate component damage.
Part 12 – Dent And Dent-Gouge Combinations	Assessment procedures are provided to evaluate dent, gouges, and dent-gouge combinations in pressure containing components.

Table 1 – Organization of API 579-1/ASME FFS-1 2007 Fitness-For-Service, 2007 Edition

Part or Annex	Overview
Part 13 – Laminations	Assessment procedures will be provided to evaluate laminations in pressure containing components.
Annex A – Thickness, MAWP And Membrane Stress Equations for a FFS Assessment	Equations for the thickness, MAWP, and membrane stress are given for most of the common pressurized components. These equations are provided to assist international practitioners who may not have access to the ASME Code and who need to determine if the local design code is similar to the ASME Code for which the FFS assessment procedures were primarily designed.
Annexes B1, B2, B3, B4 – Stress Analysis Overview for a FFS Assessment	Recommendations for stress analysis techniques that can be used to perform an FFS assessment are provided including guidelines for finite element analysis.
Annex C – Compendium of Stress Intensity Factor Solutions	A compendium of stress intensity factor solutions for common pressurized components (i.e. cylinders, spheres, nozzle, etc.) is given. These solutions are used for the assessment of crack-like flaws. The solutions presented represent the latest technology and have been re-derived using the finite element method in conjunction with weight functions.
Annex D – Compendium of Reference Stress Solutions	A compendium of reference stress solutions for common pressurized components (i.e. cylinders, spheres, nozzle, etc.) is given. These solutions are used for the assessment of crack-like flaws.
Annex E – Residual Stresses in a Fitness-For-Service Evaluation	Procedures to estimate the through-wall residual stress fields for different weld geometries are provided; this information is required for the assessment of crack-like flaws.
Annex F – Material Properties for a FFS Assessment	Material properties required for all FFS assessments are provided including: • Strength Parameters (Yield and Tensile Stress) • Physical Properties (i.e. Young's Modulus, etc.) • Fracture Toughness • Data for Fatigue Crack Growth Calculations • Fatigue Curves (Initiation) • Material Data for Creep Analysis including remaining life and creep crack growth
Annex G – Deterioration and Failure Modes	An overview of the types of flaws and damage mechanisms that can occur is provided, concentrating on service-induced degradation mechanisms. This annex provides an abridged overview on damage mechanisms.
Annex H – Validation	An overview of the research work used to validate the general and local metal loss, and the crack-like flaw assessment procedures are provided.
Annex I – Glossary of Terms and Definitions	Definitions for common terms used throughout the parts and annexes of API 579 are given.
Annex J – Technical Inquiries	Currently not used
Annex K – Crack Opening Areas	The equations for the Crack Opening Areas (COA) in this annex have been derived for both elastic and plastic conditions for cylinders and spheres with membrane and/or bending stresses.

Table 2 – Organization of Part 2 and Each Part Containing a FFS Assessment Procedure in API 579-1/ASME FFS-1 Fitness-For-Service, 2007 and 2014 Editions

Paragraph	Overview
1 – General	The scope and overall requirements for an FFS assessment are provided.
2 – Applicability and Limitations of the FFS Assessment Procedures	The applicability and limitations for each FFS assessment procedure are indicated; these limitations are stated in the front of each part for quick reference.
3 – Data Requirements	The data requirements for the FFS assessment are outlined; these data requirements include: • Original equipment design data • Maintenance and operational history • Data/measurements for a FFS assessment • Recommendations for inspection technique and sizing requirements
4 – Assessment Techniques and Acceptance Criteria	Detailed assessment rules are provided for three levels of assessment: Level 1, Level 2, and Level 3. A discussion of these assessment levels is covered in the body of this paper.
5 – Remaining Life Evaluation	Guidelines for performing a remaining life estimate are provided for the purpose of establishing an inspection interval in conjunction with the governing inspection code.
6 – Remediation	Guidelines are presented on methods to mitigate and/or control future damage. In many cases, changes can be made to the component or to the operating conditions to mitigate the progression of damage.
7 – In-Service Monitoring	Guidelines for monitoring damage while the component is in-service are provided. These guidelines are useful if a future damage rate cannot be estimated easily or the estimated remaining life is short. In-service monitoring is one method whereby future damage or conditions leading to future damage can be assessed or confidence in the remaining life estimate can be increased.
8 – Documentation	Guidelines for documentation for an assessment are provided. The general rule is that a practitioner should be able to repeat the analysis from the documentation without consulting an individual originally involved in the FFS assessment.
9 – References	A comprehensive list of technical references used in the development of the FFS assessment procedures is provided. References to codes and standards are provided.
10 – Tables and Figures	Tables and figures including logic diagrams are used extensively in each part to clarify assessment rules and procedures.

Table 3 – The General Fitness-For-Service Assessment Procedure in API 579-1/ASME FFS-1 Fitness-For-Service, 2007 and 2014 Editions

Step	Overview
1	Flaw and Damage Mechanism Identification: The first step in a Fitness-For-Service assessment is to identify the flaw type and cause of damage. The original design and fabrication practices, the material of construction, and the service history and environmental conditions can be used to ascertain the likely cause of the damage. Once the flaw type is identified, the appropriate Part of this Standard can be selected for the assessment.
2	Applicability and Limitations of the FFS Assessment Procedures: The applicability and limitations of the assessment procedure are described in each Part, and a decision on whether to proceed with an assessment can be made.
3	Data Requirements: The data required for a FFS assessment depend on the flaw type or damage mechanism being evaluated. Data requirements may include: original equipment design data, information pertaining to maintenance and operational history, expected future service, and data specific to the FFS assessment such as flaw size, state of stress in the component at the location of the flaw, and material properties. Data requirements common to all FFS assessment procedures are covered in this Part. Data requirements specific to a damage mechanism or flaw type are covered in the Part containing the corresponding assessment procedures.
4	Assessment Techniques and Acceptance Criteria: Assessment techniques and acceptance criteria are provided in each Part. If multiple damage mechanisms are present, more than one Part may have to be used for the evaluation.
5	Remaining Life Evaluation: An estimate of the remaining life or limiting flaw size should be made for establishing an inspection interval. The remaining life is established using the FFS assessment procedures with an estimate of future damage. The remaining life can be used in conjunction with an inspection code to establish an inspection interval.
6	Remediation: Remediation methods are provided in each Part based on the damage mechanism or flaw type. In some cases, remediation techniques may be used to control future damage associated with flaw growth and/or material deterioration.
7	In-Service Monitoring: Methods for in-service monitoring are provided in each Part based on the damage mechanism or flaw type. In-service monitoring may be used for those cases where a remaining life and inspection interval cannot adequately be established because of the complexities associated with the service environment.
8	Documentation: Documentation should include a record of all information and decisions made in each of the previous steps to qualify the component for continued operation. Documentation requirements common to all FFS assessment procedures are covered in this Part. Documentation requirements specific to a damage mechanism or flaw type are covered in the Part containing the corresponding assessment procedures.

Table 4 – Organization of API 579-1/ASME FFS-1 2007 Fitness-For-Service, 2014 Edition

Part or Annex	Overview
Part 1 – Introduction	Provides an introduction and definition of Fitness-For-Service (FFS) and scope of coverage by direct listing of design codes for pressurized equipment. Defines the responsibilities and qualifications of the Owner-User, Inspector and Engineer for performance of an FFS Assessment. Provides definitions of terms and references to design codes and standards. • Annex 1A – Glossary of Terms and Definitions
Part 2 – Fitness-For-Service Engineering Assessment Procedure	Provides an overview of the FFS Assessment procedures that are organized by flaw or damage type, which can be used to evaluate pressurized components containing flaws or damage. The results from the assessment procedure can be used to make run-repair or replace decisions. Defines the general Fitness-For-Service assessment procedure used for all flaw types and damage mechanisms see Table 2. • Annex 2A – Technical Basis and Validation • Annex 2B – Damage Mechanisms • Annex 2C – Thickness, MAWP and Stress Equations for a FFS Assessment • Annex 2D – Stress Analysis Overview for a FFS Assessment • Annex 2E – Material Properties for Stress Analysis • Annex 2F – Recommendations for Setting an Allowable RSF
Part 3 – Brittle Fracture	Assessment procedures are provided to evaluate the resistance to brittle fracture of in-service carbon and low alloy steel pressure vessels, piping, and storage tanks. Criteria are provided to evaluate normal operating, start-up, upset, and shutdown conditions. • Annex 3A – Technical Basis and Validation: Assessment of Existing Equipment for Brittle Fracture
Part 4 – General Metal Loss	Assessment procedures are provided to evaluate general corrosion. Thickness data used for the assessment can be either point thickness readings or detailed thickness profiles. A methodology is provided to guide the practitioner to the Local Metal Loss assessment procedures based on the type and variability of thickness data recorded during an inspection. • Annex 4A – Technical Basis and Validation: Assessment of General Metal Loss
Part 5 – Local Metal Loss	Assessment techniques are provided to evaluate single and networks of Local Thin Areas (LTAs) and groove-like flaws in pressurized components. Detailed thickness profiles are required for the assessment. The assessment procedures can also be utilized to evaluate blisters. • Annex 5A – Technical Basis and Validation: Assessment of Local Metal Loss
Part 6 – Pitting Corrosion	Assessment procedures are provided to evaluate widely scattered pitting, localized pitting, pitting which occurs within a region of local metal loss, and a region of localized metal loss located within a region of widely scattered pitting. The assessment procedures can also be utilized to evaluate a network of closely spaced blisters. The assessment procedures utilize Part 5 for Local Metal Loss. • Annex 6A – Technical Basis and Validation: Assessment of Pitting Corrosion

Table 4 – Organization of API 579-1/ASME FFS-1 2007 Fitness-For-Service, 2014 Edition

Part or Annex	Overview
Part 7 – Hydrogen Blisters, HIC and SOHIC Damage	Assessment procedures are provided to evaluate damage resulting from blisters, HIC damage, and SOHIC damage. The assessment guidelines include provisions for damage located at weld joints and structural discontinuities such as shell transitions, stiffening rings, and nozzles. • Annex 7A – Technical Basis and Validation: Assessment of Hydrogen Blisters and Hydrogen Damage Associated with HIC and SOHIC
Part 8 – Weld Misalignment and Shell Distortions	Assessment procedures are provided to evaluate stresses resulting from geometric discontinuities in shell type structures including weld misalignment and shell distortions (e.g. out-of-roundness, bulges, and dents). • Annex 8A – Technical Basis and Validation: Assessment of Weld Misalignment and Shell Distortions
Part 9 – Crack-Like Flaws	Assessment procedures are provided to evaluate crack-like flaws. Recommendations for evaluating crack growth including environmental concerns are also covered. • Annex 9A – Technical Basis and Validation: Assessment of Crack-Like Flaws • Annex 9B – Compendium of Stress Intensity Factor Solutions • Annex 9C – Compendium of Reference Stress Solutions • Annex 9D – Residual Stresses in a Fitness-For-Service Evaluation • Annex 9E – Crack Opening Areas • Annex 9F – Fracture Toughness • Annex 9G – Stress Analysis Overview for Crack-Like Flaws
Part 10 – High Temperature Operation and Creep	Assessment procedures are provided to determine the remaining life of components operating in the creep regime. • Annex 10A – Technical Basis and Validation: Assessment of Components Operating in the Creep Range • Annex 10B – Material Data for Creep Analysis
Part 11 – Fire Damage	Assessment procedures are provided to evaluate equipment subject to fire damage using a methodology to rank and screen components for evaluation based on the heat exposure experienced during the fire. The assessment procedures of the other parts of API 579 are utilized to evaluate component damage. • Annex 11A – Technical Basis and Validation: Assessment of Fire Damage • Annex 11B – Metallurgical Investigation and Evaluation of Mechanical Properties in Fire Damage Assessment
Part 12 – Dent And Dent-Gouge Combinations	Assessment procedures are provided to evaluate dent, gouges, and dent-gouge combinations in pressure containing components. • Annex 12A – Technical Basis and Validation: Assessment of Dents, Gouges, and Dent-Gouge combinations

Table 4 – Organization of API 579-1/ASME FFS-1 2007 Fitness-For-Service, 2014 Edition

Part or Annex	Overview
Part 13 – Laminations	Assessment procedures to evaluate laminations in pressure containing components are provided. • Annex 13A – Technical Basis and Validation: Assessment of Laminations
Part 14 – Fatigue Damage (NEW)	Assessment procedures are provided to determine the remaining life of components subject to fatigue. • Annex 14A – Technical Basis and Validation: Assessment of Fatigue Damage • Annex 14B – Material Data for Fatigue Analysis

Table 5 – References Covering Validation Work for API 579-1/ASME FFS-1 2007 Fitness-For-Service

WRC Bulletin	Subject
WRC Bulletins Published	
WRC 430	Review of Existing Fitness-For-Service Criteria for Crack-Like Flaws
WRC 465	Technologies for the Evaluation of Non-Crack-Like Flaws in Pressurized Components - Erosion/Corrosion, Pitting, Blisters, Shell Out-of-Roundness, Weld Misalignment, Bulges, and Dents in Pressurized Components.
WRC 471	Development of Stress Intensity Factor Solutions for Surface and Embedded Cracks in API 579
WRC 478	Stress Intensity and Crack Growth Opening Area Solutions for Through-wall Cracks in Cylinders and Spheres
WRC 455	Recent Progress in Analysis of Welding Residual Stresses
WRC 476	Recommendations for Determining Residual Stresses in Fitness-For-Service Assessments
WRC 474	Master S-N Curve Method for Fatigue Evaluation of Welded Components
WRC 505	An Overview and Validation of The Fitness-For-Service Assessment Procedures for Locally Thin Areas in API 579
WRC Bulletins in Preparation	
—	An Overview of The Fitness-For-Service Assessment Procedures for Pitting Damage in API 579-1/ASME FFS-1
—	Compendium of Temperature-Dependent Physical Properties for Pressure Vessel Materials
—	An Overview and validation of the Fitness-For-Service Rules for the Assessment of HIC/SOHIC Damage in API 579-1/ASME FFS-1
—	An Overview of the Fitness-For-Service Assessment Procedures for Weld Misalignment and Shell Distortions in API 579-1/ASME FFS-1
—	An Overview and Validation of the Fitness-For-Service Assessment Procedures for Crack-Like Flaws in API 579-1/ASME FFS-1
—	An Overview and Validation of Residual Stress Distributions for Use in the Assessment Procedures of Crack-Like Flaws in API 579-1/ASME FFS-1
—	MPC Project Omega and Procedures for Assessment of Creep Damage in API 579-1/ASME FFS-1
—	Development of a Local Strain Criteria Based on the MPC Universal Stress-Strain Equation
—	Update on the Master S-N Curve Method for Fatigue Evaluation of Welded Components
—	Development of Partial Safety Factors for Use in the Assessment of Crack-Like Flaws Using API 579-1/ASME FFS-1
—	Development of Fitness-For-Service Assessment procedures for HIC/SOHIC Damage in API 579-1/ASME FFS-1
Note: WRC Bulletins are available from: forengeineers.org.	

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PREVIEW OF WHAT TO EXPECT WITH COMING EDITIONS OF API 579

The next edition of the API 579-1/ASME FFS-1 (API 579) Fitness-For-Service (FFS) standard has finally been fully approved by the API/ASME FFS joint committee and it is currently scheduled to be published by the end of 2021. The committee has made tremendous progress towards continued improvements and enhancements in several critical areas. Overall, there have been approximately 100 ballots approved by the committee since the last publication. The intent of this article is to provide a high-level overview of what to expect with the next edition of API 579 as well as to provide insight regarding the future direction of the FFS standard.

HISTORY OF API 579

The American Petroleum Institute (API) first published *Recommended Practice for Fitness-For-Service* (API RP 579) in the year 2000. The initial publication was intended to supplement and augment the requirements in API 510, API 570 and API 653: *(i) to ensure safety of plant personnel and the public while older equipment continues to operate; (ii) to provide technically sound Fitness-For-Service assessment procedures to ensure that different service providers furnish consistent life predictions; and (iii) to help optimize maintenance and operation of existing facilities, maintain availability of older plants, and enhance long-term economic viability*. The document was published as a recommended practice, but quickly recognized as the de facto international FFS guidance document in the refining and petrochemical industry because it compiled evaluation procedures from the in-service inspection codes and it included significant technology upgrades for evaluation of equipment containing defects or flaws. API RP 579 was replaced in 2007 with the first edition of API 579-1/ASME FFS-1 *Fitness- For-Service* which was published as a joint standard of API and the American Society of Mechanical Engineers (ASME). Applicability of the FFS procedures became more readily adopted in various industries including fossil utility and pulp and paper. The 2007 edition also included technology enhancements such as the MPC Omega methodology for evaluation of high temperature creep damage as well as step-by-step procedures for evaluation of Hydrogen Induced Cracking (HIC), dents, gouges, and dent-gouge combinations. In 2016, the second edition of the API/ASME joint standard was published. The document was reorganized to facilitate use and future updates and incorporated numerous technical improvements including: recommendations for establishing an allowable Remaining Strength Factor (RSF); simplified Level 1 assessment method for local thin areas; modification of residual stress solutions for use in the assessment of crack-like flaws; updated procedures for the assessment of creep damage; new annex covering metallurgical investigation and evaluation of mechanical properties for a fire damage assessment; and development of a new Part 14 covering the assessment of fatigue damage.

CHANGES APPROVED BY THE FFS COMMITTEE

The next edition of API 579 (API 579-1/ASME FFS-1, 3rd Edition) is scheduled to be released by the end of 2021. Numerous editorial corrections, updates, and clarifications will be included throughout the standard along with several technical changes and enhancements, including the following:

- Part 2: *Fitness-For-Service Engineering Assessment Procedure*

  - Added provision that permits MAWP to be determined using the stress analysis procedures in Annex 2D.
- Annex 2C: *Thickness, MAWP, and Stress Equations for an FFS Assessment*
  - Added Svensson method for burst pressure calculation.
  - Removed option to use ASME VIII-2 allowable stress for ASME VIII-1 equipment. This was originally a carryover from API 510 back before the allowable stress criteria in ASME VIII-2 changed from a factor of safety of 3 to a factor or safety of 2.4.
  - Removed requirement for nozzle reinforcement check for small nozzles to be consistent with ASME VIII-1.
  - Removed legacy limit load nozzle reinforcement procedure which was previously eliminated in ASME VIII-1.
- Annex 2D: *Stress Analysis Overview for a FFS Assessment*
  - Elastic load cases reference ASME VIII-2 for simplicity.
  - Removed option to use ASME VIII-2 allowable stress for ASME VIII-1 equipment.
  - Modified coefficients for use in elastic-plastic calculation to cover the appropriate design margins with various current and legacy construction codes (including the appropriate design margins for pipelines).
  - Added explicit guidance on capping the yield stress used in a limit load analysis to the yield stress at temperature to prevent misapplication of the method when evaluating components fabricated from materials that have a design Code elastic allowable stress equal to 90% of the minimum specific yield stress (MSYS).
  - Limited the allowable remaining strength factor, RSF_a, for buckling assessments to no lower than 0.9.
- Annex 2E: *Material Properties for Stress Analysis*
  - Updated the Ramberg-Osgood stress-strain model for use in a Level 3 evaluation.
  - Added guidance for material properties for Level 3 evaluations involving pipeline materials.
  - Updated correlations for estimating material ultimate tensile strength (UTS) using hardness testing.
- Part 3: *Assessment of Existing Equipment for Brittle Fracture*
  - Clarified that the use of design codes/standards as an alternative to Part 3 is considered a Level 3 assessment.
  - Corrected errors related to the Minimum Allowable Temperature (MAT) for bolting and nut material specifications.
  - Expanded the definition of shock chilling and added the requirement that a Level 3 evaluation is necessary to evaluate conditions where the shock chilling screening is not satisfied.
  - Added thickness limits for Level 1 impact test exemption curves to be consistent with ASME VIII-1.
  - Clarified that no PWHT credit is permitted in a brittle fracture evaluation of a component if previous repairs were completed using alternative weld methods (such as high preheat or temper bead).
  - Added supplemental inspection requirements for brittle fracture evaluations performed on component identified to have metal loss that exceeds the original design tolerances.
  - Explicitly excluded mill tolerance effects in a brittle fracture assessment.
  - Modified impact test exemptions for flanges to address recent changes to ASME VIII-1.

- Flanges Fabricated Pre-1989:
  - As-Forged SA-105 is Curve B. Heat-treated condition is Curve C.
  - MAT for ferritic flanges meeting ASME B16.5, ASME B16.47, or the Long Weld Neck (LWN) requirements of ASME VIII-1, UCS-66(c)(4) in the as-forged condition is -20°F
- Flanges Fabricated in 1989 or Later:
  - As-Forged SA-105 is Curve A
  - Heat-treated condition SA-105 is Curve B
  - MAT for ferritic flanges meeting ASME B16.5, ASME B16.47, or LWN requirements in the as-forged is 0°F

  Note: The basis for the 1989 cutoff comes from a 1996 report indicating "a number of flange failures have been reported during the past 5 years within the various Amoco operating units" and a Chemical Risks Directive requiring impact testing of all flanges in Europe being issued in response to a failure that occurred in 1998 on a flange that was installed in 1990.
- MAT for ferritic flanges meeting ASME B16.5, ASME B16.47, or the LWN requirements in the normalized condition after forging shall be set at -20°F regardless of the year of manufacturing. (Note: No wording regarding "produced to fine grain practice" as currently included in ASME VIII-1).
- For all ASME B16.5, ASME B16.47, and LWN flanges, MAT is set equal to the impact test exemption temperature "unless the MAT determined by the governing thickness at the flange nozzle neck weld joint together with the curve associated with the flange material gives a higher value."

o Added requirement that components not exposed to general primary membrane tensile stress shall be evaluated using the pressure rating basis in a Level 2 assessment.

$$\boldsymbol{R_{ts}} = \frac{\boldsymbol{P_a}}{\boldsymbol{P_{rating}}}$$

o Added guidance that pressure rating in the stress ratio calculation can be calculated using paragraph 2C.3.10 for nozzle assemblies and paragraph 2C.3.12 for flanges.

o Limited MAT to no lower than -55°F in as-welded condition even if Level 1 MAT was established using impact testing. (Note: MAT can still be reduced to -155°F if PWHT.).

- Impact tested at or below -50°F: $\boldsymbol{MAT = max[(MAT_{Level\,1} - T_R), -155°F]}$
- Impact tested above -50°F:

  $\boldsymbol{MAT = max[(MAT_{Level\,1} - T_R), -155°F]}$ (PWHT Condition)

  $\boldsymbol{MAT = max[(MAT_{Level\,1} - T_R), -55°F]}$ (As-Welded Condition)

- Part 4: *Assessment of General Metal Loss*

  o Moved component type definitions and examples to a table to simplify designations.

  o Exempted the cylinder side of 2:1 elliptical head-to-shell junctions as Type C components and structural discontinuities for metal loss assessments (applicable to Part 4, Part 5, and Part 6 assessments).

  o Revised qualifications to utilize Point Thickness Reading (PTR) approach to prevent misapplication of the method and "washing out" of local damage.

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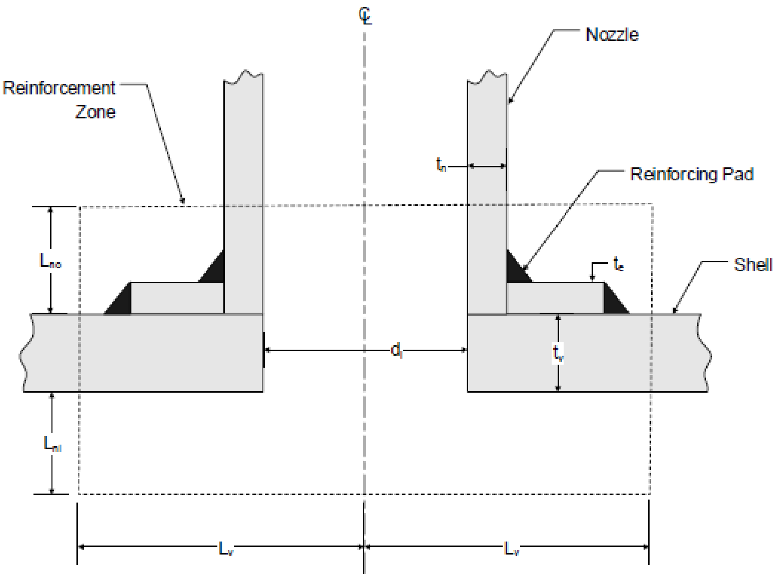
- Eliminated the check on Coefficient of Variation (COV)
- Added limitation on minimum measured thickness

$$t_{mm} \geq 0.9t_{avg}$$

- Revised length for thickness averaging at nozzles (Figure 4.13) to ensure method does not permit greater damage at nozzle junctions vs. away from nozzle junctions.



Nozzle with a Reinforcement Element

$$L_H = min[L, L_v]$$

Where,

$$L = Q\sqrt{D_{ml}t_{ml}}$$

$$L_v = max\left[d_i, \left(\frac{d_i}{2} + t_n + t_v\right)\right]$$

- Revised recommended UT grid spacing for scenarios when "corroded surface is not accessible for visual inspection."

$$L_s = min[2t_{rd}, 1\ inch]$$

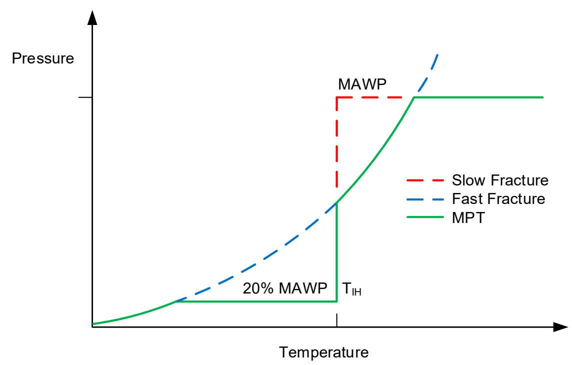
- Documented the purpose of the minimum measured thickness limit in Level 1 and Level 2 assessments.
- Included recommendations for validation of inspection results when thickness readings are less than or equal to 0.100 inches (also referenced in Part 5 *Assessment of Local Wall Loss* and Part 6 *Assessment of Pitting*).

- Part 9: *Assessment of Crack-Like Flaws*
  - Redefined crack-like flaw interaction and recategorization rules to reduce conservatism and for better alignment with ASME Section XI.
- Annex 9B: *Compendium of Stress Intensity Factor Solutions for Crack-like Flaws*
  - Expanded K-solutions to cover thick-wall cylinders.

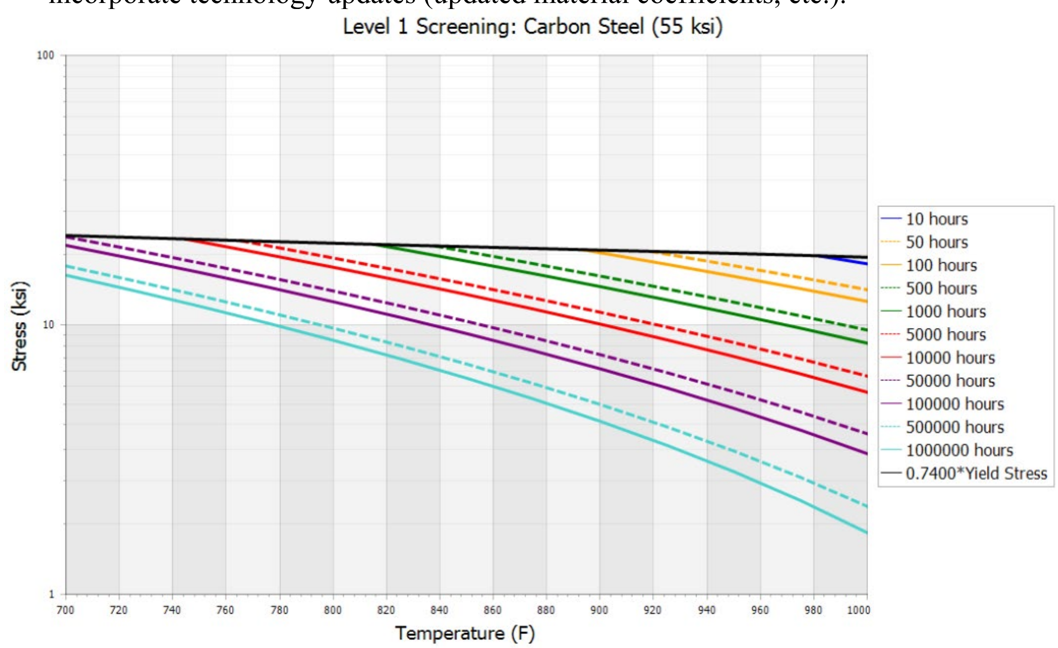
- Annex 9C: *Compendium of Reference Stress Solutions for Crack-like Flaws*
  - Expanded reference stress solutions to cover thick-wall cylinders.
  - Corrected errors with reference stress solutions for circumferential flaws in cylindrical shells subject to internal pressure.
- Annex 9F: *Material Properties for Crack-like Flaws*
  - Updated Wallin Master Curve fracture toughness correlation for carbon and low alloy steels

$$K_{mat} = 18.2 + (9.9 + 70.1exp[0.0106(T - T_o)])\left(ln\left[\frac{1}{1-P_f}\right] * \left(\frac{1}{L}\right)\right)^{0.25}$$

  - Added ductile tearing material property data. The data was included in the 2007 edition of API 579, but mistakenly removed in the 2016 edition.
  - Updated guidance on fracture toughness estimates for stainless-steel base metal and welds.
  - Incorporated guidance from WRC 562 *Recommendations for Establishing the Minimum Pressurization Temperature (MPT) for Equipment* and the API white paper *The Effects of Hydrogen for Establishing a Minimum Pressurization Temperature (MPT) for Heavy Wall Steel Reactor Vessels* to address material toughness modifications due to hydrogen and temper embrittlement effects.
  - Added guidance for ASME VIII-3 equipment (high pressure).
- New Annex 9H: *Constraint Effects for Surface Flaws in Carbon and Low-Alloy Steel Components in the Ductile-Brittle Transition Region*
  - Established a procedure to adjust material fracture toughness to take advantage of constraint effects for surface flaws in a Level 2 assessment.
  - Technical basis is documented in WRC 577 *Constraint Effects on Fracture Toughness in Ductile-Brittle Transition*.
- New Annex 9I: Alternative Estimate of Mode I Stress Intensity Factors
  - Established a procedure to reduce conservatism with the Mode I stress intensity factors using an integrated crack driving force over the crack front (rather than peak values) in a Level 2 assessment.
  - Technical basis is documented in WRC 577 *Constraint Effects on Fracture Toughness in Ductile-Brittle Transition*.
- New Annex 9J: *Determination of the Minimum Allowable Temperature (MAT) using a Fracture Mechanics Approach*
  - Established procedure for using fracture mechanics to determine the MAT.
  - Included a simplified brittle fracture screening procedure developed using fracture mechanics.
  - Provided guidance on the necessary adjustments for 2.25Cr-1Mo steel in hydrogen service and adjustments for temper embrittlement.



- Part 10: *Assessment of Components Operating in the Creep Range*
  - Updated Level 1 screening curves to ensure consistency with results from a Level 2 assessment and incorporate technology updates (updated material coefficients, etc.).



  - Revised Level 1 maximum permissible damage limit to 0.8 in the evaluation of multiple operating conditions.
  - Add structural thickness limit to Level 1 and Level 2 assessments to protect against loss of containment due to the challenges and limitations associated with inspection of furnace tubes.

$$t_{lim} = min(0.9t_{nom}, 0.100\ inches)$$

- Annex 10B: *Material Data for Creep Analysis*
  - Added new MPC Omega material coefficients
  - Added WRC 541 revision 3 Larson-Miller material coefficients.
  - Fixed elevated temperature fatigue curve coefficients.

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- Part 11: *Assessment of Fire Damage*
  - Extended the use of hardness testing to cover carbon steel, low chrome, and stainless-steel materials.
- Part 12: *Assessment of Dents, Gouges, and Dent-Gouge Combinations*
  - Updated Level 1 and Level 2 procedures, applicability and limitations, and acceptance criteria to align with The Pipeline Defect Assessment Manual (PDAM).
- Part 14: *Assessment of Fatigue Damage*
  - Added closed-form equation for smooth bar fatigue curves and data for new materials.
  - Added smooth bar fatigue curves based on fatigue testing in air.
  - Added bounds for use of smooth bar fatigue curve equations.
  - Updated fatigue screening Method C and Method D
  - Modified presentation of structural stress method for added clarity
  - Corrected plasticity correction factor, $K_{e,k}$
  - Re-wrote elastic ratcheting procedure using Bree Diagram
- Annex 14B: *Material Properties for Fatigue Analysis*
  - Added closed-form equation for smooth bar fatigue curves and added data for new materials.
  - Added smooth bar fatigue curves based on fatigue testing in air.
  - Added bounds for use of smooth bar fatigue curve equations.

WORK CURRENTLY IN-PROGRESS

A brief list of open actions within the committee are summarized below. Some items will be completed in time for inclusion in the next published edition of API 579, but others will likely be delayed until future releases of the standard. Work in-progress is broken into technology updates and new technology as follows.

FUTURE TECHNOLOGY UPDATES UNDER DEVELOPMENT:

- Part 3: *Assessment of Existing Equipment for Brittle Fracture*
  - Complete rewrite of Level 1 and Level 2 procedures and acceptance criteria to address numerous discrepancies and deficiencies (reference PVP2018-84795, PVP2018-84797, PVP2019-93207, and 2019 AIChE Paper Number 182d for additional details).
  - WRC 578 *Recommendations for Establishing the Minimum Allowable Temperature (MAT) Limits for Carbon and Low Alloy Steel Equipment and Piping* Under Development
- Part 5: *Assessment of Local Metal Loss*
  - Evaluate and document technical justification to relax Level 1 and Level 2 spacing requirements for structural discontinuities.
- Part 7: *Assessment of Hydrogen Blisters and Hydrogen Damage Associated with HIC and SOHIC*
  - Evaluate and document technical justification to relax current conservatism with evaluation of laminations (or laminar defects) in a hydrogen charging environment.
  - Evaluate and document technical justification to relax current conservatism with damage parameter, D_H, in the loss of strength assessment for HIC and SOHIC damage.
- Part 8: *Assessment of Weld Misalignment and Shell Distortions*
  - Develop Level 2 bulge procedures.
- Part 9: *Assessment of Crack-Like Flaws*

  - Update the Level 1 screening curves to gain consistency with results obtained from a Level 2 evaluation including recent technology updates (material toughness, etc.).
  - Re-evaluate guidance for weld residual stress distributions in use with fracture mechanics evaluations.
- Part 10: *Assessment of Components Operating in the Creep Range*
  - Update creep buckling evaluation methods.
- Part 14: *Assessment of Fatigue Damage*
  - Modifications for high cycle fatigue
- Opportunities for expanded guidance and upgrades to all Parts of API 579 are being reviewed for the application of FFS technology in the evaluation of atmospheric storage tanks.

NEW TECHNOLOGY UNDER DEVELOPMENT:

- New Part: *Assessment of High-Temperature Hydrogen Attack (HTHA)*
  This new Part will provide Level 1, Level 2, and Level 3 procedures for evaluation of HTHA damage in pressure vessels and piping. A draft of the new Part has been created and a task group is working to resolve remaining issues.
- New Part: *Assessment of Vibration*
  This new Part will provide Level 1, Level 2, and Level 3 procedures for evaluation of vibration damage (e.g. piping vibration). A draft of the new Part has been created and a task group is working to resolve remaining issues.
- New Part: *Assessment of Hot Spots*
  This new Part will provide Level 1, Level 2, and Level 3 procedures for evaluation of local hot spots. A task group has been established, but no draft of the new Part has been initiated yet.

API 579 FFS-2 EXAMPLE PROBLEMS MANUAL

In 2009, API/ASME published the first edition of API 579-2/ASME FFS-2 *Fitness-For-Service Example Problems Manual* (API 579-2). The document included 62 example problems generated using the assessment procedures consistent with the 2007 edition of API 579. The vast majority of the example problems were Level 1 or Level 2 assessments, but they served as a valuable tool for training and software validation. The second edition of the API 579-2 example problem manual is currently under development. The manual will include more than 85 example problems demonstrating application of Level 1, Level 2, and Level 3 FFS procedures from each Part of API 579. The next edition of API 579-2 will be in alignment with the 2021 edition of the API 579 standard. To expedite the process for publishing future example problem manuals, the API 579 committee has approved a proposal for future manuals to be delivered as ASME Pressure Technology Bulletin (PTB) documents.

E^{2}G INVOLVMENT IN API 579

FFS technology has proven to be a tremendously valuable and effective means to justify safe operation of equipment containing flaws or defects. The FFS standard has continuously evolved and improved since initial publication in 2000 and numerous changes and enhancements will be apparent with the publication of API 579-1/ASME FFS-1, 3rd Edition in 2021.

E^{2}G engineers were among the principal contributors of the landmark API 579 FFS standard when it was first developed and E^{2}G engineers remain at the forefront for advancing the technology incorporated within the standard. If there are any questions regarding the up-coming changes with API 579, please feel free to contact us.

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