

FITNESS-FOR-SERVICE

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

AN INTERNATIONAL CODE



American
Petroleum
Institute



**The American Society of
Mechanical Engineers**

All rights reserved. No part of this work may be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher.

Contact the Publisher, API Publishing Services, 1220 L Street, N.W., Washington, D.C. 20005.

Copyright © 2021 by the American Petroleum Institute and The American Society of Mechanical Engineers

ISBN 978-0-7918-7449-3

CONTENTS

| | |
|---|---------------|
| FOREWORD | XXIX |
| SPECIAL NOTES | XXXI |
| SUMMARY OF CHANGES | XXXIII |
| | |
| PART 1 – INTRODUCTION | 1-1 |
| 1.1 INTRODUCTION | 1-1 |
| 1.1.1 <i>Construction Codes and Fitness-For-Service</i> | 1-1 |
| 1.1.2 <i>Fitness-For-Service Definition</i> | 1-1 |
| 1.2 SCOPE | 1-2 |
| 1.2.1 <i>Supplement to In-Service Inspection Codes</i> | 1-2 |
| 1.2.2 <i>Application Construction Codes</i> | 1-2 |
| 1.2.3 <i>Other Recognized Codes and Standards</i> | 1-2 |
| 1.2.4 <i>Remaining Life</i> | 1-3 |
| 1.2.5 <i>Assessment Methods for Flaw Types and Damage Conditions</i> | 1-3 |
| 1.2.6 <i>Special Cases</i> | 1-3 |
| 1.3 ORGANIZATION AND USE | 1-4 |
| 1.4 RESPONSIBILITIES | 1-4 |
| 1.4.1 <i>Owner-User</i> | 1-4 |
| 1.4.2 <i>Inspector</i> | 1-4 |
| 1.4.3 <i>Engineer</i> | 1-4 |
| 1.4.4 <i>Plant Engineer</i> | 1-5 |
| 1.5 QUALIFICATIONS | 1-5 |
| 1.5.1 <i>Education and Experience</i> | 1-5 |
| 1.5.2 <i>Owner-User</i> | 1-5 |
| 1.5.3 <i>Inspector</i> | 1-5 |
| 1.5.4 <i>Engineer</i> | 1-6 |
| 1.6 DEFINITION OF TERMS | 1-6 |
| 1.7 REFERENCES | 1-6 |
| 1.7.1 <i>Types</i> | 1-6 |
| 1.7.2 <i>Code, Standards and Recommended Practices</i> | 1-6 |
| 1.7.3 <i>Technical reports and Other Publications</i> | 1-6 |
| 1.8 TABLES | 1-7 |
| | |
| ANNEX 1A – GLOSSARY OF TERMS AND DEFINITIONS | 1A-1 |
| | |
| PART 2 – FITNESS-FOR-SERVICE ENGINEERING ASSESSMENT PROCEDURE | 2-1 |
| 2.1 GENERAL | 2-1 |
| 2.1.1 <i>Fitness-For-Service and Continued Operation</i> | 2-1 |
| 2.1.2 <i>Organization by Flaw Type and Damage Mechanism</i> | 2-2 |
| 2.1.3 <i>FFS Assessment Procedure</i> | 2-2 |
| 2.2 APPLICABILITY AND LIMITATIONS OF THE FFS ASSESSMENT PROCEDURES | 2-3 |
| 2.2.1 <i>FFS Procedures for Pressurized or Unpressurized Components</i> | 2-3 |
| 2.2.2 <i>Component Definition</i> | 2-3 |
| 2.2.3 <i>Construction Codes</i> | 2-3 |

API 579-1/ASME FFS-1 2021 Fitness-For-Service

2.2.4 *Specific Applicability and Limitations* 2-3

2.3 DATA REQUIREMENTS..... 2-4

2.3.1 *Original Equipment Design Data*..... 2-4

2.3.2 *Maintenance and Operational History* 2-5

2.3.3 *Required Data/Measurements for an FFS Assessment* 2-6

2.3.4 *Recommendations for Inspection Technique and Sizing Requirements*..... 2-6

2.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA 2-6

2.4.1 *Assessment Levels* 2-6

2.4.2 *FFS Acceptance Criteria*..... 2-7

2.4.3 *Data Uncertainties* 2-8

2.5 REMAINING LIFE ASSESSMENT 2-9

2.5.1 *Remaining Life* 2-9

2.5.2 *Guidance on Remaining Life Determination* 2-10

2.6 REMEDIATION..... 2-10

2.6.1 *Requirements for Remediation* 2-10

2.6.2 *Guidelines for Remediation*..... 2-10

2.7 IN-SERVICE MONITORING..... 2-10

2.8 DOCUMENTATION 2-11

2.8.1 *General* 2-11

2.8.2 *Applicability and Limitations*..... 2-11

2.8.3 *Data Requirements* 2-11

2.8.4 *Assessment Techniques and Acceptance Criteria* 2-11

2.8.5 *Remaining Life Assessment* 2-12

2.8.6 *Remediation Methods* 2-12

2.8.7 *In-Service Monitoring*..... 2-12

2.8.8 *Retention*..... 2-12

2.9 NOMENCLATURE..... 2-12

2.10 REFERENCES 2-13

2.11 TABLES 2-14

2.12 FIGURES 2-16

ANNEX 2A – TECHNICAL BASIS AND VALIDATION – FITNESS-FOR-SERVICE ENGINEERING ASSESSMENT PROCEDURE..... 2A-1

2A.1 TECHNICAL BASIS AND VALIDATION..... 2A-1

2A.2 REFERENCES..... 2A-1

ANNEX 2B – DAMAGE MECHANISMS 2B-1

2B.1 DETERIORATION AND FAILURE MODES..... 2B-1

2B.2 FFS ASSESSMENT AND THE IDENTIFICATION OF DAMAGE MECHANISMS..... 2B-1

2B.3 PRE-SERVICE DEFICIENCIES 2B-2

2B.3.1 *Types of Pre-Service Deficiencies* 2B-2

2B.3.2 *In-Service Inspection*..... 2B-2

2B.4 IN-SERVICE DETERIORATION AND DAMAGE 2B-2

2B.4.1 *Overview* 2B-2

2B.4.2 *General Metal Loss Due to Corrosion and/or Erosion*..... 2B-3

2B.4.3 *Localized Metal Loss Due to Corrosion and/or Erosion*..... 2B-3

2B.4.4 *Surface Connected Cracking* 2B-4

2B.4.5 *Subsurface Cracking and Microfissuring/Microvoid Formation*..... 2B-5

2B.4.6 *Metallurgical Changes*..... 2B-6

API 579-1/ASME FFS-1 2021 Fitness-For-Service

| | | |
|---|--|-------|
| 2B.5 | REFERENCES..... | 2B-7 |
| 2B.6 | TABLES | 2B-8 |
| | | |
| ANNEX 2C – THICKNESS, MAWP AND STRESS EQUATIONS FOR AN FFS ASSESSMENT..... | 2C-1 | |
| 2C.1 | GENERAL | 2C-2 |
| 2C.1.1 | Scope..... | 2C-2 |
| 2C.1.2 | MAWP and MFH | 2C-2 |
| 2C.1.3 | Construction Codes and Common Rules..... | 2C-2 |
| 2C.1.4 | Use of VIII-2 Design Equations..... | 2C-3 |
| 2C.2 | CALCULATION OF T_{MIN} , MAWP (MFH), AND MEMBRANE STRESS | 2C-3 |
| 2C.2.1 | Overview | 2C-3 |
| 2C.2.2 | Minimum Required Wall Thickness and MAWP (MFH) | 2C-3 |
| 2C.2.3 | Code Revisions | 2C-4 |
| 2C.2.4 | Determination of Allowable Stresses | 2C-4 |
| 2C.2.5 | Treatment of Weld and Riveted Joint Efficiency, and Ligament Efficiency | 2C-5 |
| 2C.2.6 | Treatment of Damage in Formed Heads..... | 2C-6 |
| 2C.2.7 | Thickness for Supplemental Loads | 2C-7 |
| 2C.2.7.1 | Definition..... | 2C-7 |
| 2C.2.7.2 | Required Thickness | 2C-7 |
| 2C.2.7.3 | Vertical Vessels..... | 2C-7 |
| 2C.2.7.4 | Design-by-Rule Using VIII-2..... | 2C-8 |
| 2C.2.7.5 | Piping Systems..... | 2C-8 |
| 2C.2.8 | Determination of Metal Loss and Future Corrosion Allowance..... | 2C-8 |
| 2C.2.9 | Treatment of Metal Loss and Future Corrosion Allowance | 2C-8 |
| 2C.2.10 | Treatment of Shell Distortions..... | 2C-8 |
| 2C.3 | PRESSURE VESSELS AND BOILER COMPONENTS – INTERNAL PRESSURE | 2C-9 |
| 2C.3.1 | Overview | 2C-9 |
| 2C.3.2 | Shell Tolerances | 2C-9 |
| 2C.3.3 | Shell Thickness and MAWP..... | 2C-9 |
| 2C.3.3.1 | Cylindrical Shells..... | 2C-9 |
| 2C.3.3.2 | Spherical Shell or Hemispherical Head | 2C-10 |
| 2C.3.3.3 | Elliptical Head..... | 2C-11 |
| 2C.3.3.4 | Torispherical Head..... | 2C-11 |
| 2C.3.3.5 | Conical Shell..... | 2C-12 |
| 2C.3.3.6 | Toriconical Head | 2C-13 |
| 2C.3.3.7 | Conical Transition | 2C-13 |
| 2C.3.4 | Nozzles Connections in Shells..... | 2C-16 |
| 2C.3.4.1 | General..... | 2C-16 |
| 2C.3.4.2 | Required Reinforcement..... | 2C-16 |
| 2C.3.4.3 | Weld Strength Analysis | 2C-17 |
| 2C.3.5 | Junction Reinforcement Requirements at Conical Transitions | 2C-19 |
| 2C.3.6 | Other Components | 2C-19 |
| 2C.4 | PRESSURE VESSELS AND BOILER COMPONENTS – EXTERNAL PRESSURE | 2C-20 |
| 2C.5 | PIPING COMPONENTS AND BOILER TUBES..... | 2C-20 |
| 2C.5.1 | Overview | 2C-20 |
| 2C.5.2 | Metal Loss..... | 2C-20 |
| 2C.5.3 | Required Thickness and MAWP – Straight Pipes Subject to Internal Pressure..... | 2C-20 |
| 2C.5.4 | Required Thickness and MAWP – Boiler Tubes..... | 2C-21 |
| 2C.5.5 | Required Thickness and MAWP – Pipe Bends Subject to Internal Pressure..... | 2C-21 |
| 2C.5.6 | Required Thickness and MAWP for External Pressure | 2C-23 |
| 2C.5.7 | Branch Connections | 2C-23 |

API 579-1/ASME FFS-1 2021 Fitness-For-Service

2C.6 API 650 STORAGE TANKS2C-23
 2C.6.1 *Overview*2C-23
 2C.6.2 *Metal Loss*2C-24
 2C.6.3 *Required Thickness and MFH for Liquid Hydrostatic Loading*2C-24
2C.7 ESTIMATION OF BURST PRESSURE2C-24
 2C.7.1 *Svensson’s Method*2C-24
 2C.7.2 *Cylindrical Shell Burst Pressure*2C-25
 2C.7.3 *Spherical Shell Burst Pressure*2C-25
2C.8 NOMENCLATURE2C-26
2C.9 REFERENCES2C-32
2C.10 TABLES2C-34
2C.11 FIGURES2C-36

ANNEX 2D – STRESS ANALYSIS OVERVIEW FOR AN FFS ASSESSMENT2D-1

2D.1 GENERAL REQUIREMENTS2D-1
 2D.1.1 *Scope*2D-1
 2D.1.2 *ASME B&PV Code, Section VIII, Division 2 (VIII-2)*2D-1
 2D.1.3 *Applicability*2D-2
 2D.1.4 *Protection Against Failure Modes*2D-2
 2D.1.5 *Numerical Analysis*2D-2
 2D.1.6 *Material Properties*2D-2
 2D.1.7 *Applicable Loads and Load Case Combinations*2D-3
 2D.1.8 *Loading Histogram*2D-3
2D.2 PROTECTION AGAINST PLASTIC COLLAPSE2D-4
 2D.2.1 *Overview*2D-4
 2D.2.2 *Elastic Stress Analysis Method*2D-4
 2D.2.3 *Limit Load Analysis Method*2D-4
 2D.2.4 *Elastic-Plastic Stress Analysis Method*2D-4
 2D.2.5 *Treatment of the Weld Joint Efficiency*2D-4
2D.3 PROTECTION AGAINST LOCAL FAILURE2D-5
 2D.3.1 *Overview*2D-5
 2D.3.2 *Elastic Analysis Method*2D-5
 2D.3.3 *Elastic-Plastic Analysis Method*2D-6
2D.4 PROTECTION AGAINST COLLAPSE FROM BUCKLING2D-6
 2D.4.1 *Assessment Procedure*2D-6
 2D.4.2 *Supplemental Requirements for Components with Flaws*2D-6
2D.5 SUPPLEMENTAL REQUIREMENTS FOR STRESS CLASSIFICATION IN NOZZLE NECKS2D-6
2D.6 NOMENCLATURE2D-6
2D.7 REFERENCES2D-7
2D.8 TABLES2D-8

ANNEX 2E – MATERIAL PROPERTIES FOR STRESS ANALYSIS 2E-1

2E.1 GENERAL 2E-1
 2E.1.1 *Material Properties Required* 2E-1
 2E.1.2 *Material Properties and In-Service Degradation* 2E-2
2E.2 STRENGTH PARAMETERS 2E-2
 2E.2.1 *Yield and Tensile Strength* 2E-2
 2E.2.1.1 *Mean Estimates of Tensile Strength from Hardness Tests* 2E-2
 2E.2.1.2 *Minimum Specified Yield and Tensile Strength from MPC Correlations* 2E-2

API 579-1/ASME FFS-1 2021 Fitness-For-Service

| | | |
|---|--|-------------|
| 2E.2.1.3 | Minimum Specified Yield and Tensile Strength from API Std 530 and WRC Bulletin 541 | 2E-3 |
| 2E.2.1.4 | Minimum Specified Yield and Tensile Strength Data from ASME Code, Section II, Part D | 2E-3 |
| 2E.2.1.5 | Mean Values of Yield and tensile Strength from Minimum Specified Values | 2E-3 |
| 2E.2.2 | Flow Stress | 2E-3 |
| 2E.2.2.1 | Definition | 2E-3 |
| 2E.2.2.2 | Estimation of Flow Stress | 2E-3 |
| 2E.3 | MONOTONIC STRESS-STRAIN RELATIONSHIPS | 2E-4 |
| 2E.3.1 | <i>MPC True Stress-Strain Curve Model</i> | 2E-4 |
| 2E.3.2 | <i>MPC Tangent Modulus Model</i> | 2E-5 |
| 2E.3.3 | <i>Ramberg-Osgood Stress-Strain Model</i> | 2E-6 |
| 2E.3.3.1 | True Stress-Strain Curve | 2E-6 |
| 2E.3.3.2 | Engineering Stress-Strain Curve | 2E-7 |
| 2E.3.4 | <i>Ramberg-Osgood Tangent Modulus Model</i> | 2E-8 |
| 2E.3.5 | <i>Engineering Stress-Strain Models for API 5L Pipeline Materials</i> | 2E-8 |
| 2E.3.5.1 | Stress-Strain Model from CSA Z662 | 2E-8 |
| 2E.3.5.2 | API 5L Grades X52 to X80 | 2E-8 |
| 2E.3.5.3 | API 5L Grades X80 to X100 | 2E-8 |
| 2E.3.6 | <i>Tangent Modulus Model for API 5L Pipeline Materials</i> | 2E-10 |
| 2E.4 | CYCLIC STRESS-STRAIN RELATIONSHIPS | 2E-10 |
| 2E.4.1 | <i>Ramberg-Osgood Equation</i> | 2E-10 |
| 2E.4.2 | <i>Estimation of Cyclic Stress-Strain Curve Parameters</i> | 2E-10 |
| 2E.4.2.1 | Estimation from Monotonic Properties | 2E-10 |
| 2E.4.2.2 | Uniform Material Law | 2E-11 |
| 2E.5 | PHYSICAL PROPERTIES | 2E-11 |
| 2E.5.1 | <i>Elastic Modulus</i> | 2E-11 |
| 2E.5.2 | <i>Poisson's Ratio</i> | 2E-11 |
| 2E.5.3 | <i>Coefficient of Thermal Expansion</i> | 2E-11 |
| 2E.5.4 | <i>Thermal Conductivity</i> | 2E-11 |
| 2E.5.5 | <i>Thermal Diffusivity</i> | 2E-11 |
| 2E.5.6 | <i>Density</i> | 2E-12 |
| 2E.6 | NOMENCLATURE | 2E-12 |
| 2E.7 | REFERENCES | 2E-14 |
| 2E.8 | TABLES | 2E-16 |
| ANNEX 2F – ALTERNATIVE METHOD FOR ESTABLISHING THE REMAINING STRENGTH FACTOR | | 2F-1 |
| 2F.1 | OVERVIEW | 2F-1 |
| 2F.2 | ESTABLISHING AN ALLOWABLE REMAINING STRENGTH FACTOR – RSF_A | 2F-1 |
| 2F.3 | NOMENCLATURE | 2F-2 |
| 2F.4 | REFERENCES | 2F-2 |
| PART 3 – ASSESSMENT OF EXISTING EQUIPMENT FOR BRITTLE FRACTURE | | 3-1 |
| 3.1 | GENERAL | 3-2 |
| 3.1.1 | <i>Evaluation of Resistance to Brittle Fracture</i> | 3-2 |
| 3.1.2 | <i>Avoidance of Catastrophic Brittle Fracture</i> | 3-2 |
| 3.1.3 | <i>Use of Construction Codes and Standards for Brittle Fracture Assessment</i> | 3-2 |
| 3.1.4 | <i>Boilers and Boiler External Piping</i> | 3-2 |
| 3.1.5 | <i>Supplemental Brittle Fracture Assessment to Other FFS Assessment Procedures</i> | 3-2 |
| 3.1.6 | <i>Critical Exposure Temperature (CET)</i> | 3-3 |
| 3.1.7 | <i>Minimum Allowable Temperature (MAT)</i> | 3-3 |
| 3.2 | APPLICABILITY AND LIMITATIONS OF THE PROCEDURE | 3-3 |

API 579-1/ASME FFS-1 2021 Fitness-For-Service

3.2.1 *Equipment Covered*..... 3-3
3.2.2 *Components Subject to Metal Loss* 3-4
3.2.3 *Requirements for In-Service Inspection and Maintenance Programs*..... 3-4
3.2.4 *Supplemental Guidance for SA-212 Grade B Material* 3-4
3.3 DATA REQUIREMENTS..... 3-4
3.3.1 *Original Equipment Design Data* 3-5
3.3.2 *Maintenance and Operational History* 3-5
3.3.3 *Required Data/Measurements for an FFS Assessment* 3-5
3.3.4 *Recommendations for Inspection Technique and Sizing Requirements*..... 3-6
3.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 3-6
3.4.1 *Overview* 3-6
3.4.2 *Level 1 Assessment* 3-7
3.4.3 *Level 2 Assessment* 3-10
3.4.4 *Level 3 Assessment* 3-15
3.5 REMAINING LIFE ASSESSMENT 3-16
3.5.1 *Acceptability for Continued Service* 3-16
3.5.2 *Pressure Vessels* 3-17
3.5.3 *Piping Systems*..... 3-17
3.5.4 *Atmospheric and Low Pressure Storage Tanks*..... 3-17
3.6 REMEDIATION 3-17
3.6.1 *Potential Use of Remediation Methods* 3-17
3.6.2 *Remediation Methods* 3-17
3.7 IN-SERVICE MONITORING..... 3-19
3.7.1 *In-Service Monitoring and Control of Process Conditions* 3-19
3.7.2 *Monitoring for Degradation of Low Alloy Steel Notch Toughness* 3-19
3.7.3 *Monitoring for Criticality of Growing Flaws*..... 3-19
3.7.4 *Assessment of Non-Growing Flaws Detected In-Service*..... 3-19
3.8 DOCUMENTATION 3-19
3.8.1 *Documentation Requirements for Each Assessment Level* 3-19
3.8.2 *Documentation Retention* 3-20
3.9 NOMENCLATURE..... 3-20
3.10 REFERENCES..... 3-21
3.11 TABLES 3-22
3.12 FIGURES 3-28

ANNEX 3A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF EXISTING EQUIPMENT FOR BRITTLE FRACTURE **3A-1**
3A.1 TECHNICAL BASIS AND VALIDATION 3A-1
3A.2 REFERENCES 3A-1

PART 4 – ASSESSMENT OF GENERAL METAL LOSS **4-1**
4.1 GENERAL 4-1
4.1.1 *Assessment Procedures for General Metal Loss*..... 4-1
4.1.2 *Thickness Averaging Approach Used for the Assessment*..... 4-1
4.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 4-2
4.2.1 *General Metal Loss Assessment*..... 4-2
4.2.2 *Limitations Based on Flaw Type*..... 4-2
4.2.3 *Calculation of the MAWP_r and MFH_r and Coincident Temperature* 4-2

API 579-1/ASME FFS-1 2021 Fitness-For-Service

| | | |
|---|--|-------------|
| 4.2.4 | <i>Limitations Based on Temperature</i> | 4-2 |
| 4.2.5 | <i>Definition of Component Types</i> | 4-2 |
| 4.2.6 | <i>Applicability of the Level 1 and Level 2 Assessment Procedures</i> | 4-2 |
| 4.2.7 | <i>Applicability of the Level 3 Assessment Procedures</i> | 4-3 |
| 4.3 | DATA REQUIREMENTS..... | 4-3 |
| 4.3.1 | <i>Original Equipment Design Data</i> | 4-3 |
| 4.3.2 | <i>Maintenance and Operational History</i> | 4-3 |
| 4.3.3 | <i>Required Data/Measurements for an FFS Assessment</i> | 4-4 |
| 4.3.4 | <i>Recommendations for Inspection Technique and Sizing Requirements</i> | 4-6 |
| 4.4 | ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... | 4-7 |
| 4.4.1 | <i>Overview</i> | 4-7 |
| 4.4.2 | <i>Level 1 Assessment</i> | 4-8 |
| 4.4.3 | <i>Level 2 Assessment</i> | 4-9 |
| 4.4.4 | <i>Level 3 Assessment</i> | 4-11 |
| 4.5 | REMAINING LIFE ASSESSMENT | 4-12 |
| 4.5.1 | <i>Thickness Approach</i> | 4-12 |
| 4.5.2 | <i>MAWP Approach</i> | 4-12 |
| 4.6 | REMEDIATION | 4-13 |
| 4.6.1 | <i>Objectives</i> | 4-13 |
| 4.6.2 | <i>Methods</i> | 4-13 |
| 4.7 | IN-SERVICE MONITORING..... | 4-15 |
| 4.7.1 | <i>Objectives</i> | 4-15 |
| 4.7.2 | <i>Monitoring Methods</i> | 4-15 |
| 4.7.3 | <i>Calibration</i> | 4-15 |
| 4.8 | DOCUMENTATION | 4-15 |
| 4.8.1 | <i>General</i> | 4-15 |
| 4.8.2 | <i>Inspection Data</i> | 4-15 |
| 4.9 | NOMENCLATURE..... | 4-15 |
| 4.10 | REFERENCES..... | 4-18 |
| 4.11 | TABLES | 4-19 |
| 4.12 | FIGURES | 4-28 |
| ANNEX 4A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF GENERAL METAL LOSS | | 4A-1 |
| 4A.1 | TECHNICAL BASIS AND VALIDATION..... | 4A-1 |
| 4A.2 | REFERENCES | 4A-1 |
| PART 5 – ASSESSMENT OF LOCAL METAL LOSS | | 5-1 |
| 5.1 | GENERAL | 5-1 |
| 5.1.1 | <i>Assessment Procedures for Local Metal Loss</i> | 5-1 |
| 5.1.2 | <i>Choice of Part 4 or Part 5 Assessment Procedures</i> | 5-2 |
| 5.1.3 | <i>Pitting Damage</i> | 5-2 |
| 5.2 | APPLICABILITY AND LIMITATIONS OF THE PROCEDURE | 5-2 |
| 5.2.1 | <i>Local Metal Loss Assessment</i> | 5-2 |
| 5.2.2 | <i>Limitations Based on Flaw Type</i> | 5-2 |
| 5.2.3 | <i>Calculation of the MAWP_r and MFH_r, and Coincident Temperature</i> | 5-2 |
| 5.2.4 | <i>Limitations Based on Temperature</i> | 5-3 |
| 5.2.5 | <i>Applicability of the Level 1 and Level 2 Assessment Procedures</i> | 5-3 |
| 5.2.6 | <i>Applicability of the Level 3 Assessment Procedures</i> | 5-3 |

API 579-1/ASME FFS-1 2021 Fitness-For-Service

5.2.7 *Assessment of Blend Ground Areas for Crack-Like Flaw Removal*..... 5-4

5.3 DATA REQUIREMENTS..... 5-4

5.3.1 *Original Equipment Design Data* 5-4

5.3.2 *Maintenance and Operational History* 5-4

5.3.3 *Required Data/Measurements for an FFS Assessment* 5-4

5.3.4 *Recommendations for Inspection Technique and Sizing Requirements*..... 5-5

5.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 5-6

5.4.1 *Overview* 5-6

5.4.2 *Level 1 Assessment* 5-6

5.4.3 *Level 2 Assessment* 5-8

5.4.4 *Level 3 Assessment* 5-14

5.5 REMAINING LIFE ASSESSMENT 5-14

5.5.1 *Thickness Approach* 5-14

5.5.2 *MAWP Approach*..... 5-15

5.6 REMEDIATION 5-15

5.7 IN-SERVICE MONITORING..... 5-15

5.8 DOCUMENTATION 5-15

5.8.1 *General*..... 5-15

5.8.2 *Inspection Data* 5-15

5.9 NOMENCLATURE..... 5-16

5.10 REFERENCES..... 5-20

5.11 TABLES 5-21

5.12 FIGURES 5-27

ANNEX 5A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF LOCAL METAL LOSS 5A-1

5A.1 TECHNICAL BASIS AND VALIDATION..... 5A-1

5A.2 REFERENCES 5A-1

PART 6 – ASSESSMENT OF PITTING CORROSION 6-1

6.1 GENERAL 6-1

6.1.1 *Assessment of Pitting Corrosion*..... 6-1

6.1.2 *Assessment of Blister Arrays* 6-1

6.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 6-1

6.2.1 *Assessment of Four Types of Pitting Corrosion* 6-2

6.2.2 *Calculation of the MAWP_r and MFH_r and Coincident Temperature* 6-2

6.2.3 *Limitations Based on Flaw Type*..... 6-2

6.2.4 *Limitations Based on Temperature* 6-2

6.2.5 *Applicability of the Level 1 and Level 2 Assessment Procedures* 6-2

6.2.6 *Applicability of the Level 3 Assessment Procedures*..... 6-3

6.2.7 *Assessment for Active Pitting Corrosion* 6-3

6.2.8 *Future Corrosion Allowance*..... 6-3

6.3 DATA REQUIREMENTS..... 6-4

6.3.1 *Original Equipment Design Data* 6-4

6.3.2 *Maintenance and Operational History* 6-4

6.3.3 *Required Data/Measurements for an FFS Assessment* 6-4

6.3.4 *Recommendation for Inspection Technique and Sizing Requirements*..... 6-5

6.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 6-6

6.4.1 *Overview* 6-6

API 579-1/ASME FFS-1 2021 Fitness-For-Service

6.4.2 Level 1 Assessment 6-6
6.4.3 Level 2 Assessment 6-8
6.4.4 Level 3 Assessment 6-13
6.5 REMAINING LIFE ASSESSMENT 6-14
6.5.1 MAWP Approach..... 6-14
6.5.2 MAWP Procedure for Remaining Life Determination 6-14
6.6 REMEDIATION 6-15
6.7 IN-SERVICE MONITORING..... 6-15
6.8 DOCUMENTATION 6-15
6.8.1 General..... 6-15
6.8.2 Inspection Data 6-15
6.9 NOMENCLATURE..... 6-15
6.10 REFERENCES..... 6-18
6.11 TABLES 6-19
6.12 FIGURES 6-21

ANNEX 6A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF PITTING CORROSION..... 6A-1

6A.1 TECHNICAL BASIS AND VALIDATION..... 6A-1
6A.2 REFERENCES 6A-1

PART 7 – ASSESSMENT OF HYDROGEN BLISTERS AND HYDROGEN DAMAGE ASSOCIATED WITH HIC AND SOHIC 7-1

7.1 GENERAL 7-2
7.1.1 Assessment Procedures for Hydrogen Blisters, HIC and SOHIC 7-2
7.1.2 HIC Definition..... 7-2
7.1.3 SOHIC Definition..... 7-2
7.1.4 Hydrogen Blistering Definition..... 7-2
7.1.5 HIC, SOHIC and Blistering Distinct Damage Types 7-3
7.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 7-3
7.2.1 HIC, SOHIC and Blistering Distinct Damage Types 7-3
7.2.2 Calculation of the MAWP_r and MFH_r and Coincident Temperature 7-3
7.2.3 Limitations Based on Temperature 7-3
7.2.4 Applicability of the Level 1 and Level 2 Assessment Procedures 7-3
7.2.5 Applicability of the Level 3 Assessment Procedure 7-4
7.3 DATA REQUIREMENTS..... 7-4
7.3.1 Original Equipment Design Data 7-4
7.3.2 Maintenance and Operational History 7-4
7.3.3 Required Data/Measurements for an FFS Assessment 7-4
7.3.4 Recommendations for Detection, Characterization, and Sizing 7-7
7.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 7-7
7.4.1 Overview 7-7
7.4.2 Level 1 Assessment 7-8
7.4.3 Level 2 Assessment 7-10
7.4.4 Level 3 Assessment 7-14
7.5 REMAINING LIFE ASSESSMENT 7-15
7.5.1 HIC and SOHIC Growth Rates 7-15
7.5.2 Blister Growth 7-16
7.6 REMEDIATION 7-16

API 579-1/ASME FFS-1 2021 Fitness-For-Service

7.6.1 *Elimination of Hydrogen Charging*..... 7-16
7.6.2 *Controlling Hydrogen Charging* 7-16
7.6.3 *Venting of Blisters* 7-16
7.6.4 *Blend Grinding*..... 7-16
7.6.5 *Repair and Replacement of Damaged Material* 7-17
7.6.6 *NACE Standard SP0296-10*..... 7-17
7.7 IN-SERVICE MONITORING..... 7-17
7.7.1 *Monitoring for Hydrogen Charging* 7-17
7.7.2 *Inspection Methods for Monitoring* 7-17
7.7.3 *Detection of HIC, SOHIC, or Blister Damage Growth* 7-17
7.8 DOCUMENTATION 7-17
7.8.1 *General*..... 7-17
7.8.2 *Inspection Data* 7-17
7.8.3 *In-Service Monitoring*..... 7-18
7.9 NOMENCLATURE..... 7-18
7.10 REFERENCES..... 7-19
7.11 TABLES 7-20
7.12 FIGURES 7-22

ANNEX 7A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF HYDROGEN BLISTERS AND HYDROGEN DAMAGE ASSOCIATED WITH HIC AND SOHIC..... 7A-1

7A.1 TECHNICAL BASIS AND VALIDATION..... 7A-1
7A.2 REFERENCES 7A-1

PART 8 – ASSESSMENT OF WELD MISALIGNMENT AND SHELL DISTORTIONS..... 8-1

8.1 GENERAL 8-1
8.1.1 *Evaluation of Weld Misalignment and Shell Distortions* 8-1
8.1.2 *ASME B&PV Code, Section VIII, Division 2*..... 8-1
8.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 8-2
8.2.1 *Types of Weld Misalignment and Shell Distortions*..... 8-2
8.2.2 *Limitations Based on Flaw Type*..... 8-2
8.2.3 *Calculation of the MAWP_r and MFH_r and Coincident Temperature* 8-2
8.2.4 *Limitations Based on Temperature* 8-2
8.2.5 *Applicability of the Level 1 and Level 2 Assessment Procedures* 8-3
8.2.6 *Applicability of the Level 3 Assessment* 8-3
8.3 DATA REQUIREMENTS..... 8-4
8.3.1 *Original Equipment Design Data* 8-4
8.3.2 *Maintenance and Operational History* 8-4
8.3.3 *Required Data/Measurements for an FFS Assessment* 8-4
8.3.4 *Recommendations for Inspection Technique and Sizing Requirements*..... 8-4
8.4 EVALUATION TECHNIQUES AND ACCEPTANCE CRITERIA 8-6
8.4.1 *Overview* 8-6
8.4.2 *Level 1 Assessment* 8-6
8.4.3 *Level 2 Assessment* 8-7
8.4.4 *Level 3 Assessment* 8-12
8.5 REMAINING LIFE ASSESSMENT 8-13
8.5.1 *Categories – Metal Loss, Cyclic Loading, High Temperature Operation* 8-13
8.5.2 *Requirements for a Level 3 Assessment*..... 8-14

API 579-1/ASME FFS-1 2021 Fitness-For-Service

8.6 REMEDIATION 8-14
 8.6.1 Addition of Reinforcement 8-14
 8.6.2 Correction of Tolerances by Mechanical Means 8-14
8.7 IN-SERVICE MONITORING..... 8-14
 8.7.1 Overview 8-14
 8.7.2 Groove-Like and Crack-Like Flaws 8-14
8.8 DOCUMENTATION 8-14
8.9 NOMENCLATURE..... 8-14
8.10 REFERENCES..... 8-19
8.11 TABLES 8-20
8.12 FIGURES 8-34

ANNEX 8A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF WELD MISALIGNMENT AND SHELL DISTORTIONS.....8A-1

8A.1 TECHNICAL BASIS AND VALIDATION.....8A-1
8A.2 REFERENCES.....8A-1

PART 9 – ASSESSMENT OF CRACK-LIKE FLAWS..... 9-1

9.1 GENERAL 9-1
 9.1.1 Assessment Procedures for Crack-Like Flaws..... 9-1
 9.1.2 ASME B&PV Code, Section VIII, Division 2 (VIII-2) 9-2
 9.1.3 Crack-Like Flaw Definition 9-2
 9.1.4 Treatment of Volumetric Flaws as Crack-Like Flaws 9-2
 9.1.5 Use of Assessment Procedures to Evaluate Brittle Fracture 9-2
 9.1.6 Service Environment and Material Interactions with Crack-Like flaws 9-2
9.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 9-3
 9.2.1 Overview 9-3
 9.2.2 Applicability of the Level 1 and Level 2 Assessment Procedures 9-3
 9.2.3 Applicability of the Level 3 Assessment Procedure 9-4
 9.2.4 Assessment Procedures for Notches in Groove-Like Flaws 9-4
9.3 DATA REQUIREMENTS 9-4
 9.3.1 General 9-4
 9.3.2 Original Equipment Design Data 9-5
 9.3.3 Maintenance and Operating History 9-5
 9.3.4 Required Data/Measurements for an FFS Assessment – Loads and Stresses 9-6
 9.3.5 Required Data/Measurements for an FFS Assessment – Material Properties 9-7
 9.3.6 Required Data/Measurements for an FFS Assessment – Flaw Characterization 9-8
 9.3.7 Recommendation for Inspection Technique and Sizing Requirements 9-12
9.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 9-13
 9.4.1 Overview 9-13
 9.4.2 Level 1 Assessment 9-14
 9.4.3 Level 2 Assessment 9-15
 9.4.4 Level 3 Assessment 9-19
9.5 REMAINING LIFE ASSESSMENT 9-21
 9.5.1 Subcritical Crack Growth 9-21
 9.5.2 Leak-Before-Break Analysis..... 9-23
9.6 REMEDIATION 9-25
 9.6.1 Objectives of Remediation..... 9-25

API 579-1/ASME FFS-1 2021 Fitness-For-Service

9.6.2 Remediation Methods 9-25

9.7 IN-SERVICE MONITORING..... 9-26

9.7.1 Monitoring of Subcritical Crack Growth 9-26

9.7.2 Validation of Monitoring Method 9-26

9.8 DOCUMENTATION 9-26

9.8.1 General..... 9-26

9.8.2 Assessment Procedure..... 9-27

9.8.3 Remediation Methods 9-27

9.8.4 In-Service Monitoring..... 9-28

9.9 NOMENCLATURE..... 9-28

9.10 REFERENCES..... 9-29

9.11 TABLES 9-30

9.12 FIGURES 9-34

ANNEX 9A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF CRACK-LIKE FLAWS 9A-1

9A.1 TECHNICAL BASIS AND VALIDATION 9A-1

9A.2 REFERENCES 9A-2

ANNEX 9B – COMPENDIUM OF STRESS INTENSITY FACTOR SOLUTIONS 9B-1

9B.1 GENERAL 9B-1

9B.2 STRESS ANALYSIS..... 9B-2

9B.3 STRESS INTENSITY FACTOR SOLUTIONS FOR PLATES..... 9B-4

9B.4 STRESS INTENSITY FACTOR SOLUTIONS FOR PLATES WITH HOLES 9B-15

9B.5 STRESS INTENSITY FACTOR SOLUTIONS FOR CYLINDERS..... 9B-21

9B.6 STRESS INTENSITY FACTOR SOLUTIONS FOR SPHERES..... 9B-30

9B.7 STRESS INTENSITY FACTOR SOLUTIONS FOR ELBOWS AND PIPE BENDS..... 9B-33

9B.8 STRESS INTENSITY FACTOR SOLUTIONS FOR NOZZLES AND PIPING TEES..... 9B-33

9B.9 STRESS INTENSITY FACTOR SOLUTIONS FOR RING-STIFFENED CYLINDERS..... 9B-35

9B.10 STRESS INTENSITY FACTOR SOLUTIONS FOR SLEEVE REINFORCED CYLINDERS 9B-36

9B.11 STRESS INTENSITY FACTOR SOLUTIONS FOR ROUND BARS AND BOLTS..... 9B-36

9B.12 STRESS INTENSITY FACTOR SOLUTIONS FOR CRACKS AT FILLET WELDS..... 9B-39

9B.13 STRESS INTENSITY FACTOR SOLUTIONS CRACKS IN CLAD PLATES AND SHELLS 9B-41

9B.14 THE WEIGHT FUNCTION METHOD FOR SURFACE CRACKS 9B-41

9B.15 NOMENCLATURE..... 9B-45

9B.16 REFERENCES..... 9B-50

9B.17 TABLES 9B-54

9B.18 FIGURES 9B-225

ANNEX 9C – COMPENDIUM OF REFERENCE STRESS SOLUTIONS FOR CRACK-LIKE FLAWS 9C-1

9C.1 GENERAL 9C-1

9C.2 STRESS ANALYSIS..... 9C-2

9C.3 REFERENCE STRESS SOLUTIONS FOR PLATES..... 9C-9

9C.4 REFERENCE STRESS SOLUTIONS FOR PLATES WITH HOLES..... 9C-12

9C.5 REFERENCE STRESS SOLUTIONS FOR CYLINDERS..... 9C-13

9C.6 REFERENCE STRESS SOLUTIONS FOR SPHERES..... 9C-22

9C.7 REFERENCE STRESS SOLUTIONS FOR ELBOWS AND PIPE BENDS..... 9C-23

9C.8 REFERENCE STRESS SOLUTIONS FOR NOZZLES AND PIPING TEES..... 9C-24

API 579-1/ASME FFS-1 2021 Fitness-For-Service

| | | |
|---|--|-------|
| 9C.9 | REFERENCE STRESS SOLUTIONS FOR RING-STIFFENED CYLINDERS | 9C-25 |
| 9C.10 | REFERENCE STRESS SOLUTIONS FOR SLEEVE REINFORCED CYLINDERS..... | 9C-25 |
| 9C.11 | REFERENCE STRESS SOLUTIONS FOR ROUND BARS AND BOLTS..... | 9C-25 |
| 9C.12 | REFERENCE STRESS SOLUTIONS FOR CRACKS AT FILLET WELDS | 9C-27 |
| 9C.13 | REFERENCE STRESS SOLUTIONS FOR CRACKS IN CLAD PLATES AND SHELLS | 9C-27 |
| 9C.14 | REFERENCE STRESS SOLUTIONS FOR CRACKS IN HEAVY WALL CYLINDERS $1 \leq t/Ri \leq 3$ | 9C-27 |
| 9C.15 | NOMENCLATURE..... | 9C-28 |
| 9C.16 | REFERENCES..... | 9C-31 |
| 9C.17 | TABLES | 9C-33 |
| 9C.18 | FIGURES | 9C-45 |
| | | |
| ANNEX 9D – RESIDUAL STRESSES IN A FITNESS-FOR-SERVICE EVALUATION | 9D-1 | |
| 9D.1 | GENERAL | 9D-2 |
| 9D.1.1 | Scope..... | 9D-2 |
| 9D.1.2 | Crack Driving Force Associated with Residual Stress | 9D-2 |
| 9D.2 | APPLICABILITY AND LIMITATIONS | 9D-2 |
| 9D.2.1 | Residual Stress Solutions for In-Service and New Welded Joints | 9D-2 |
| 9D.2.2 | Technical Basis | 9D-3 |
| 9D.2.3 | Applicable Materials | 9D-3 |
| 9D.2.4 | Weld Joint Geometry..... | 9D-3 |
| 9D.2.5 | Residual Stress Distributions | 9D-3 |
| 9D.2.6 | Residual Stress Distribution Reference Point..... | 9D-3 |
| 9D.2.7 | Use of Alternative Residual Stress Solutions | 9D-3 |
| 9D.2.8 | Residual Stress Distributions from Welding Simulation | 9D-3 |
| 9D.3 | DATA REQUIREMENTS AND DEFINITION OF VARIABLES | 9D-4 |
| 9D.3.1 | Required Data | 9D-4 |
| 9D.3.2 | Optional Data..... | 9D-4 |
| 9D.3.3 | Yield Strength in Residual Stress Calculations | 9D-4 |
| 9D.4 | RESIDUAL STRESS DISTRIBUTION MODIFYING FACTORS | 9D-4 |
| 9D.4.1 | Post Weld Heat Treatment | 9D-4 |
| 9D.4.2 | Pressure Tests | 9D-5 |
| 9D.5 | FULL PENETRATION CIRCUMFERENTIAL WELDS IN PIPING & PRESSURE VESSEL CYLINDRICAL SHELLS..... | 9D-5 |
| 9D.5.1 | Residual Stress Perpendicular to the Weld Seam (Circumferential Flaw) | 9D-5 |
| 9D.5.2 | Residual Stress Parallel to the Weld Seam (Longitudinal Flaw)..... | 9D-6 |
| 9D.5.3 | Technical Basis | 9D-7 |
| 9D.6 | FULL PENETRATION LONGITUDINAL WELDS IN PIPING & PRESSURE VESSEL CYLINDRICAL SHELLS..... | 9D-7 |
| 9D.6.1 | Residual Stress Perpendicular to the Weld Seam (Longitudinal Flaw) | 9D-7 |
| 9D.6.2 | Residual Stress Parallel to the Weld Seam (Circumferential Flaw) | 9D-7 |
| 9D.6.3 | Technical basis..... | 9D-8 |
| 9D.7 | FULL PENETRATION CIRCUMFERENTIAL WELDS IN SPHERES AND PRESSURE VESSEL HEADS..... | 9D-8 |
| 9D.7.1 | Residual Stress Perpendicular to the Weld Seam (Circumferential Flaw) | 9D-8 |
| 9D.7.2 | Residual Stress Parallel to the Weld Seam (Meridional Flaw)..... | 9D-8 |
| 9D.7.3 | Technical Basis | 9D-8 |
| 9D.8 | FULL PENETRATION MERIDIONAL (SEAM) WELDS IN SPHERES AND PRESSURE VESSEL HEADS | 9D-9 |
| 9D.8.1 | Residual Stress Perpendicular to the Weld Seam (Meridional Flaw) | 9D-9 |
| 9D.8.2 | Residual Stress Parallel to the Weld Seam (Circumferential Flaw) | 9D-9 |
| 9D.8.3 | Technical Basis | 9D-9 |
| 9D.9 | FULL PENETRATION WELDS IN STORAGE TANKS..... | 9D-9 |
| 9D.10 | FULL PENETRATION WELDS AT CORNER JOINTS (NOZZLES OR PIPING BRANCH CONNECTIONS)..... | 9D-9 |
| 9D.10.1 | Corner Joint, Set-In Nozzle Weld (See Figure 9D.7 and Figure 9D.8, Weld Joint A)..... | 9D-9 |

API 579-1/ASME FFS-1 2021 Fitness-For-Service

9D.10.1.1 Residual Stress Perpendicular to the Weld Seam (See Figure 9D.9)..... 9D-9
9D.10.1.2 Residual Stress Parallel to the Weld Seam (See Figure 9D.9)..... 9D-10
9D.10.2 *Corner Joint, Set-On Nozzle Weld (See Figure 9D.7 and Figure 9D.8, Weld Joint B)*..... 9D-10
9D.10.2.1 Residual Stress Perpendicular to the Weld Seam 9D-10
9D.10.2.2 Residual Stress Parallel to the Weld Seam..... 9D-11
9D.10.3 *Reinforcing Pad Shell Fillet Weld (See Figure 9D.7 and Figure 9D.8, Weld Joint C)* 9D-11
9D.10.3.1 Residual Stress Perpendicular to the Weld Seam 9D-11
9D.10.3.2 Residual Stress Parallel to the Weld Seam..... 9D-11
9D.10.4 *Piping Branch Connection (See Figure 9D.11)* 9D-11
9D.10.4.1 Residual Stress Perpendicular to the Weld Seam (See Figure 9D.11)..... 9D-11
9D.10.4.2 Residual Stress Parallel to the Weld Seam (see Figure 9D.11)..... 9D-12
9D.10.5 *Technical Basis* 9D-12
9D.11 FULL PENETRATION AND FILLET WELDS AT A TEE JOINT..... 9D-13
9D.11.1 *Main Plate (See Figure 9D.12, Figure 9D.13 and Figure 9D.15)*..... 9D-13
9D.11.1.1 Residual Stress Perpendicular to the Weld Seam 9D-13
9D.11.1.2 Residual Stress Parallel to the Weld Seam..... 9D-13
9D.11.2 *Stay Plate (See Figure 9D.12, Figure 9D.14 and Figure 9D.15)* 9D-14
9D.11.2.1 Residual Stress Perpendicular to the Weld 9D-14
9D.11.2.2 Residual Stress Parallel to the Weld Seam..... 9D-14
9D.11.3 *Technical Basis* 9D-14
9D.12 REPAIR WELDS..... 9D-15
9D.12.1 *Residual Stress Perpendicular to the Weld* 9D-15
9D.12.2 *Residual Stress Parallel to the Weld Seam* 9D-15
9D.12.3 *Technical Basis* 9D-15
9D.13 WELDING SIMULATION-BASED STRESS DISTRIBUTIONS..... 9D-16
9D.13.1 *General*..... 9D-16
9D.13.2 *Description of Simplified Method* 9D-16
9D.13.3 *Simulation References* 9D-17
9D.14 NOMENCLATURE..... 9D-18
9D.15 REFERENCES..... 9D-19
9D.16 TABLES 9D-23
9D.17 FIGURES 9D-25

ANNEX 9E – CRACK OPENING AREAS..... 9E-1

9E.1 INTRODUCTION 9E-1
9E.1.1 *Scope*..... 9E-1
9E.1.2 *Overview of Crack Opening Area Calculations* 9E-1
9E.2 CRACK OPENING AREAS (COA) FOR CYLINDERS AND SPHERES 9E-2
9E.2.1 *Longitudinal Cracks in Cylinders* 9E-2
9E.2.2 *Circumferential Cracks in Cylinders* 9E-2
9E.2.3 *Meridional Cracks in Spheres* 9E-4
9E.2.4 *Plasticity Correction for the COA*..... 9E-4
9E.2.5 *Nomenclature* 9E-5
9E.2.6 *References*..... 9E-6
9E.2.7 *Tables* 9E-7

ANNEX 9F – MATERIAL PROPERTIES FOR CRACK-LIKE FLAWS..... 9F-1

9F.1 GENERAL 9F-2

API 579-1/ASME FFS-1 2021 Fitness-For-Service

| | | |
|-----------|---|-------|
| 9F.2 | CHARPY V-NOTCH IMPACT ENERGY | 9F-3 |
| 9F.2.1 | Definition | 9F-3 |
| 9F.2.2 | Charpy V-Notch (CVN) Test | 9F-3 |
| 9F.2.3 | Charpy V-Notch Transition Curve | 9F-5 |
| 9F.2.4 | Charpy Transition Curves and ASME Division 1 and 2 Toughness Exemption Curves | 9F-6 |
| 9F.2.4.1 | Section VIII, Divisions 1 and 2 Toughness Requirements | 9F-6 |
| 9F.2.4.2 | Charpy Transition Curve for Toughness Exemption | 9F-6 |
| 9F.2.4.3 | Reference Temperature Determination | 9F-7 |
| 9F.2.4.4 | Reference Temperature for Part 9, Level 1 Assessments | 9F-7 |
| 9F.2.4.5 | Reference Temperature for Part 12 Assessments of Gouges and Dent-Gouge Combinations | 9F-7 |
| 9F.3 | FRACTURE TOUGHNESS | 9F-8 |
| 9F.3.1 | Definition | 9F-8 |
| 9F.3.2 | Fracture Toughness Parameters | 9F-8 |
| 9F.3.3 | Fracture Toughness Testing | 9F-9 |
| 9F.3.3.1 | Obtaining Samples for Toughness Testing | 9F-9 |
| 9F.3.3.2 | Fracture Toughness Tests | 9F-9 |
| 9F.3.3.3 | JR-Curve | 9F-10 |
| 9F.3.4 | Fracture Toughness Estimation from Charpy V-Notch Data | 9F-10 |
| 9F.3.5 | ASME B&PV Code, Section VIII Division 1 and 2 Fracture Toughness | 9F-10 |
| 9F.4 | FRACTURE TOUGHNESS ESTIMATION FOR AN FFS ASSESSMENT | 9F-11 |
| 9F.4.1 | Introduction | 9F-11 |
| 9F.4.2 | ASME Section XI Fracture Toughness | 9F-11 |
| 9F.4.2.1 | Indexing Procedure for Fracture Toughness Determination | 9F-11 |
| 9F.4.2.2 | Lower Bound Toughness Based on ASME Section XI Reference Curves | 9F-12 |
| 9F.4.3 | Fracture Toughness Master Curve | 9F-12 |
| 9F.4.3.1 | Overview | 9F-12 |
| 9F.4.3.2 | Determining the Master Curve Reference Transition Temperature T_0 | 9F-13 |
| 9F.4.3.3 | Fracture Toughness Prediction Using the Master Curve | 9F-17 |
| 9F.4.3.4 | Determining the Master Curve Reference Transition Temperature T_0 for Modern Cr-Mo Steels | 9F-18 |
| 9F.4.4 | Upper Shelf Fracture Toughness | 9F-18 |
| 9F.4.4.1 | Overview | 9F-18 |
| 9F.4.4.2 | Fracture Toughness Prediction | 9F-18 |
| 9F.4.5 | Dynamic and Crack Arrest Fracture Toughness | 9F-19 |
| 9F.4.5.1 | Overview | 9F-19 |
| 9F.4.5.2 | Dynamic Fracture Toughness Prediction | 9F-19 |
| 9F.4.5.3 | Arrest Fracture Toughness Prediction | 9F-20 |
| 9F.4.6 | Fracture Toughness for Materials Subject to In-Service Degradation | 9F-21 |
| 9F.4.6.1 | Service Environment Effects on Fracture Toughness | 9F-21 |
| 9F.4.6.2 | Hydrogen Effects on Fracture Toughness and Flaw Assessment | 9F-21 |
| 9F.4.6.3 | Overview of Metallurgical Embrittlement that Reduces Ductility and Fracture Toughness | 9F-22 |
| 9F.4.7 | Aging Effects on the Fracture Toughness of Cr-Mo Steels | 9F-23 |
| 9F.4.7.1 | Overview | 9F-23 |
| 9F.4.7.2 | Effect of Tramp Elements on the Fracture Toughness of 1.25Cr-0.5Mo | 9F-23 |
| 9F.4.7.3 | Effect of Tramp Elements on the Fracture Toughness of 2.25Cr-1Mo | 9F-24 |
| 9F.4.8 | Fracture Toughness of Electroslag Welds in 2.25Cr-1Mo Vessels | 9F-25 |
| 9F.4.9 | Fracture Toughness as a Function of Temperature for Ferritic Materials | 9F-26 |
| 9F.4.10 | The Effect of Warm Pre-stress on Fracture Toughness | 9F-26 |
| 9F.4.10.1 | Introduction | 9F-26 |
| 9F.4.10.2 | Benefits | 9F-26 |
| 9F.4.10.3 | Procedure | 9F-26 |
| 9F.4.10.4 | Conditions to be Satisfied | 9F-27 |
| 9F.4.11 | Fracture Toughness Estimation for Brittle Fracture Assessments | 9F-27 |
| 9F.4.12 | Fracture Toughness of Austenitic Stainless Steel | 9F-28 |
| 9F.4.13 | Ductile Tearing Assessment Using a JR-curve | 9F-28 |

API 579-1/ASME FFS-1 2021 Fitness-For-Service

9F.5 MATERIAL DATA FOR CRACK GROWTH CALCULATIONS9F-28

 9F.5.1 *Categories of Crack Growth*.....9F-28

 9F.5.1.1 Crack Growth by Fatigue..... 9F-28

 9F.5.1.2 Crack Growth by Stress Corrosion Cracking (SCC)..... 9F-29

 9F.5.1.3 Crack Growth by Hydrogen Assisted Cracking (HAC) 9F-29

 9F.5.1.4 Crack Growth by Corrosion Fatigue 9F-29

 9F.5.2 *Fatigue Crack Growth Equations*9F-30

 9F.5.2.1 Overview 9F-30

 9F.5.2.2 Paris Equation..... 9F-30

 9F.5.2.3 Modified Paris Equation for Welded Joints..... 9F-31

 9F.5.2.4 Walker Equation..... 9F-31

 9F.5.2.5 Trilinear and Bilinear Equations 9F-32

 9F.5.2.6 Modified Forman Equation 9F-32

 9F.5.2.7 NASGRO Equation 9F-33

 9F.5.2.8 Collipriest Equation 9F-33

 9F.5.2.9 ASME B&PV Code, Section VIII, Division 3 9F-33

 9F.5.3 *Fatigue Crack Growth Data*9F-34

 9F.5.3.1 Sources for Crack Growth Data 9F-34

 9F.5.3.2 ASME B&PV Code, Section VIII, Division 3 9F-34

 9F.5.3.3 ASME B&PV Code, Section XI..... 9F-34

 9F.5.3.4 AFCEN Code, RSE-M..... 9F-34

 9F.5.3.5 Barsom Original Crack Growth Data 9F-34

 9F.5.3.6 Crack Growth Data for Welds..... 9F-34

 9F.5.3.7 BS 7910 Crack Growth Data for Screening..... 9F-35

 9F.5.3.8 BS 7910 Bilinear Crack Growth Data 9F-35

 9F.5.3.9 Crack Growth Data for Pipeline Steels..... 9F-35

 9F.5.3.10 NASGRO Crack Growth Data 9F-36

 9F.5.4 *Hydrogen Assisted Crack Growth*.....9F-36

 9F.5.4.1 ASME B31.12..... 9F-36

 9F.5.4.2 ASME B&PV Code, Section VIII, Division 3 9F-36

 9F.5.5 *Stress Corrosion Crack (SCC) Growth Equations*9F-36

 9F.5.6 *Stress Corrosion Crack Growth Data*.....9F-37

 9F.5.7 *Conversion of Units for Crack Growth Data*.....9F-37

 9F.5.7.1 Cyclic Crack Growth Conversion Method..... 9F-37

 9F.5.7.2 Time-Dependent Crack Growth Conversion Method..... 9F-37

9F.6 NOMENCLATURE.....9F-38

9F.7 REFERENCES9F-43

9F.8 TABLES.....9F-46

9F.9 FIGURES9F-59

ANNEX 9G – STRESS ANALYSIS FOR CRACK-LIKE FLAWS9G-1

9G.1 GENERAL REQUIREMENTS 9G-1

 9G.1.1 *Scope*..... 9G-1

 9G.1.2 *ASME B&PV Code, Section VIII, Division 2 (VIII-2)* 9G-2

 9G.1.3 *FAD-Based Assessment Procedure* 9G-2

 9G.1.4 *Assessment Using Stress Analysis Results – Uncracked Configuration* 9G-2

 9G.1.5 *Assessment Using Stress Analysis Results – Crack Incorporated into the Model* 9G-2

 9G.1.6 *Assessment of Growing Cracks*..... 9G-2

 9G.1.7 *Numerical Analysis* 9G-2

 9G.1.8 *Applicable Loads and Load Case Combinations* 9G-2

9G.2 STRESS ANALYSIS OF THE UN-CRACKED CONFIGURATION..... 9G-3

 9G.2.1 *Overview* 9G-3

API 579-1/ASME FFS-1 2021 Fitness-For-Service

9G.2.2 *Categorization and Linearization of Stress Results*..... 9G-3
9G.2.3 *Fitting Stress Results to a Polynomial* 9G-3
9G.2.4 *The Weight Function Method* 9G-3
9G.3 FINITE ELEMENT ANALYSIS OF COMPONENTS WITH CRACKS 9G-4
9G.3.1 *Overview* 9G-4
9G.3.2 *Output Quantity* 9G-4
9G.3.3 *Mesh Design* 9G-4
9G.3.4 *Crack Tip Modeling Approaches*..... 9G-4
9G.3.5 *Focused Mesh Approach* 9G-4
9G.3.6 *Finite Radius Approach*..... 9G-5
9G.3.7 *Small Strain vs. Large Strain Analysis*..... 9G-6
9G.3.8 *Convergence* 9G-6
9G.3.9 *Initial and Thermal Strains*..... 9G-7
9G.3.10 *Modeling Procedure*..... 9G-7
9G.4 FAD-BASED METHOD FOR NON-GROWING CRACKS 9G-8
9G.4.1 *Overview* 9G-8
9G.4.2 *Assessment Procedure* 9G-8
9G.5 DRIVING FORCE METHOD FOR NON-GROWING CRACKS 9G-10
9G.5.1 *Overview* 9G-10
9G.5.2 *Assessment Procedure* 9G-10
9G.6 ASSESSMENT OF GROWING CRACKS 9G-11
9G.6.1 *Crack Growth Models*..... 9G-11
9G.6.2 *Crack Parameter Solutions*..... 9G-11
9G.6.3 *Determination of a Remaining Life*..... 9G-11
9G.6.4 *Crack Growth Using Numerical Methods* 9G-11
9G.7 NOMENCLATURE 9G-11
9G.8 REFERENCES 9G-12
9G.9 FIGURES 9G-14

ANNEX 9H – CONSTRAINT EFFECTS FOR SURFACE FLAWS IN CARBON AND LOW-ALLOY STEEL COMPONENTS IN THE DUCTILE-BRITTLE TRANSITION REGION..... 9H-1

9H.1 GENERAL 9H-1
9H.1.1 *Overview* 9H-1
9H.1.2 *Applicability and Limitations of the Procedure* 9H-1
9H.1.3 *Fracture Toughness Estimation Procedure* 9H-2
9H.2 NOMENCLATURE 9H-4
9H.3 REFERENCES 9H-5
9H.4 TABLES 9H-6
9H.5 FIGURES 9H-11

ANNEX 9I – ALTERNATIVE ESTIMATE OF MODE I STRESS INTENSITY FACTORS FOR FFS ASSESSMENTS IN THE DUCTILE-BRITTLE TRANSITION REGION 9I-1

9I.1 GENERAL 9I-1
9I.1.1 *Overview* 9I-1
9I.1.2 *Applicability and Limitations of the Procedure* 9I-1
9I.1.3 *Alternative Estimate of Mode I Stress Intensity Factors for K_I Determination* 9I-2
9I.2 NOMENCLATURE 9I-3
9I.3 REFERENCES 9I-4

API 579-1/ASME FFS-1 2021 Fitness-For-Service

9I.4 FIGURES 9I-5

ANNEX 9J – DETERMINATION OF THE MINIMUM ALLOWABLE TEMPERATURE (MAT) USING A LEVEL 2 FRACTURE MECHANICS APPROACH CONSISTENT WITH PARTS 3 AND 9..... 9J-1

9J.1 INTRODUCTION 9J-1
9J.2 PROCEDURE TO DETERMINE THE MAT 9J-1
 9J.2.1 *General Procedure* 9J-1
 9J.2.2 *Simplified Procedure* 9J-3
9J.3 REQUIRED MODIFICATIONS FOR HYDROGEN SERVICE 9J-4
 9J.3.1 *Overview* 9J-4
 9J.3.2 *2.25 Cr – 1 Mo* 9J-4
 9J.3.3 *2.25 Cr – 1 Mo - V* 9J-5
 9J.3.4 *Carbon Steel and Other Low-Chrome Alloys* 9J-5
9J.4 MAT ENVELOPE 9J-6
9J.5 NOMENCLATURE 9J-6
9J.6 REFERENCES 9J-7
9J.7 TABLES 9J-8
9J.8 FIGURES 9J-11

PART 10 – ASSESSMENT OF COMPONENTS OPERATING IN THE CREEP RANGE..... 10-1

10.1 GENERAL 10-2
 10.1.1 *FFS Procedures and Temperature Limits* 10-2
 10.1.2 *Remaining Life of Components with and without Crack-Like Flaws* 10-2
10.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 10-2
 10.2.1 *Suitability for Service and Remaining Life* 10-2
 10.2.2 *Applicability and Limitations* 10-2
 10.2.3 *Recommendations for Life Predictions Exceeding 35 Years* 10-4
10.3 DATA REQUIREMENTS 10-4
 10.3.1 *General* 10-4
 10.3.2 *Original Equipment Design Data* 10-4
 10.3.3 *Maintenance and Operational History* 10-4
 10.3.4 *Required Data for an FFS Assessment – Loads and Stresses* 10-5
 10.3.5 *Required Data for an FFS Assessment – Material Properties* 10-6
 10.3.6 *Required Data for an FFS Assessment – Damage Characterization* 10-7
 10.3.7 *Recommendation for Inspection Technique and Sizing Requirements* 10-8
10.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA 10-10
 10.4.1 *Overview* 10-10
 10.4.2 *Level 1 Assessment* 10-11
 10.4.3 *Level 2 Assessment* 10-12
 10.4.4 *Level 3 Assessment* 10-13
10.5 REMAINING LIFE ASSESSMENT 10-13
 10.5.1 *Overview* 10-13
 10.5.2 *Creep Rupture Life* 10-15
 10.5.3 *Creep-Fatigue Interaction* 10-22
 10.5.4 *Creep Crack Growth* 10-22
 10.5.5 *Creep Buckling* 10-27
 10.5.6 *Creep-Fatigue Assessment of Ferritic-Austenitic Dissimilar Weld Joints* 10-29
 10.5.7 *Microstructural Approach* 10-32

API 579-1/ASME FFS-1 2021 Fitness-For-Service

10.6 REMEDIATION 10-34
 10.6.1 Components with and without a Crack-Like Flaw 10-34
 10.6.2 Components with a Crack-Like Flaw 10-34
10.7 IN-SERVICE MONITORING..... 10-34
10.8 DOCUMENTATION 10-34
 10.8.1 General..... 10-34
 10.8.2 Assumptions Used in the Assumption 10-34
 10.8.3 Documentation for Life Assessment 10-34
 10.8.4 Supplemental Documentation for Creep Crack Growth..... 10-35
 10.8.5 Supplemental Documentation for Microstructural Approaches..... 10-35
10.9 NOMENCLATURE..... 10-36
10.10 REFERENCES..... 10-43
10.11 TABLES 10-44
10.12 FIGURES 10-51

ANNEX 10A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF COMPONENTS OPERATING IN THE CREEP RANGE..... 10A-1

10A.1 TECHNICAL BASIS AND VALIDATION..... 10A-1
10A.2 TECHNICAL BASIS AND VALIDATION REFERENCES..... 10A-1
10A.3 ADDITIONAL REFERENCES 10A-3

ANNEX 10B – MATERIAL DATA FOR CREEP ANALYSIS 10B-1

10B.1 GENERAL 10B-1
10B.2 CREEP RUPTURE DATA..... 10B-1
 10B.2.1 MPC Project Omega..... 10B-1
 10B.2.2 API Std 530, 6th Edition, September 2008 10B-3
 10B.2.3 WRC Bulletin 541..... 10B-3
10B.3 TANGENT AND SECANT MODULUS 10B-4
10B.4 CREEP STRAIN-RATE DATA 10B-5
10B.5 ISOCHRONOUS STRESS-STRAIN CURVES 10B-5
10B.6 CREEP REGIME FATIGUE CURVES (CRACK INITIATION)..... 10B-6
10B.7 CREEP CRACK GROWTH DATA 10B-6
10B.8 NOMENCLATURE..... 10B-7
10B.9 REFERENCES..... 10B-9
 10B.9.1 Technical References – High Temperature Assessment..... 10B-9
 10B.9.2 Creep Rupture Strength and Creep Strain Rate Data 10B-10
 10B.9.3 Creep Crack Growth Data 10B-12
10B.10 TABLES 10B-14
10B.11 FIGURES 10B-59

PART 11 – ASSESSMENT OF FIRE DAMAGE..... 11-1

11.1 GENERAL 11-1
 11.1.1 Assessment of Fire Damage..... 11-1
 11.1.2 Assessment of Process Upsets..... 11-1
 11.1.3 Guidelines and Assessment Flowchart 11-2
 11.1.4 Forms of Fire Damage 11-2
 11.1.5 Alternative Methods for Equipment Not Suitable for Operation 11-2

API 579-1/ASME FFS-1 2021 Fitness-For-Service

11.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 11-2
 11.2.1 *Equipment and Components Covered by the Assessment Procedure*..... 11-2
 11.2.2 *Equipment and Components Not Covered by the Assessment Procedure* 11-2
11.3 DATA REQUIREMENTS..... 11-3
 11.3.1 *Original Equipment Design Data* 11-3
 11.3.2 *Maintenance and Operational History* 11-3
 11.3.3 *Required Data/Measurements for an FFS Assessment* 11-3
 11.3.4 *Recommendations for Inspection Techniques and Sizing Requirements*..... 11-7
11.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 11-8
 11.4.1 *Overview* 11-8
 11.4.2 *Level 1 Assessment* 11-9
 11.4.3 *Level 2 Assessment* 11-9
 11.4.4 *Level 3 Assessment* 11-11
11.5 REMAINING LIFE ASSESSMENT 11-12
 11.5.1 *Thinning and Crack-Like Flaw Damage* 11-12
 11.5.2 *Creep Damage* 11-12
11.6 REMEDIATION 11-12
 11.6.1 *Techniques* 11-12
 11.6.2 *Need for Repair or Replacement*..... 11-12
11.7 IN-SERVICE MONITORING..... 11-12
11.8 DOCUMENTATION 11-12
 11.8.1 *General*..... 11-12
 11.8.2 *Heat Exposure Zones*..... 11-13
 11.8.3 *Record Retention* 11-13
11.9 NOMENCLATURE..... 11-13
11.10 REFERENCES..... 11-13
11.11 TABLES 11-14
11.12 FIGURES 11-38

ANNEX 11A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF FIRE DAMAGE..... 11A-1

 11A.1 TECHNICAL BASIS AND VALIDATION..... 11A-1
 11A.2 REFERENCES..... 11A-1

**ANNEX 11B – METALLURGICAL INVESTIGATION AND EVALUATION OF MECHANICAL PROPERTIES
IN FIRE DAMAGE ASSESSMENT 11B-1**

 11B.1 GENERAL 11B-2
 11B.1.1 *Metallurgical Investigations* 11B-2
 11B.1.2 *Materials Covered*..... 11B-2
 11B.1.3 *Change in material properties from Fire Damage*..... 11B-2
 11B.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 11B-2
 11B.3 SPECIFIC RESPONSIBILITIES AND QUALIFICATIONS..... 11B-2
 11B.3.1 *Overview*..... 11B-2
 11B.3.2 *Field Assessment Team* 11B-2
 11B.3.3 *Laboratory Assessment Team* 11B-3
 11B.4 EVALUATION TECHNIQUES 11B-3
 11B.5 FIELD ASSESSMENT TECHNIQUES 11B-3
 11B.5.1 *Field Hardness Testing* 11B-3
 11B.5.2 *In-situ Metallography or Replication*..... 11B-4

API 579-1/ASME FFS-1 2021 Fitness-For-Service

11B.5.3 *Positive Material Identification*..... 11B-4

11B.6 LABORATORY ASSESSMENT TECHNIQUES..... 11B-5

 11B.6.1 *Coupon or Sample Removal* 11B-5

 11B.6.2 *Metallurgical Mounts and Mechanical Testing Specimens*..... 11B-5

11B.7 WORK PROCEDURE..... 11B-5

 11B.7.1 *STEP 1 – Select Equipment and Component Subject to Analysis*..... 11B-5

 11B.7.2 *STEP 2 – Select Sampling Technique(s)* 11B-6

 11B.7.3 *STEP 3 – Perform In-situ Metallography or Replica Evaluation* 11B-6

 11B.7.4 *STEP 4 – Take Field Hardness Readings* 11B-6

 11B.7.5 *STEP 5 – Remove Samples for Laboratory Analysis and Mechanical Testing (Optional)* 11B-7

11B.8 GUIDANCE FOR METALLOGRAPHIC ANALYSIS AND MECHANICAL TESTING INTERPRETATION 11B-7

 11B.8.1 *Overview*..... 11B-7

 11B.8.2 *Reduction in Tensile Strength*..... 11B-7

 11B.8.3 *Reduction in Toughness* 11B-7

 11B.8.4 *Decrease of Corrosion Resistance*..... 11B-8

 11B.8.5 *Consideration for Reuse* 11B-8

 11B.8.6 *Heat Treatment* 11B-8

11B.9 EXAMPLE OF METALLOGRAPHY ANALYSIS AND HARDNESS TESTING RESULTS..... 11B-8

 11B.9.1 *Overview*..... 11B-8

 11B.9.2 *Samples*..... 11B-9

 11B.9.3 *Test Sequence* 11B-9

 11B.9.4 *Test Results – Metallography*..... 11B-9

 11B.9.5 *Test Results – Hardness*..... 11B-10

11B.10 FIGURES 11B-11

PART 12 – ASSESSMENT OF DENTS, GOUGES, AND DENT-GOUGE COMBINATIONS 12-1

12.1 GENERAL 12-1

 12.1.1 *Assessment Procedures for Dents, Gouges and Dent-Gouge Combinations*..... 12-1

 12.1.2 *Assessment Procedures for LTAs, Grooves, and Other Shell Distortions* 12-2

12.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 12-2

 12.2.1 *Overview* 12-2

 12.2.2 *Calculation of the MAWP and Coincident Temperature* 12-2

 12.2.3 *Limitations Based on Flaw Type*..... 12-2

 12.2.4 *Limitations Based on Temperature* 12-2

 12.2.5 *Applicability of the Level 1 and Level 2 Assessment Procedures* 12-3

 12.2.6 *Applicability of the Level 3 Assessment Procedure* 12-4

12.3 DATA REQUIREMENTS..... 12-4

 12.3.1 *Original Equipment Design Data* 12-4

 12.3.2 *Maintenance and Operational History* 12-4

 12.3.3 *Required Data/Measurements for an FFS Assessment* 12-4

 12.3.4 *Recommendations for Inspection Technique and Sizing Requirements*..... 12-7

12.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 12-7

 12.4.1 *Overview* 12-7

 12.4.2 *Level 1 Assessment* 12-8

 12.4.3 *Level 2 Assessment* 12-10

 12.4.4 *Level 3 Assessment* 12-13

12.5 REMAINING LIFE ASSESSMENT 12-14

 12.5.1 *Categories of Remaining Life Assessment*..... 12-14

 12.5.2 *Requirements for a Level 3 Assessment*..... 12-14

12.6 REMEDIATION 12-14

API 579-1/ASME FFS-1 2021 Fitness-For-Service

12.6.1 *Flaw Severity and Evaluation of Material Condition* 12-14
12.6.2 *Reinforcement of Dents, Gouges and Dent-Gouge Combinations* 12-14
12.6.3 *Use of General Corrosion Remediation Methods* 12-14
12.7 IN-SERVICE MONITORING 12-15
 12.7.1 *Requirements for In-Service Monitoring* 12-15
 12.7.2 *Visual Inspection and Field Measurements of Distortion* 12-15
12.8 DOCUMENTATION 12-15
 12.8.1 *Requirements* 12-15
 12.8.2 *Inspection and Field Measurements* 12-15
12.9 NOMENCLATURE 12-15
12.10 REFERENCES 12-17
12.11 TABLES 12-18
12.12 FIGURES 12-21

ANNEX 12A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF DENTS, GOUGES, AND DENT-GOUGE COMBINATIONS..... 12A-1

12A.1 TECHNICAL BASIS AND VALIDATION 12A-1
12A.2 REFERENCES 12A-1

PART 13 – ASSESSMENT OF LAMINATIONS 13-1

13.1 GENERAL 13-1
 13.1.1 *Assessment Procedures for Laminations* 13-1
 13.1.2 *Definition of Laminations* 13-2
 13.1.3 *Laminations in Hydrogen Charging Service* 13-2
 13.1.4 *Detection of Laminations* 13-2
 13.1.5 *Acceptance of Laminations* 13-2
13.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 13-2
 13.2.1 *Applicability and Limitations of the Assessments Procedures for Laminations* 13-2
 13.2.2 *Calculation of MAWP and Coincident Temperature* 13-2
 13.2.3 *Limitations Based on Temperature* 13-2
 13.2.4 *Limitations Based on Flaw Type* 13-3
 13.2.5 *Applicability of the Level 1 and Level 2 Assessment Procedures* 13-3
 13.2.6 *Applicability of the Level 3 Assessment* 13-3
13.3 DATA REQUIREMENTS 13-4
 13.3.1 *Original Equipment Design Data* 13-4
 13.3.2 *Maintenance and Operational History* 13-4
 13.3.3 *Required Data/Measurements for an FFS Assessment* 13-4
 13.3.4 *Recommendations for Inspection Technique and Sizing Requirements* 13-5
13.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA 13-5
 13.4.1 *Overview* 13-5
 13.4.2 *Level 1 Assessment* 13-5
 13.4.3 *Level 2 Assessment* 13-6
 13.4.4 *Level 3 Assessment* 13-7
13.5 REMAINING LIFE ASSESSMENT 13-7
13.6 REMEDIATION 13-7
13.7 IN-SERVICE MONITORING 13-7
13.8 DOCUMENTATION 13-7
 13.8.1 *General* 13-7

API 579-1/ASME FFS-1 2021 Fitness-For-Service

13.8.2 *Documentation of Flaw Size and Conditions* 13-8
13.8.3 *Documentation of Flaw Growth*..... 13-8
13.9 NOMENCLATURE..... 13-8
13.10 REFERENCES..... 13-8
13.11 TABLES 13-9
13.12 FIGURES 13-10

ANNEX 13A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF LAMINATIONS 13A-1

13A.1 TECHNICAL BASIS AND VALIDATION..... 13A-1
13A.2 REFERENCES..... 13A-1

PART 14 – ASSESSMENT OF FATIGUE DAMAGE 14-1

14.1 GENERAL 14-2
14.1.1 *Assessment Procedures for Fatigue Damage*..... 14-2
14.1.2 *Damage Tolerance* 14-2
14.1.3 *Fatigue Evaluation in the Creep Range*..... 14-2
14.1.4 *Fatigue Evaluation and Crack-Like Flaws*..... 14-2
14.1.5 *ASME B&PV Code, Section VIII, Division 2 (VIII-2)* 14-3
14.1.6 *Use of Fatigue Curves in Performing Assessments* 14-3
14.1.7 *Adjustment for Mean Stress*..... 14-3
14.1.8 *Ratcheting* 14-3
14.2 APPLICABILITY AND LIMITATIONS OF THE PROCEDURE 14-3
14.2.1 *Applicability and Limitations of the Assessment Procedures* 14-3
14.2.2 *Calculation of MAWP and Coincident Temperature* 14-3
14.2.3 *Limitations Based on Temperature* 14-4
14.2.4 *Limitations Based on Flaw Type*..... 14-4
14.2.5 *Applicability of the Level 1 and Level 2 Assessment Procedures* 14-4
14.2.6 *Applicability of the Level 3 Assessment* 14-4
14.3 DATA REQUIREMENTS..... 14-5
14.3.1 *Original Equipment Design Data* 14-5
14.3.2 *Maintenance and Operational History* 14-5
14.3.3 *Required Data/Measurements for an FFS Assessment* 14-5
14.3.4 *Recommendations for Inspection Technique and Sizing Requirements*..... 14-5
14.4 ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA..... 14-6
14.4.1 *Overview* 14-6
14.4.2 *Level 1 Assessment* 14-6
14.4.2.1 *Overview*..... 14-6
14.4.2.2 *Method A – Fatigue Screening Based on Experience with Comparable Equipment* 14-7
14.4.2.3 *Method B – Fatigue Screening*..... 14-7
14.4.2.4 *Method C – Fatigue Screening* 14-8
14.4.2.5 *Method D – Fatigue Screening, Welded Joints* 14-10
14.4.2.6 *Level 1 Assessment Results* 14-12
14.4.3 *Level 2 Assessment* 14-12
14.4.3.1 *Overview*..... 14-12
14.4.3.2 *Method A – Fatigue Assessment Using Elastic Stress Analysis and Equivalent Stresses* 14-13
14.4.3.3 *Method B – Fatigue Assessment Using Elastic-Plastic Stress Analysis and Equivalent Strain* 14-17
14.4.3.4 *Method C – Fatigue Assessment of Welds Using the Equivalent Structural Stress*..... 14-19
14.4.3.5 *Ratcheting Assessment – Elastic Stress Analysis* 14-23
14.4.3.6 *Ratcheting Assessment – Elastic-Plastic Stress Analysis*..... 14-25
14.4.3.7 *Ratcheting Assessment – Non-Integral Connections* 14-26

API 579-1/ASME FFS-1 2021 Fitness-For-Service

14.4.3.8 Level 2 Assessment Results 14-26

14.4.4 Level 3 Assessment 14-26

14.4.4.1 Overview..... 14-26

14.4.4.2 Method A – Elastic Stress Analysis and Critical Plane Approach 14-27

14.4.4.3 Method B – Elastic-Plastic Stress Analysis and Critical Plane Approach 14-28

14.4.4.4 Method C – Recognized Codes and Standards 14-29

14.5 REMAINING LIFE ASSESSMENT 14-29

14.5.1 Included in Level 2 and Level 3 Assessments..... 14-29

14.5.2 Loading Time History..... 14-29

14.6 REMEDIATION 14-29

14.6.1 Overview 14-29

14.6.2 Removal or Reduction of the Driving Energy Source or Forces..... 14-30

14.6.3 Alteration of Component Constraint, Mechanical Design, or Weld Quality 14-30

14.6.4 Reduction of Temperature Differentials or Gradients 14-31

14.7 IN-SERVICE MONITORING..... 14-31

14.8 DOCUMENTATION 14-31

14.8.1 General..... 14-31

14.8.2 Assessment Level..... 14-31

14.8.3 Loading Time History..... 14-31

14.8.4 Material Properties..... 14-32

14.8.5 Stress Analysis Results..... 14-32

14.8.6 Assessment Results..... 14-32

14.8.7 Remaining Life Assessment..... 14-32

14.8.8 Remediation Methods 14-32

14.8.9 In-Service Monitoring..... 14-32

14.9 NOMENCLATURE..... 14-32

14.10 REFERENCES..... 14-41

14.11 TABLES 14-42

14.12 FIGURES 14-65

ANNEX 14A – TECHNICAL BASIS AND VALIDATION – ASSESSMENT OF FATIGUE DAMAGE 14A-1

14A.1 TECHNICAL BASIS AND VALIDATION..... 14A-1

14A.2 REFERENCES..... 14A-1

ANNEX 14B – MATERIAL PROPERTIES FOR FATIGUE ANALYSIS..... 14B-1

14B.1 SMOOTH BAR DESIGN FATIGUE CURVES – ASME CODE, SECTION VIII, DIVISION 2 14B-1

14B.1.1 Temperature Correction..... 14B-1

14B.1.2 Interpolation 14B-1

14B.1.3 Design Fatigue Curves Based on Testing in Air..... 14B-1

14B.1.4 Design Fatigue Curve Models..... 14B-2

14B.1.5 Computation of Allowable Cycles..... 14B-4

14B.2 SMOOTH BAR DESIGN FATIGUE CURVES – MEAN CURVE WITH EXPLICIT MARGINS..... 14B-4

14B.3 UNIFORM MATERIAL LAW..... 14B-5

14B.4 WELDED JOINT FATIGUE CURVES – ASME CODE, SECTION VIII, DIVISION 2 14B-5

14B.4.1 Fatigue Curve Models..... 14B-5

14B.4.2 Computation of Allowable Cycles..... 14B-5

14B.5 NOMENCLATURE..... 14B-6

14B.6 REFERENCES..... 14B-8

14B.7 TABLES 14B-10

API 579-1/ASME FFS-1 2021 Fitness-For-Service

14B.8 FIGURES14B-17

ANNEX 14C – PLASTICITY CORRECTION AND CYCLE COUNTING FOR FATIGUE ANALYSIS..... 14C-1

14C.1 INTRODUCTION 14C-1

 14C.1.1 *Cycle Counting* 14C-1

 14C.1.2 *Plasticity Correction* 14C-1

 14C.1.3 *Definitions*..... 14C-2

 14C.1.4 *Histogram Development* 14C-3

14C.2 PLASTICITY CORRECTION 14C-3

 14C.2.1 *Uniaxial Plasticity Correction*..... 14C-3

 14C.2.2 *Multiaxial Plasticity Correction* 14C-3

14C.3 UNIAXIAL CYCLE COUNTING 14C-8

 14C.3.1 *Rainflow Cycle Counting – With Reordering*..... 14C-8

 14C.3.2 *Additional Rainflow Cycle Counting – Without Reordering*..... 14C-10

14C.4 MULTIAXIAL CYCLE COUNTING 14C-10

 14C.4.1 *Wang-Brown Cycle Counting* 14C-10

 14C.4.2 *Critical Plane Cycle Counting*..... 14C-14

14C.5 NOMENCLATURE..... 14C-18

14C.6 REFERENCES..... 14C-24

14C.7 FIGURES 14C-25

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.

API 579-1/ASME FFS-1 2021 Fitness-For-Service

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.

Although every effort has been made to assure the accuracy and reliability of the information that is presented in this standard, API and ASME make no representation, warranty, or guarantee in connection with this publication and expressly disclaim any liability or responsibility for loss or damage resulting from its use or for the violation of any regulation with which this publication may conflict.

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.

Nothing contained in this document is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in this document be construed as insuring anyone against liability for infringement of letters patent.

Neither API nor ASME nor any employees, subcontractors, consultants, committees, or other assignees of API or ASME make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this document. Neither API nor ASME nor any employees, subcontractors, consultants, or other assignees of API or ASME represent that use of this document would not infringe upon privately owned rights.

This document may be used by anyone desiring to do so. Every effort has been made to assure the accuracy and reliability of the data contained herein; however, API and ASME make no representation, warranty, or guarantee in connection with this document and hereby expressly disclaim any liability or responsibility for loss or damage resulting from its use or for the violation of any requirements of authorities having jurisdiction with which this document may conflict.

This document is published to facilitate the broad availability of proven, sound engineering and operating practices. This document is not intended to obviate the need for applying sound engineering judgment regarding when and where this document should be utilized. The formulation and publication of this document is not intended in any way to inhibit anyone from using any other practices.

Classified areas may vary depending on the location, conditions, equipment, and substances involved in any given situation. Users of this Code should consult with the appropriate authorities having jurisdiction.

Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the Instructions. At all times users should employ sound business, scientific, engineering, and judgment safety when using this Code.

Users of this Code should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

API and ASME are not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

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 of 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_{α} , 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.

API 579-1/ASME FFS-1 2021 Fitness-For-Service

- 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):

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

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

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.

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

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

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

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

- 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*.

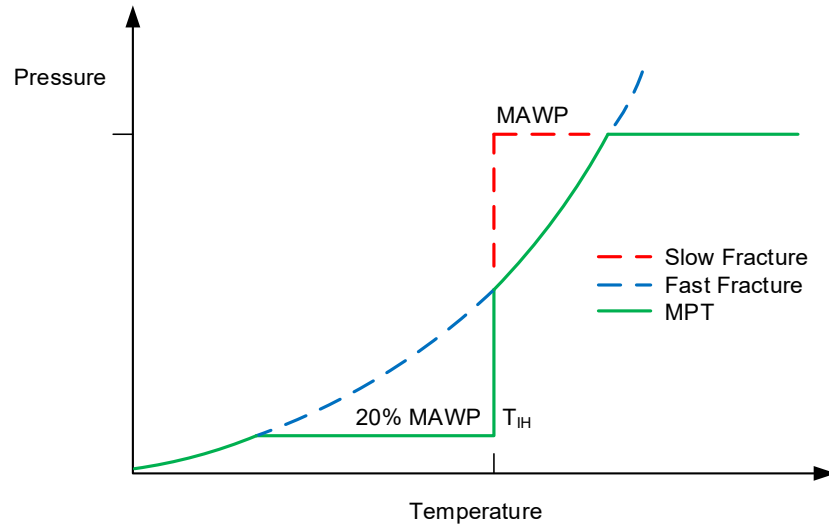
New Annex 9I: *Alternative Estimate of Mode I Stress Intensity Factors*

- 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*

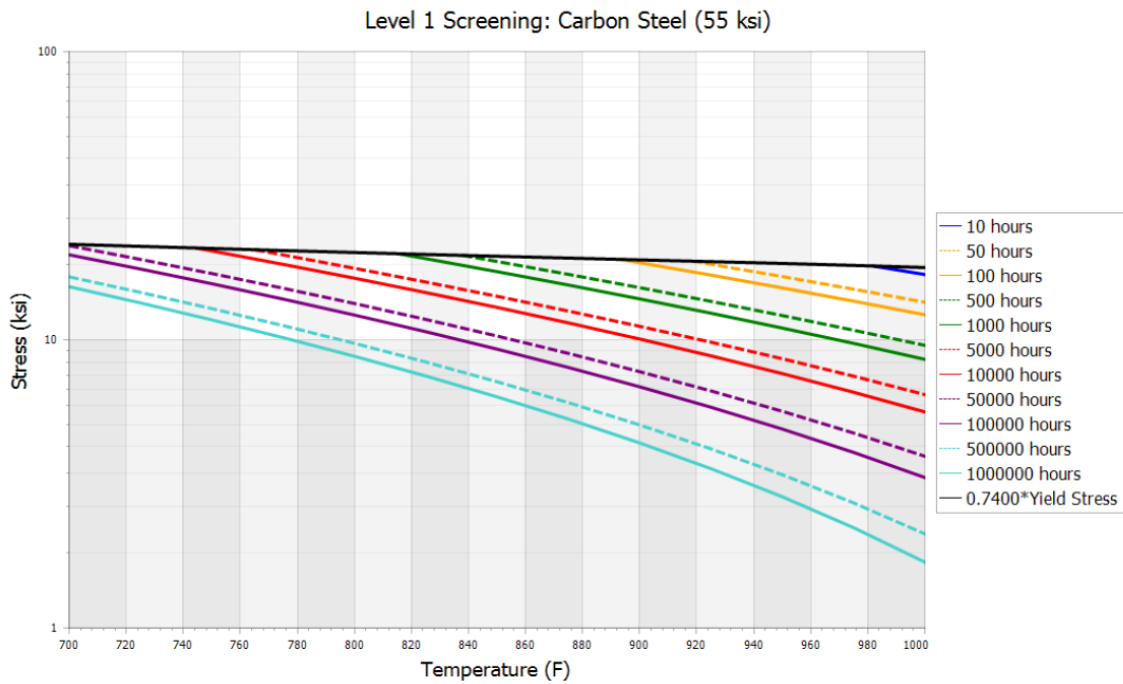
- Established procedure for using fracture mechanics to determine the *MAT*.
- Included a simplified brittle fracture screening procedure developed using fracture mechanics.
- Provided guidance on the necessary adjustments for 2.25Cr-1Mo steel in hydrogen service.

API 579-1/ASME FFS-1 2021 Fitness-For-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.

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

Annex 10B: Material Data for Creep Analysis

- Updated existing and added new MPC Omega material coefficients.

API 579-1/ASME FFS-1 2021 Fitness-For-Service

- 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

| | |
|---|------------|
| PART 1 – INTRODUCTION | 1-1 |
| 1.1 INTRODUCTION | 1-1 |
| 1.1.1 Construction Codes and Fitness-For-Service | 1-1 |
| 1.1.2 Fitness-For-Service Definition | 1-1 |
| 1.2 SCOPE | 1-2 |
| 1.2.1 Supplement to In-Service Inspection Codes | 1-2 |
| 1.2.2 Application Construction Codes | 1-2 |
| 1.2.3 Other Recognized Codes and Standards | 1-2 |
| 1.2.4 Remaining Life | 1-3 |
| 1.2.5 Assessment Methods for Flaw Types and Damage Conditions | 1-3 |
| 1.2.6 Special Cases | 1-3 |
| 1.3 ORGANIZATION AND USE | 1-4 |
| 1.4 RESPONSIBILITIES | 1-4 |
| 1.4.1 Owner-User | 1-4 |
| 1.4.2 Inspector | 1-4 |
| 1.4.3 Engineer | 1-4 |
| 1.4.4 Plant Engineer | 1-5 |
| 1.5 QUALIFICATIONS | 1-5 |
| 1.5.1 Education and Experience | 1-5 |
| 1.5.2 Owner-User | 1-5 |
| 1.5.3 Inspector | 1-5 |
| 1.5.4 Engineer | 1-6 |
| 1.6 DEFINITION OF TERMS | 1-6 |
| 1.7 REFERENCES | 1-6 |
| 1.7.1 Types | 1-6 |
| 1.7.2 Code, Standards and Recommended Practices | 1-6 |
| 1.7.3 Technical reports and Other Publications | 1-6 |
| 1.8 TABLES | 1-7 |

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