FITNESS-FOR-SERVICE

API 579-1/ASME FFS-1, December 2021

AN INTERNATIONAL CODE

American Petroleum Institute

The American Society of Mechanical Engineers

ISBN 978-0-7918-7449-3

CONTENTS

FOREWORD

In contrast to the straightforward and conservative calculations that are typically found in design codes, more sophisticated assessment of metallurgical conditions and analyses of stresses and strains can more precisely indicate whether operating equipment is fit for its intended service or whether fabrication defects or in-service deterioration threaten its integrity. Such analyses offer a sound basis for decisions to continue to run as is or to alter, repair, monitor, retire or replace the equipment.

The publication of the American Petroleum Institute's Recommended Practice 579, Fitness-For-Service, in January 2000 provided the refining and petrochemical industry with a compendium of consensus methods for reliable assessment of the structural integrity of equipment containing identified flaws or damage. API RP 579 was written to be used in conjunction with the refining and petrochemical industry's existing codes for pressure vessels, piping and aboveground storage tanks (i.e., API 510, API 570 and API 653). The standardized Fitness-For-Service Assessment procedures presented in API RP 579 provide technically sound consensus approaches that ensure the safety of plant personnel and the public while aging equipment continues to operate and can be used to optimize maintenance and operation practices, maintain availability and enhance the long-term economic performance of plant equipment.

API RP 579 was prepared by a committee of the American Petroleum Institute with representatives of the Chemical Manufacturers Association, as well as some individuals associated with related industries. It grew out of a resource document developed by a Joint Industry Program on Fitness-For-Service administered by The Materials Properties Council. Although it incorporated the best practices known to the committee members, it was written as a Recommended Practice rather than as a mandatory standard or code.

While API was developing Fitness-For-Service methodology for the refining and petrochemical industry, the American Society of Mechanical Engineers (ASME) also began to address post-construction integrity issues. Realizing the possibility of overlap, duplication, and conflict in parallel standards, ASME and API formed the Joint Fitness-For-Service Committee in 2001 to develop and maintain a Fitness-For-Service standard for equipment operated in a wide range of process, manufacturing, and power generation industries. It was intended that this collaboration would promote the widespread adoption of these practices by regulatory bodies. The Joint Committee included the original members of the API Committee that were involved in the development of API Recommended Practice 579, complemented by a similar number of ASME members representing similar areas of expertise in other industries such as chemicals, power generation, and pulp and paper. In addition to owner representatives, it included substantial international participation and subject matter experts from universities and consulting firms.

In June 2007, the API and ASME Fitness-For-Service Joint Committee published the first edition of API 579-1/ASME FFS-1 Fitness-For-Service. The main enhancement in this publication relative to 2000 Edition API 579 was the addition of Part 10 covering the assessment of components operating in the creep range.

The 2016 Edition of API 579-1/ASME FFS-1 included many modifications and technical improvements. Some of the more significant changes are the following: reorganized the standard to facilitate use and updates by renumbering annexes that are directly associated with the relevant part of the document, Expanded equipment design code coverage, added a new annex for establishing an allowable Remaining Strength Factor (RSF), re-wrote weld residual stress solution annex for use in the assessment of crack-like flaws, updated guidance on material toughness predictions for use in the assessment of crack-like flaws, updated evaluation procedures for the assessment of creep damage, added an annex covering metallurgical investigation and evaluation of mechanical properties in a fire damage assessment, and developed new Part 14 covering the assessment of fatigue damage.

Numerous changes have been made for the 2021 Edition of API 579-1/ASME FFS-1 to address user feedback and to introduce new technology. A summary of these changes is provided on pages xxxv to xl.

This publication is written as a standard. Its words *shall* and *must* indicate explicit requirements that are essential for an assessment procedure to be correct. The word *should* indicate recommendations that are good practice but not essential. The word *may* indicate recommendations that are optional.

Most of the original technology that underlies this standard was developed by the Joint Industry Program on Fitness-For-Service, administered by The Materials Properties Council of the Welding Research Council, Inc., (WRC). The sponsorship of the member companies of this research consortium and the voluntary efforts of their company representatives are acknowledged with gratitude. Most of the next generation technology has been developed by WRC with some funding from API and ASME.

The committee encourages the broad use of the state-of-the-art methods presented here for evaluating all types of pressure vessels, boiler components, piping and tanks. The committee intends to continuously improve this standard as improved methodology is developed and as user feedback is received. All users are encouraged to inform the committee if they discover areas in which these procedures should be corrected, revised or expanded. Suggestions should be submitted to the Secretary, API/ASME Fitness-For-Service Joint Committee, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016, or SecretaryFFS@asme.org.

There is an option available to receive an e-mail notification when errata are posted to a particular code or standard. This option can be found on the Committee Web at http://go.asme.org/ffscommittee after selecting “errata” in the “Publication Information” section.

This standard is under the jurisdiction of the ASME Board on Pressure Technology Codes and Standards and the API CRE Committee and is the direct responsibility of the API/ASME Fitness-For-Service Joint Committee. The American National Standards Institute approved API 579-1/ASME FFS-1 2021 in December 2021.

SPECIAL NOTES

This international Code was developed under the ASME/API Joint Committee on Fitness-For-Service Policies and Procedures, which were approved by ANSI and accredited as meeting the criteria for American National Standards and it is an American National Standard. The Standards Committee that approved this Code was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed Code was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

This document addresses problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

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SUMMARY OF CHANGES

A summary of editorial corrections, updates, and clarifications that are included throughout the standard along with several technical changes and enhancements are described below.

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 before the allowable stress criteria in ASME VIII-2 changed from a factor of safety of 3.0 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 an 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 -29°C (-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 -29°C (-20°F) regardless of the year of manufacturing. (Note: Wording regarding "produced to fine grain practice" as currently included in ASME VIII-1 is not included).
  - 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."
- 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.

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

  - Added guidance that pressure rating in the stress ratio calculation can be calculated using paragraph 2C.3.4 for nozzle assemblies and paragraph 2C.3.6 for flanges.
  - Limited MAT to no lower than -48°C (-55°F) in as-welded condition even if Level 1 MAT was established using impact testing. (Note: MAT can still be reduced to -104°F (-155°F) if $PWHT$.)
    - Impact tested at or below -46°C (-50°F):

$$MAT = \max\left[\left(MAT_{Level\,1} - T_R\right),\ -104^{\circ}F\,(-155^{\circ}F)\right]$$

    - Impact tested above -46°C (-50°F):

$$MAT = \max\left[\left(MAT_{Level\,1} - T_R\right),\ -48^{\circ}F\,(-55^{\circ}F)\right] \quad \left(As - Welded\ Condition\right)$$

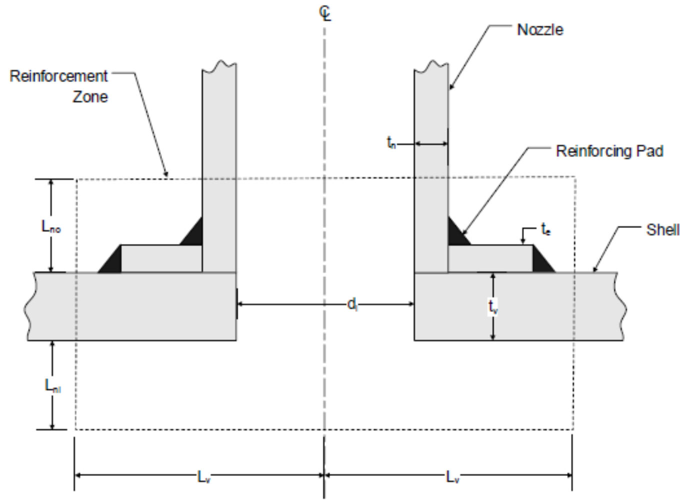
$$MAT = \max\left[\left(MAT_{Level\,1} - T_R\right),\ -104^{\circ}F\,(-155^{\circ}F)\right] \quad \left(PWHT\ Condition\right)$$

Part 4: *Assessment of General Metal Loss*

- Moved component type definitions and examples to a table to simplify designations.
- 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).
- Revised qualifications to utilize Point Thickness Reading (PTR) approach to prevent misapplication of the method and "washing out" of local damage.

- Eliminated the check on Coefficient of Variation (COV).
- Added limitation on minimum measured thickness, i.e., $t_{mm} \geq 0.9 \cdot t_{avg}$.

- 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

Notes:

1. Thickness averaging zone in the horizontal direction (see paragraph 4.3.3.4.a): $L_H = \min[L,\ L_v]$. L is calculated using Equation 4.7. $L_v = \max[d_i,\ (d_i/2 + t_n + t_v)]$.
2. Thickness averaging zone in the vertical direction on the outside of the shell (see paragraph 4.3.3.4.a). $L_{vno} = \min[L, L_{no}]$ L is calculated using Equation 4.7. $L_{no} = \min[2.5t_v,\ (2.5t_n + t_e)]$.
3. Thickness averaging zone in the vertical direction on the inside of the shell (see paragraph 4.3.3.4.a): $L_{vni} = \min[L, L_{ni}]$. L is calculated using Equation 4.7. $L_{ni} = \min[2.5t_v,\ 2.5t_n]$.

Figure 4.13 – Zone for Thickness Averaging – Nozzles and Fabricated Branch Connections

- Revised recommended UT grid spacing for scenarios when “corroded surface is not accessible for visual inspection, $L_s = \min[2t_{rd}, 25\ mm\ (1\ inch)]$.
- 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 2.5 mm (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.
- Table 9.2 updated to reflect new Wallin Master Curve fracture toughness correlation for carbon and low alloy steels in Annex 9F.

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*

- Updated solutions for circumferential flaws in cylinders.
- Expanded reference solutions to cover thick-wall cylinders.

Annex 9F: *Material Properties for Crack-like Flaws*

- Updated Wallin Master Curve fracture toughness correlation for carbon and low alloy steels,

$$K_{Jc} = 20 + \left(11 + 77\exp\left[0.0190\left(T - T_0\right)\right]\right)\left(\ln\left[\frac{1}{1-P_f}\right]\cdot\left(\frac{25}{L}\right)\right)^{0.25} \qquad \left(MPa\sqrt{m},\, ^\circ C,\, mm\right)$$

$$K_{Jc} = 18.2 + \left(9.9 + 70.1\exp\left[0.0106\left(T - T_0\right)\right]\right)\left(\ln\left[\frac{1}{1-P_f}\right]\cdot\left(\frac{1}{L}\right)\right)^{0.25} \qquad \left(ksi\sqrt{in},\, ^\circ F,\, in\right)$$

- 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 Bulletin 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*

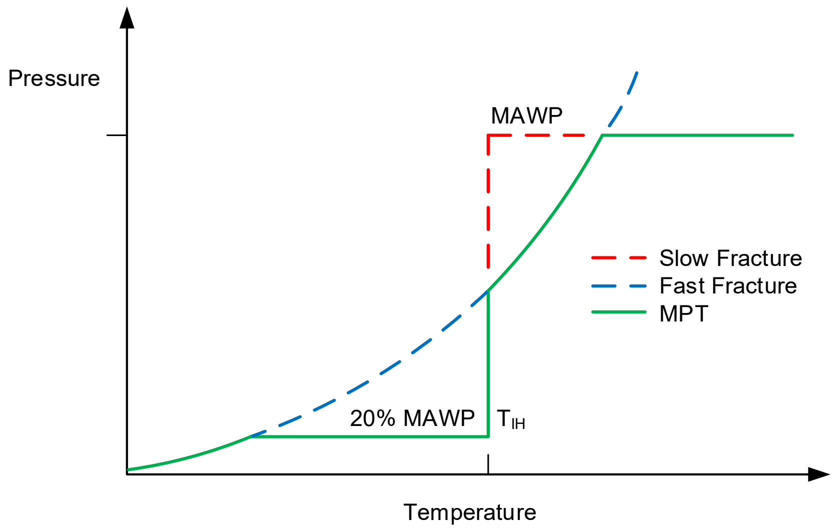
- Established a procedure to adjust material fracture toughness to take advantage of constraint effects for surface flaws in a Level 2 Assessment.
- Technical basis is documented in WRC Bulletin 577 *Constraint Effects on Fracture Toughness in Ductile-Brittle Transition*.

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 Bulletin 577 *Constraint Effects on Fracture Toughness in Ductile-Brittle Transition*.

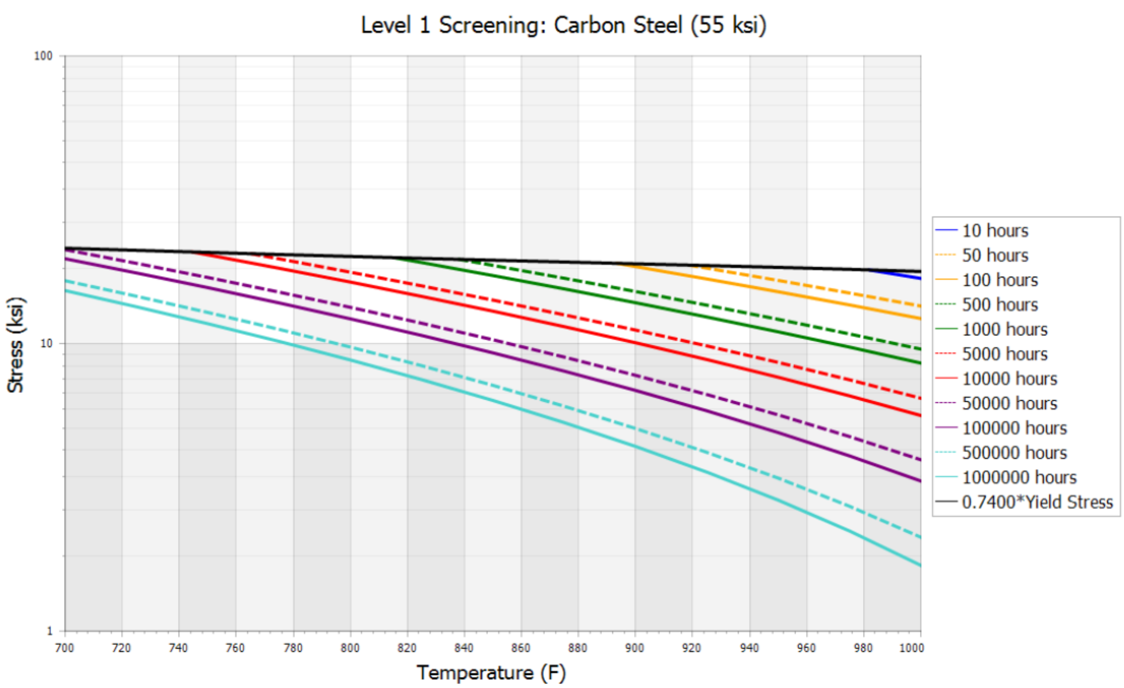
New Annex 9J: *Determination of the Minimum Allowable Temperature (MAT) using a Fracture Mechanics Approach*

- 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.



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.

$$t_{\lim} = \min\left[0.9t_{nom},\ 2.5\,mm\ (0.100\ inches)\right]$$

Annex 10B: *Material Data for Creep Analysis*

- Updated existing and added new MPC Omega material coefficients.

- Added WRC Bulletin 541 revision 3 Larson-Miller material coefficients.
- Fixed elevated temperature fatigue curve coefficients.

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).
- Table 12.2 updated to reflect new Wallin Master Curve fracture toughness correlation for carbon and low alloy steels in Annex 9F.

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.
- Corrected plasticity correction factor, $K_{e,k}$.
- Elastic ratcheting procedure re-written using Bree Diagram.
- Updated Level 2 procedure for Method C Fatigue Assessment.

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.

PART 1 – INTRODUCTION

CONTENTS

1.1 Introduction

1.1.1 Construction Codes and Fitness-For-Service

The ASME and API new construction 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 rules to evaluate equipment that degrades while in-service and deficiencies caused by degradation or from original fabrication that may be found during subsequent inspections. API 510, API 570, API 653, and NB-23 Codes/Standards for the inspection, repair, alteration, and rerating of in-service pressure vessels, piping systems, and storage tanks do address the fact that equipment degrades while in service.

1.1.2 Fitness-For-Service Definition

Fitness-For-Service (FFS) Assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage, or that may be operating under a specific condition that might cause a failure. This Standard provides guidance for conducting FFS Assessments using methodologies specifically prepared for pressurized equipment. The guidelines provided in this Standard can be used to make run-repair-replace decisions to help determine if components in pressurized