

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

[Intentionally Left Blank]

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	<i>Specific Applicability and Limitations</i>	2-3
2.3	DATA REQUIREMENTS.....	2-4
2.3.1	<i>Original Equipment Design Data</i>	2-4
2.3.2	<i>Maintenance and Operational History</i>	2-5
2.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	2-6
2.3.4	<i>Recommendations for Inspection Technique and Sizing Requirements</i>	2-6
2.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA	2-6
2.4.1	<i>Assessment Levels</i>	2-6
2.4.2	<i>FFS Acceptance Criteria</i>	2-7
2.4.3	<i>Data Uncertainties</i>	2-8
2.5	REMAINING LIFE ASSESSMENT	2-9
2.5.1	<i>Remaining Life</i>	2-9
2.5.2	<i>Guidance on Remaining Life Determination</i>	2-10
2.6	REMEDICATION	2-10
2.6.1	<i>Requirements for Remediation</i>	2-10
2.6.2	<i>Guidelines for Remediation</i>	2-10
2.7	IN-SERVICE MONITORING	2-10
2.8	DOCUMENTATION	2-11
2.8.1	<i>General</i>	2-11
2.8.2	<i>Applicability and Limitations</i>	2-11
2.8.3	<i>Data Requirements</i>	2-11
2.8.4	<i>Assessment Techniques and Acceptance Criteria</i>	2-11
2.8.5	<i>Remaining Life Assessment</i>	2-12
2.8.6	<i>Remediation Methods</i>	2-12
2.8.7	<i>In-Service Monitoring</i>	2-12
2.8.8	<i>Retention</i>	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	<i>Types of Pre-Service Deficiencies</i>	2B-2
2B.3.2	<i>In-Service Inspection</i>	2B-2
2B.4	IN-SERVICE DETERIORATION AND DAMAGE	2B-2
2B.4.1	<i>Overview</i>	2B-2
2B.4.2	<i>General Metal Loss Due to Corrosion and/or Erosion</i>	2B-3
2B.4.3	<i>Localized Metal Loss Due to Corrosion and/or Erosion</i>	2B-3
2B.4.4	<i>Surface Connected Cracking</i>	2B-4
2B.4.5	<i>Subsurface Cracking and Microfissuring/Microvoid Formation</i>	2B-5
2B.4.6	<i>Metallurgical Changes</i>	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 TANKS	2C-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 PRESSURE	2C-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	NOMENCLATURE	2C-26
2C.9	REFERENCES	2C-32
2C.10	TABLES	2C-34
2C.11	FIGURES	2C-36

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

2D.1	GENERAL REQUIREMENTS	2D-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 COLLAPSE	2D-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 FAILURE	2D-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 BUCKLING	2D-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 NECKS	2D-6
2D.6	NOMENCLATURE	2D-6
2D.7	REFERENCES	2D-7
2D.8	TABLES	2D-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	MPC True Stress-Strain Curve Model	2E-4
2E.3.2	MPC Tangent Modulus Model	2E-5
2E.3.3	Ramberg-Osgood Stress-Strain Model	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	Ramberg-Osgood Tangent Modulus Model	2E-8
2E.3.5	Engineering Stress-Strain Models for API 5L Pipeline Materials	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	Tangent Modulus Model for API 5L Pipeline Materials	2E-10
2E.4	CYCLIC STRESS-STRAIN RELATIONSHIPS	2E-10
2E.4.1	Ramberg-Osgood Equation	2E-10
2E.4.2	Estimation of Cyclic Stress-Strain Curve Parameters	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	Elastic Modulus	2E-11
2E.5.2	Poisson's Ratio	2E-11
2E.5.3	Coefficient of Thermal Expansion	2E-11
2E.5.4	Thermal Conductivity	2E-11
2E.5.5	Thermal Diffusivity	2E-11
2E.5.6	Density	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	<i>Equipment Covered</i>	3-3
3.2.2	<i>Components Subject to Metal Loss</i>	3-4
3.2.3	<i>Requirements for In-Service Inspection and Maintenance Programs</i>	3-4
3.2.4	<i>Supplemental Guidance for SA-212 Grade B Material</i>	3-4
3.3	DATA REQUIREMENTS.....	3-4
3.3.1	<i>Original Equipment Design Data</i>	3-5
3.3.2	<i>Maintenance and Operational History</i>	3-5
3.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	3-5
3.3.4	<i>Recommendations for Inspection Technique and Sizing Requirements</i>	3-6
3.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	3-6
3.4.1	<i>Overview</i>	3-6
3.4.2	<i>Level 1 Assessment</i>	3-7
3.4.3	<i>Level 2 Assessment</i>	3-10
3.4.4	<i>Level 3 Assessment</i>	3-15
3.5	REMAINING LIFE ASSESSMENT	3-16
3.5.1	<i>Acceptability for Continued Service</i>	3-16
3.5.2	<i>Pressure Vessels</i>	3-17
3.5.3	<i>Piping Systems</i>	3-17
3.5.4	<i>Atmospheric and Low Pressure Storage Tanks</i>	3-17
3.6	REMEDATION	3-17
3.6.1	<i>Potential Use of Remediation Methods</i>	3-17
3.6.2	<i>Remediation Methods</i>	3-17
3.7	IN-SERVICE MONITORING.....	3-19
3.7.1	<i>In-Service Monitoring and Control of Process Conditions</i>	3-19
3.7.2	<i>Monitoring for Degradation of Low Alloy Steel Notch Toughness</i>	3-19
3.7.3	<i>Monitoring for Criticality of Growing Flaws</i>	3-19
3.7.4	<i>Assessment of Non-Growing Flaws Detected In-Service</i>	3-19
3.8	DOCUMENTATION	3-19
3.8.1	<i>Documentation Requirements for Each Assessment Level</i>	3-19
3.8.2	<i>Documentation Retention</i>	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	<i>Assessment Procedures for General Metal Loss</i>	4-1
4.1.2	<i>Thickness Averaging Approach Used for the Assessment</i>	4-1
4.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	4-2
4.2.1	<i>General Metal Loss Assessment</i>	4-2
4.2.2	<i>Limitations Based on Flaw Type</i>	4-2
4.2.3	<i>Calculation of the MAWP_r and MFH_r and Coincident Temperature</i>	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	REMEDICATION	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	<i>Assessment of Blend Ground Areas for Crack-Like Flaw Removal</i>	5-4
5.3	DATA REQUIREMENTS.....	5-4
5.3.1	<i>Original Equipment Design Data</i>	5-4
5.3.2	<i>Maintenance and Operational History</i>	5-4
5.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	5-4
5.3.4	<i>Recommendations for Inspection Technique and Sizing Requirements</i>	5-5
5.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	5-6
5.4.1	<i>Overview</i>	5-6
5.4.2	<i>Level 1 Assessment</i>	5-6
5.4.3	<i>Level 2 Assessment</i>	5-8
5.4.4	<i>Level 3 Assessment</i>	5-14
5.5	REMAINING LIFE ASSESSMENT	5-14
5.5.1	<i>Thickness Approach</i>	5-14
5.5.2	<i>MAWP Approach</i>	5-15
5.6	REMEDICATION	5-15
5.7	IN-SERVICE MONITORING.....	5-15
5.8	DOCUMENTATION	5-15
5.8.1	<i>General</i>	5-15
5.8.2	<i>Inspection Data</i>	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 LOSS5A-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	<i>Assessment of Pitting Corrosion</i>	6-1
6.1.2	<i>Assessment of Blister Arrays</i>	6-1
6.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	6-1
6.2.1	<i>Assessment of Four Types of Pitting Corrosion</i>	6-2
6.2.2	<i>Calculation of the MAWP_r and MFH_r and Coincident Temperature</i>	6-2
6.2.3	<i>Limitations Based on Flaw Type</i>	6-2
6.2.4	<i>Limitations Based on Temperature</i>	6-2
6.2.5	<i>Applicability of the Level 1 and Level 2 Assessment Procedures</i>	6-2
6.2.6	<i>Applicability of the Level 3 Assessment Procedures</i>	6-3
6.2.7	<i>Assessment for Active Pitting Corrosion</i>	6-3
6.2.8	<i>Future Corrosion Allowance</i>	6-3
6.3	DATA REQUIREMENTS.....	6-4
6.3.1	<i>Original Equipment Design Data</i>	6-4
6.3.2	<i>Maintenance and Operational History</i>	6-4
6.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	6-4
6.3.4	<i>Recommendation for Inspection Technique and Sizing Requirements</i>	6-5
6.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	6-6
6.4.1	<i>Overview</i>	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	REMEDATION	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	REMEDATION	7-16

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

7.6.1	<i>Elimination of Hydrogen Charging</i>	7-16
7.6.2	<i>Controlling Hydrogen Charging</i>	7-16
7.6.3	<i>Venting of Blisters</i>	7-16
7.6.4	<i>Blend Grinding</i>	7-16
7.6.5	<i>Repair and Replacement of Damaged Material</i>	7-17
7.6.6	<i>NACE Standard SP0296-10</i>	7-17
7.7	IN-SERVICE MONITORING.....	7-17
7.7.1	<i>Monitoring for Hydrogen Charging</i>	7-17
7.7.2	<i>Inspection Methods for Monitoring</i>	7-17
7.7.3	<i>Detection of HIC, SOHIC, or Blister Damage Growth</i>	7-17
7.8	DOCUMENTATION	7-17
7.8.1	<i>General</i>	7-17
7.8.2	<i>Inspection Data</i>	7-17
7.8.3	<i>In-Service Monitoring</i>	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	<i>Evaluation of Weld Misalignment and Shell Distortions</i>	8-1
8.1.2	<i>ASME B&PV Code, Section VIII, Division 2</i>	8-1
8.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	8-2
8.2.1	<i>Types of Weld Misalignment and Shell Distortions</i>	8-2
8.2.2	<i>Limitations Based on Flaw Type</i>	8-2
8.2.3	<i>Calculation of the MAWP_r and MFH_r and Coincident Temperature</i>	8-2
8.2.4	<i>Limitations Based on Temperature</i>	8-2
8.2.5	<i>Applicability of the Level 1 and Level 2 Assessment Procedures</i>	8-3
8.2.6	<i>Applicability of the Level 3 Assessment</i>	8-3
8.3	DATA REQUIREMENTS.....	8-4
8.3.1	<i>Original Equipment Design Data</i>	8-4
8.3.2	<i>Maintenance and Operational History</i>	8-4
8.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	8-4
8.3.4	<i>Recommendations for Inspection Technique and Sizing Requirements</i>	8-4
8.4	EVALUATION TECHNIQUES AND ACCEPTANCE CRITERIA	8-6
8.4.1	<i>Overview</i>	8-6
8.4.2	<i>Level 1 Assessment</i>	8-6
8.4.3	<i>Level 2 Assessment</i>	8-7
8.4.4	<i>Level 3 Assessment</i>	8-12
8.5	REMAINING LIFE ASSESSMENT	8-13
8.5.1	<i>Categories – Metal Loss, Cyclic Loading, High Temperature Operation</i>	8-13
8.5.2	<i>Requirements for a Level 3 Assessment</i>	8-14

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

8.6	REMEDATION	8-14
8.6.1	<i>Addition of Reinforcement</i>	8-14
8.6.2	<i>Correction of Tolerances by Mechanical Means</i>	8-14
8.7	IN-SERVICE MONITORING.....	8-14
8.7.1	<i>Overview</i>	8-14
8.7.2	<i>Groove-Like and Crack-Like Flaws</i>	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	<i>Assessment Procedures for Crack-Like Flaws</i>	9-1
9.1.2	<i>ASME B&PV Code, Section VIII, Division 2 (VIII-2)</i>	9-2
9.1.3	<i>Crack-Like Flaw Definition</i>	9-2
9.1.4	<i>Treatment of Volumetric Flaws as Crack-Like Flaws</i>	9-2
9.1.5	<i>Use of Assessment Procedures to Evaluate Brittle Fracture</i>	9-2
9.1.6	<i>Service Environment and Material Interactions with Crack-Like flaws</i>	9-2
9.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	9-3
9.2.1	<i>Overview</i>	9-3
9.2.2	<i>Applicability of the Level 1 and Level 2 Assessment Procedures</i>	9-3
9.2.3	<i>Applicability of the Level 3 Assessment Procedure</i>	9-4
9.2.4	<i>Assessment Procedures for Notches in Groove-Like Flaws</i>	9-4
9.3	DATA REQUIREMENTS.....	9-4
9.3.1	<i>General</i>	9-4
9.3.2	<i>Original Equipment Design Data</i>	9-5
9.3.3	<i>Maintenance and Operating History</i>	9-5
9.3.4	<i>Required Data/Measurements for an FFS Assessment – Loads and Stresses</i>	9-6
9.3.5	<i>Required Data/Measurements for an FFS Assessment – Material Properties</i>	9-7
9.3.6	<i>Required Data/Measurements for an FFS Assessment – Flaw Characterization</i>	9-8
9.3.7	<i>Recommendation for Inspection Technique and Sizing Requirements</i>	9-12
9.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	9-13
9.4.1	<i>Overview</i>	9-13
9.4.2	<i>Level 1 Assessment</i>	9-14
9.4.3	<i>Level 2 Assessment</i>	9-15
9.4.4	<i>Level 3 Assessment</i>	9-19
9.5	REMAINING LIFE ASSESSMENT	9-21
9.5.1	<i>Subcritical Crack Growth</i>	9-21
9.5.2	<i>Leak-Before-Break Analysis</i>	9-23
9.6	REMEDATION	9-25
9.6.1	<i>Objectives of Remediation</i>	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 $1 \leq t/R_i \leq 3$	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 CALCULATIONS	9F-28
9F.5.1	<i>Categories of Crack Growth</i>	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	<i>Fatigue Crack Growth Equations</i>	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	<i>Fatigue Crack Growth Data</i>	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	<i>Hydrogen Assisted Crack Growth</i>	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	<i>Stress Corrosion Crack (SCC) Growth Equations</i>	9F-36
9F.5.6	<i>Stress Corrosion Crack Growth Data</i>	9F-37
9F.5.7	<i>Conversion of Units for Crack Growth Data</i>	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	REFERENCES	9F-43
9F.8	TABLES	9F-46
9F.9	FIGURES	9F-59

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

9G.1	GENERAL REQUIREMENTS	9G-1
9G.1.1	<i>Scope</i>	9G-1
9G.1.2	<i>ASME B&PV Code, Section VIII, Division 2 (VIII-2)</i>	9G-2
9G.1.3	<i>FAD-Based Assessment Procedure</i>	9G-2
9G.1.4	<i>Assessment Using Stress Analysis Results – Uncracked Configuration</i>	9G-2
9G.1.5	<i>Assessment Using Stress Analysis Results – Crack Incorporated into the Model</i>	9G-2
9G.1.6	<i>Assessment of Growing Cracks</i>	9G-2
9G.1.7	<i>Numerical Analysis</i>	9G-2
9G.1.8	<i>Applicable Loads and Load Case Combinations</i>	9G-2
9G.2	STRESS ANALYSIS OF THE UN-CRACKED CONFIGURATION	9G-3
9G.2.1	<i>Overview</i>	9G-3

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

9G.2.2	<i>Categorization and Linearization of Stress Results</i>	9G-3
9G.2.3	<i>Fitting Stress Results to a Polynomial</i>	9G-3
9G.2.4	<i>The Weight Function Method</i>	9G-3
9G.3	FINITE ELEMENT ANALYSIS OF COMPONENTS WITH CRACKS.....	9G-4
9G.3.1	<i>Overview</i>	9G-4
9G.3.2	<i>Output Quantity</i>	9G-4
9G.3.3	<i>Mesh Design</i>	9G-4
9G.3.4	<i>Crack Tip Modeling Approaches</i>	9G-4
9G.3.5	<i>Focused Mesh Approach</i>	9G-4
9G.3.6	<i>Finite Radius Approach</i>	9G-5
9G.3.7	<i>Small Strain vs. Large Strain Analysis</i>	9G-6
9G.3.8	<i>Convergence</i>	9G-6
9G.3.9	<i>Initial and Thermal Strains</i>	9G-7
9G.3.10	<i>Modeling Procedure</i>	9G-7
9G.4	FAD-BASED METHOD FOR NON-GROWING CRACKS.....	9G-8
9G.4.1	<i>Overview</i>	9G-8
9G.4.2	<i>Assessment Procedure</i>	9G-8
9G.5	DRIVING FORCE METHOD FOR NON-GROWING CRACKS.....	9G-10
9G.5.1	<i>Overview</i>	9G-10
9G.5.2	<i>Assessment Procedure</i>	9G-10
9G.6	ASSESSMENT OF GROWING CRACKS.....	9G-11
9G.6.1	<i>Crack Growth Models</i>	9G-11
9G.6.2	<i>Crack Parameter Solutions</i>	9G-11
9G.6.3	<i>Determination of a Remaining Life</i>	9G-11
9G.6.4	<i>Crack Growth Using Numerical Methods</i>	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	<i>Overview</i>	9H-1
9H.1.2	<i>Applicability and Limitations of the Procedure</i>	9H-1
9H.1.3	<i>Fracture Toughness Estimation Procedure</i>	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	<i>Overview</i>	9I-1
9I.1.2	<i>Applicability and Limitations of the Procedure</i>	9I-1
9I.1.3	<i>Alternative Estimate of Mode I Stress Intensity Factors for K_I Determination</i>	9I-2
9I.2	NOMENCLATURE.....	9I-3
9I.3	REFERENCES.....	9I-4

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	<i>General Procedure</i>	9J-1
9J.2.2	<i>Simplified Procedure</i>	9J-3
9J.3	REQUIRED MODIFICATIONS FOR HYDROGEN SERVICE	9J-4
9J.3.1	<i>Overview</i>	9J-4
9J.3.2	<i>2.25 Cr – 1 Mo</i>	9J-4
9J.3.3	<i>2.25 Cr – 1 Mo - V</i>	9J-5
9J.3.4	<i>Carbon Steel and Other Low-Chrome Alloys</i>	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	<i>FFS Procedures and Temperature Limits</i>	10-2
10.1.2	<i>Remaining Life of Components with and without Crack-Like Flaws</i>	10-2
10.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	10-2
10.2.1	<i>Suitability for Service and Remaining Life</i>	10-2
10.2.2	<i>Applicability and Limitations</i>	10-2
10.2.3	<i>Recommendations for Life Predictions Exceeding 35 Years</i>	10-4
10.3	DATA REQUIREMENTS.....	10-4
10.3.1	<i>General</i>	10-4
10.3.2	<i>Original Equipment Design Data</i>	10-4
10.3.3	<i>Maintenance and Operational History</i>	10-4
10.3.4	<i>Required Data for an FFS Assessment – Loads and Stresses</i>	10-5
10.3.5	<i>Required Data for an FFS Assessment – Material Properties</i>	10-6
10.3.6	<i>Required Data for an FFS Assessment – Damage Characterization</i>	10-7
10.3.7	<i>Recommendation for Inspection Technique and Sizing Requirements</i>	10-8
10.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	10-10
10.4.1	<i>Overview</i>	10-10
10.4.2	<i>Level 1 Assessment</i>	10-11
10.4.3	<i>Level 2 Assessment</i>	10-12
10.4.4	<i>Level 3 Assessment</i>	10-13
10.5	REMAINING LIFE ASSESSMENT	10-13
10.5.1	<i>Overview</i>	10-13
10.5.2	<i>Creep Rupture Life</i>	10-15
10.5.3	<i>Creep-Fatigue Interaction</i>	10-22
10.5.4	<i>Creep Crack Growth</i>	10-22
10.5.5	<i>Creep Buckling</i>	10-27
10.5.6	<i>Creep-Fatigue Assessment of Ferritic-Austenitic Dissimilar Weld Joints</i>	10-29
10.5.7	<i>Microstructural Approach</i>	10-32

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

10.6	REMEDICATION	10-34
10.6.1	<i>Components with and without a Crack-Like Flaw</i>	10-34
10.6.2	<i>Components with a Crack-Like Flaw</i>	10-34
10.7	IN-SERVICE MONITORING.....	10-34
10.8	DOCUMENTATION	10-34
10.8.1	<i>General</i>	10-34
10.8.2	<i>Assumptions Used in the Assumption</i>	10-34
10.8.3	<i>Documentation for Life Assessment</i>	10-34
10.8.4	<i>Supplemental Documentation for Creep Crack Growth</i>	10-35
10.8.5	<i>Supplemental Documentation for Microstructural Approaches</i>	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	<i>MPC Project Omega</i>	10B-1
10B.2.2	<i>API Std 530, 6th Edition, September 2008</i>	10B-3
10B.2.3	<i>WRC Bulletin 541</i>	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	<i>Technical References – High Temperature Assessment</i>	10B-9
10B.9.2	<i>Creep Rupture Strength and Creep Strain Rate Data</i>	10B-10
10B.9.3	<i>Creep Crack Growth Data</i>	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	<i>Assessment of Fire Damage</i>	11-1
11.1.2	<i>Assessment of Process Upsets</i>	11-1
11.1.3	<i>Guidelines and Assessment Flowchart</i>	11-2
11.1.4	<i>Forms of Fire Damage</i>	11-2
11.1.5	<i>Alternative Methods for Equipment Not Suitable for Operation</i>	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	<i>Equipment and Components Covered by the Assessment Procedure</i>	11-2
11.2.2	<i>Equipment and Components Not Covered by the Assessment Procedure</i>	11-2
11.3	DATA REQUIREMENTS.....	11-3
11.3.1	<i>Original Equipment Design Data</i>	11-3
11.3.2	<i>Maintenance and Operational History</i>	11-3
11.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	11-3
11.3.4	<i>Recommendations for Inspection Techniques and Sizing Requirements</i>	11-7
11.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	11-8
11.4.1	<i>Overview</i>	11-8
11.4.2	<i>Level 1 Assessment</i>	11-9
11.4.3	<i>Level 2 Assessment</i>	11-9
11.4.4	<i>Level 3 Assessment</i>	11-11
11.5	REMAINING LIFE ASSESSMENT	11-12
11.5.1	<i>Thinning and Crack-Like Flaw Damage</i>	11-12
11.5.2	<i>Creep Damage</i>	11-12
11.6	REMEDICATION	11-12
11.6.1	<i>Techniques</i>	11-12
11.6.2	<i>Need for Repair or Replacement</i>	11-12
11.7	IN-SERVICE MONITORING.....	11-12
11.8	DOCUMENTATION	11-12
11.8.1	<i>General</i>	11-12
11.8.2	<i>Heat Exposure Zones</i>	11-13
11.8.3	<i>Record Retention</i>	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	<i>Metallurgical Investigations</i>	11B-2
11B.1.2	<i>Materials Covered</i>	11B-2
11B.1.3	<i>Change in material properties from Fire Damage</i>	11B-2
11B.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	11B-2
11B.3	SPECIFIC RESPONSIBILITIES AND QUALIFICATIONS.....	11B-2
11B.3.1	<i>Overview</i>	11B-2
11B.3.2	<i>Field Assessment Team</i>	11B-2
11B.3.3	<i>Laboratory Assessment Team</i>	11B-3
11B.4	EVALUATION TECHNIQUES	11B-3
11B.5	FIELD ASSESSMENT TECHNIQUES	11B-3
11B.5.1	<i>Field Hardness Testing</i>	11B-3
11B.5.2	<i>In-situ Metallography or Replication</i>	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	REMEDICATION	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	<i>Documentation of Flaw Size and Conditions</i>	13-8
13.8.3	<i>Documentation of Flaw Growth</i>	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	<i>Assessment Procedures for Fatigue Damage</i>	14-2
14.1.2	<i>Damage Tolerance</i>	14-2
14.1.3	<i>Fatigue Evaluation in the Creep Range</i>	14-2
14.1.4	<i>Fatigue Evaluation and Crack-Like Flaws</i>	14-2
14.1.5	<i>ASME B&PV Code, Section VIII, Division 2 (VIII-2)</i>	14-3
14.1.6	<i>Use of Fatigue Curves in Performing Assessments</i>	14-3
14.1.7	<i>Adjustment for Mean Stress</i>	14-3
14.1.8	<i>Ratcheting</i>	14-3
14.2	APPLICABILITY AND LIMITATIONS OF THE PROCEDURE	14-3
14.2.1	<i>Applicability and Limitations of the Assessment Procedures</i>	14-3
14.2.2	<i>Calculation of MAWP and Coincident Temperature</i>	14-3
14.2.3	<i>Limitations Based on Temperature</i>	14-4
14.2.4	<i>Limitations Based on Flaw Type</i>	14-4
14.2.5	<i>Applicability of the Level 1 and Level 2 Assessment Procedures</i>	14-4
14.2.6	<i>Applicability of the Level 3 Assessment</i>	14-4
14.3	DATA REQUIREMENTS.....	14-5
14.3.1	<i>Original Equipment Design Data</i>	14-5
14.3.2	<i>Maintenance and Operational History</i>	14-5
14.3.3	<i>Required Data/Measurements for an FFS Assessment</i>	14-5
14.3.4	<i>Recommendations for Inspection Technique and Sizing Requirements</i>	14-5
14.4	ASSESSMENT TECHNIQUES AND ACCEPTANCE CRITERIA.....	14-6
14.4.1	<i>Overview</i>	14-6
14.4.2	<i>Level 1 Assessment</i>	14-6
14.4.2.1	<i>Overview</i>	14-6
14.4.2.2	<i>Method A – Fatigue Screening Based on Experience with Comparable Equipment</i>	14-7
14.4.2.3	<i>Method B – Fatigue Screening</i>	14-7
14.4.2.4	<i>Method C – Fatigue Screening</i>	14-8
14.4.2.5	<i>Method D – Fatigue Screening, Welded Joints</i>	14-10
14.4.2.6	<i>Level 1 Assessment Results</i>	14-12
14.4.3	<i>Level 2 Assessment</i>	14-12
14.4.3.1	<i>Overview</i>	14-12
14.4.3.2	<i>Method A – Fatigue Assessment Using Elastic Stress Analysis and Equivalent Stresses</i>	14-13
14.4.3.3	<i>Method B – Fatigue Assessment Using Elastic-Plastic Stress Analysis and Equivalent Strain</i>	14-17
14.4.3.4	<i>Method C – Fatigue Assessment of Welds Using the Equivalent Structural Stress</i>	14-19
14.4.3.5	<i>Ratcheting Assessment – Elastic Stress Analysis</i>	14-23
14.4.3.6	<i>Ratcheting Assessment – Elastic-Plastic Stress Analysis</i>	14-25
14.4.3.7	<i>Ratcheting Assessment – Non-Integral Connections</i>	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	<i>Included in Level 2 and Level 3 Assessments</i>	14-29
14.5.2	<i>Loading Time History</i>	14-29
14.6	REMEDICATION	14-29
14.6.1	Overview	14-29
14.6.2	<i>Removal or Reduction of the Driving Energy Source or Forces</i>	14-30
14.6.3	<i>Alteration of Component Constraint, Mechanical Design, or Weld Quality</i>	14-30
14.6.4	<i>Reduction of Temperature Differentials or Gradients</i>	14-31
14.7	IN-SERVICE MONITORING	14-31
14.8	DOCUMENTATION	14-31
14.8.1	<i>General</i>	14-31
14.8.2	<i>Assessment Level</i>	14-31
14.8.3	<i>Loading Time History</i>	14-31
14.8.4	<i>Material Properties</i>	14-32
14.8.5	<i>Stress Analysis Results</i>	14-32
14.8.6	<i>Assessment Results</i>	14-32
14.8.7	<i>Remaining Life Assessment</i>	14-32
14.8.8	<i>Remediation Methods</i>	14-32
14.8.9	<i>In-Service Monitoring</i>	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	<i>Temperature Correction</i>	14B-1
14B.1.2	<i>Interpolation</i>	14B-1
14B.1.3	<i>Design Fatigue Curves Based on Testing in Air</i>	14B-1
14B.1.4	<i>Design Fatigue Curve Models</i>	14B-2
14B.1.5	<i>Computation of Allowable Cycles</i>	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	<i>Fatigue Curve Models</i>	14B-5
14B.4.2	<i>Computation of Allowable Cycles</i>	14B-5
14B.5	NOMENCLATURE.....	14B-6
14B.6	REFERENCES.....	14B-8
14B.7	TABLES	14B-10

14B.8	FIGURES	14B-17
-------	---------------	--------

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

14C.1	INTRODUCTION	14C-1
14C.1.1	<i>Cycle Counting</i>	14C-1
14C.1.2	<i>Plasticity Correction</i>	14C-1
14C.1.3	<i>Definitions</i>	14C-2
14C.1.4	<i>Histogram Development</i>	14C-3
14C.2	PLASTICITY CORRECTION	14C-3
14C.2.1	<i>Uniaxial Plasticity Correction</i>	14C-3
14C.2.2	<i>Multiaxial Plasticity Correction</i>	14C-3
14C.3	UNIAXIAL CYCLE COUNTING	14C-8
14C.3.1	<i>Rainflow Cycle Counting – With Reordering</i>	14C-8
14C.3.2	<i>Additional Rainflow Cycle Counting – Without Reordering</i>	14C-10
14C.4	MULTIAXIAL CYCLE COUNTING	14C-10
14C.4.1	<i>Wang-Brown Cycle Counting</i>	14C-10
14C.4.2	<i>Critical Plane Cycle Counting</i>	14C-14
14C.5	NOMENCLATURE	14C-18
14C.6	REFERENCES	14C-24
14C.7	FIGURES	14C-25