

CONTENTS

Foreword	xix
Statements of Policy	xxi
Personnel	xxiii

PART 1 - GENERAL REQUIREMENTS

1.1	General	1-2
1.1.1	Introduction	1-2
1.1.2	Organization	1-2
1.1.3	Definitions	1-2
1.2	Scope	1-3
1.2.1	Overview	1-3
1.2.2	Additional Requirements for Very High Pressure Vessels	1-4
1.2.3	Geometric Scope of This Division.....	1-4
1.2.4	Classifications Outside the Scope of this Division	1-4
1.2.5	Combination Units.....	1-5
1.2.6	Field Assembly of Vessels.....	1-5
1.2.7	Pressure Relief Devices	1-6
1.3	Standards Referenced by This Division	1-6
1.4	Units of Measurement	1-6
1.5	Technical Inquires	1-7
1.6	Tables	1-8

Annex 1.A Submittal Of Technical Inquiries To The Boiler And Pressure Vessel Standards Committee

1.A.1	Introduction	1-10
1.A.2	Inquiry Format.....	1-10
1.A.3	Code Revisions or Additions.....	1-11
1.A.4	Code Cases	1-11
1.A.5	Code Interpretations	1-11
1.A.6	Submittals.....	1-12

Annex 1.B Definitions

1.B.1	Introduction	1-13
1.B.2	Definition of Terms	1-13

Annex 1.C Guidance For The Use Of US Customary And SI Units In The ASME Boiler And Pressure Vessel Codes

1.C.1	Use of Units in Equations.....	1-15
1.C.2	Guidelines Used to Develop SI Equivalents.....	1-15
1.C.3	Soft Conversion Factors	1-16
1.C.4	Tables	1-17

PART 2 - RESPONSIBILITIES AND DUTIES

2.1	General	2-3
2.1.1	Introduction	2-3
2.1.2	Definitions	2-3
2.1.3	Code Reference.....	2-3
2.2	User Responsibilities	2-3
2.2.1	General.....	2-3
2.2.2	User's Design Specification.....	2-3
2.3	Manufacturer's Responsibilities	2-6
2.3.1	Code Compliance.....	2-6
2.3.2	Materials Selection	2-6

2.3.3	Manufacturer’s Design Report.....	2-6
2.3.4	Manufacturer’s Data Report	2-7
2.3.5	Manufacturer’s Construction Records	2-7
2.3.6	Quality Control System	2-7
2.3.7	Certification of Subcontracted Services.....	2-8
2.3.8	Inspection and Examination.....	2-8
2.3.9	Application of Code Stamp.....	2-8
2.4	The Inspector.....	2-8
2.4.1	Identification of Inspector.....	2-8
2.4.2	Inspector Qualification	2-8
2.4.3	Inspector’s Duties	2-9

Annex 2.A Guide For Certifying A User’s Design Specification

2.A.1	General	2-10
2.A.2	Certification of the User’s Design specification.....	2-10
2.A.3	Tables	2-12

Annex 2.B Guide For Certifying A Manufacturer’s Design Report

2.B.1	General	2-13
2.B.2	Certification of Manufacture’s Design Report	2-13
2.B.3	Tables	2-15

Annex 2.C Report Forms And Maintenance Of Records

2.C.1	Manufacturer’s Data Reports.....	2-16
2.C.2	Partial Data Reports.....	2-17
2.C.3	Maintenance of Records.....	2-17

Annex 2.D Guide For Preparing Manufacturer’s Data Reports

2.D.1	Introduction	2-18
2.D.2	Tables	2-19

Annex 2.E Quality Control System

2.E.1	General	2-28
2.E.2	Outline of Features Included in the Quality Control System.....	2-28
2.E.3	Authority and Responsibility.....	2-28
2.E.4	Organization	2-29
2.E.5	Drawings, Design Calculations, and Specification Control.....	2-29
2.E.6	Material Control	2-29
2.E.7	Examination and Inspection Program.....	2-29
2.E.8	Correction of Nonconformities.....	2-29
2.E.9	Welding.....	2-29
2.E.10	Nondestructive Examination	2-29
2.E.11	Heat Treatment	2-29
2.E.12	Calibration of Measurement and Test Equipment	2-29
2.E.13	Records Retention	2-30
2.E.14	Sample Forms.....	2-30
2.E.15	Inspection of Vessels and Vessel Parts.....	2-30
2.E.16	Inspection of Pressure Relief Valves.....	2-30

ANNEX 2.F Contents And Method Of Stamping

2.F.1	Required Marking for Vessels.....	2-31
-------	-----------------------------------	------

2.F.2	Methods of Marking Vessels with Two or More Independent Chambers	2-31
2.F.3	Application of Stamp	2-32
2.F.4	Part Marking	2-32
2.F.5	Application of Markings	2-32
2.F.6	Duplicate Nameplate	2-33
2.F.7	Size and Arrangements of Characters for Nameplate and Direct Stamping of Vessels	2-33
2.F.8	Attachment of Nameplate or Tag	2-33
2.F.9	Figures	2-34

Annex 2.G Obtaining And Using Code Stamps

2.G.1	Code Stamps Bearing Official Symbol	2-35
2.G.2	Application for Authorization	2-35
2.G.3	Issuance of Authorization	2-35
2.G.4	Inspection Agreement	2-36
2.G.5	Quality Control System	2-36
2.G.6	Evaluation for Authorization and Reauthorization	2-36
2.G.7	Code Construction Before Receipt of Certificate of Authorization	2-37

Annex 2.H Guide To Information Appearing On The Certificate Of Authorization

2.H.1	Introduction	2-38
2.H.2	Tables	2-39
2.H.3	Figure	2-40

PART 3 - MATERIALS REQUIREMENTS

3.1	General Requirements	3-4
3.2	Materials Permitted For Construction of Vessel Parts	3-4
3.2.1	Materials for Pressure Parts	3-4
3.2.2	Materials for Attachments to Pressure Parts	3-4
3.2.3	Welding Materials	3-5
3.2.4	Dissimilar Materials	3-5
3.2.5	Product Specifications	3-5
3.2.6	Certification	3-6
3.2.7	Product Identification and Traceability	3-6
3.2.8	Prefabricated or Preformed Pressure Parts	3-7
3.2.9	Definition of Product Form Thickness	3-8
3.2.10	Product Form Tolerances	3-8
3.2.11	Purchase Requirements	3-9
3.3	Supplemental Requirements for Ferrous Materials	3-9
3.3.1	General	3-9
3.3.2	Chemistry Requirements	3-9
3.3.3	Ultrasonic Examination of Plates	3-9
3.3.4	Ultrasonic Examination of Forgings	3-9
3.3.5	Magnetic Particle and Liquid Penetrant Examination of Forgings	3-10
3.3.6	Integral and Weld Metal Overlay Clad Base Metal	3-10
3.4	Supplemental Requirements for Cr-Mo Steels	3-11
3.4.1	General	3-11
3.4.2	Postweld Heat Treatment	3-11
3.4.3	Test Specimen Heat Treatment	3-11
3.4.4	Weld Procedure Qualifications and Weld Consumables Testing	3-11
3.4.5	Toughness Requirements	3-12
3.5	Supplemental Requirements for Q&T Steels with Enhanced Tensile Properties	3-12
3.5.1	General	3-12
3.5.2	Parts for Which Q&T Steels May be Used	3-12
3.5.3	Structural Attachments	3-12

3.6	Supplemental Requirements for Nonferrous Materials	3-13
3.6.1	General.....	3-13
3.6.2	Ultrasonic Examination of Plates.....	3-13
3.6.3	Ultrasonic Examination of Forgings.....	3-13
3.6.4	Liquid Penetrant Examination of Forgings.....	3-13
3.6.5	Clad Plate and Products.....	3-14
3.7	Supplemental Requirements for Bolting	3-14
3.7.1	General.....	3-14
3.7.2	Examination of Bolts, Studs, and Nuts.....	3-14
3.7.3	Threading and Machining of Studs.....	3-15
3.7.4	Use of Washers.....	3-15
3.7.5	Ferrous Bolting.....	3-15
3.7.6	Nonferrous Bolting.....	3-15
3.7.7	Materials for Ferrous and Nonferrous Nuts of Special Design.....	3-16
3.8	Supplemental Requirements for Castings.....	3-16
3.8.1	General.....	3-16
3.8.2	Requirements for Ferrous Castings.....	3-16
3.8.3	Requirements for Nonferrous Castings.....	3-18
3.9	Supplemental Requirements for Hubs Machined From Plate.....	3-19
3.9.1	General.....	3-19
3.9.2	Material Requirements.....	3-19
3.9.3	Examination Requirements.....	3-19
3.9.4	Data Reports and Marking.....	3-19
3.10	Material Test Requirements	3-20
3.10.1	General.....	3-20
3.10.2	Requirements for Sample Test Coupons.....	3-20
3.10.3	Exemptions from Requirement of Sample Test Coupons.....	3-20
3.10.4	Procedure for Obtaining Test Specimens and Coupons.....	3-20
3.10.5	Procedure for Heat Treating Test Specimens from Ferrous Materials.....	3-22
3.10.6	Test Coupon Heat Treatment for Nonferrous Materials	3-22
3.11	Material Toughness Requirements	3-23
3.11.1	General.....	3-23
3.11.2	Carbon and Low Alloy Steels Except Bolting.....	3-23
3.11.3	Q&T Ferritic Steels.....	3-28
3.11.4	High Alloy Steels Except Bolting.....	3-29
3.11.5	Non-Ferrous Alloys	3-32
3.11.6	Bolting Materials	3-32
3.11.7	Toughness Testing Procedures	3-32
3.11.8	Impact Testing Of Welding Procedures and Test Plates of Ferrous Materials	3-34
3.12	Allowable Design Stresses	3-36
3.13	Strength Parameters.....	3-36
3.14	Physical Properties	3-36
3.15	Design Fatigue Curves	3-36
3.16	Nomenclature	3-37
3.17	Definitions.....	3-37
3.18	Tables	3-38
3.19	Figures.....	3-48

Annex 3.A Allowable Design Stresses

3.A.1	Allowable Stress Basis – All Materials Except Bolting	3-70
3.A.2	Allowable Stress Basis – Bolting Materials	3-70
3.A.3	Tables	3-72

Annex 3.B Requirements for Material Procurement (Currently Not Used)

Annex 3.C ISO Material Group Numbers (Currently Not Used)

Annex 3.D Strength Parameters

3.D.1	Yield Strength.....	3-98
3.D.2	Ultimate Tensile Strength.....	3-98
3.D.3	Stress Strain Curve.....	3-98
3.D.4	Cyclic Stress Strain Curve.....	3-99
3.D.5	Tangent Modulus.....	3-99
3.D.5.1	Tangent Modulus Based on the Stress-Strain Curve Model.....	3-99
3.D.5.2	Tangent Modulus Based on External Pressure Charts.....	3-100
3.D.6	Nomenclature.....	3-101
3.D.7	Tables.....	3-102

Annex 3.E Physical Properties

3.E.1	Young’s Modulus.....	3-107
3.E.2	Thermal Expansion Coefficient.....	3-107
3.E.3	Thermal Conductivity.....	3-107
3.E.4	Thermal Diffusivity.....	3-107

Annex 3.E Design Fatigue Curves

3.F.1	Smooth Bar Design Fatigue Curves.....	3-108
3.F.2	Welded Joint Design Fatigue Curves.....	3-109
3.F.3	Nomenclature.....	3-111
3.F.4	Tables.....	3-112

PART 4 - DESIGN BY RULE REQUIREMENTS

4.1	General Requirements.....	4-6
4.1.1	Scope.....	4-6
4.1.2	Minimum Thickness Requirements.....	4-6
4.1.3	Material Thickness Requirements.....	4-7
4.1.4	Corrosion Allowance in Design Equations.....	4-7
4.1.5	Design Basis.....	4-7
4.1.6	Design Allowable Stress.....	4-9
4.1.7	Materials in Combination.....	4-10
4.1.8	Combination Units.....	4-10
4.1.9	Cladding and Weld Overlay.....	4-11
4.1.10	Internal Linings.....	4-11
4.1.11	Flanges and Pipe Fittings.....	4-11
4.1.12	Nomenclature.....	4-12
4.1.13	Tables.....	4-13
4.2	Design Rules for Welded Joints.....	4-14
4.2.1	Scope.....	4-14
4.2.2	Weld Category.....	4-14
4.2.3	Weld Joint Type.....	4-14
4.2.4	Weld Joint Factor.....	4-14
4.2.5	Types of Joints Permitted.....	4-14
4.2.6	Nomenclature.....	4-22
4.2.7	Tables.....	4-23
4.2.8	Figures.....	4-44
4.3	Design Rules for Shells Under Pressure.....	4-48
4.3.1	Scope.....	4-48
4.3.2	Shell Tolerances.....	4-48
4.3.3	Cylindrical Shells.....	4-49
4.3.4	Conical Shells.....	4-49
4.3.5	Spherical Shells and Hemispherical Heads.....	4-49
4.3.6	Torispherical Heads.....	4-49
4.3.7	Ellipsoidal Heads.....	4-52
4.3.8	Local Thin Areas.....	4-52
4.3.9	Drilled Holes Not Penetrating Through the Vessel Wall.....	4-53
4.3.10	Combined Loadings and Allowable Stresses.....	4-53

4.3.11	Cylindrical-To-Conical Shell Transition Junctions Without a Knuckle	4-55
4.3.12	Cylindrical-To-Conical Shell Transition Junctions with a Knuckle	4-58
4.3.13	Nomenclature.....	4-60
4.3.14	Tables.....	4-64
4.3.15	Figures	4-74
4.4	Design Rules for Shells Under External Pressure and Allowable Compressive Stresses.....	4-81
4.4.1	Scope	4-81
4.4.2	Design Factors	4-82
4.4.3	Material Properties.....	4-82
4.4.4	Shell Tolerances.....	4-83
4.4.5	Cylindrical Shell	4-84
4.4.6	Conical Shell.....	4-88
4.4.7	Spherical Shell and Hemispherical Head.....	4-89
4.4.8	Torispherical Head.....	4-90
4.4.9	Ellipsoidal Head.....	4-91
4.4.10	Local Thin Areas	4-91
4.4.11	Drilled Holes Not Penetrating Through the Vessel Wall.....	4-91
4.4.12	Combined Loadings and Allowable Compressive Stresses	4-91
4.4.13	Cylindrical-To-Conical Shell Transition Junctions Without A Knuckle	4-100
4.4.14	Cylindrical-To-Conical Shell Transition Junctions With A Knuckle	4-100
4.4.15	Nomenclature.....	4-101
4.4.16	Tables.....	4-105
4.4.17	Figures	4-106
4.5	Design Rules for Shells Openings in Shells and Heads.....	4-113
4.5.1	Scope	4-113
4.5.2	Dimensions and Shape of Nozzles.....	4-113
4.5.3	Method of Nozzle Attachment.....	4-113
4.5.4	Nozzle Neck Minimum Thickness Requirements	4-114
4.5.5	Radial Nozzle in a Cylindrical Shell.....	4-114
4.5.6	Hillside Nozzle in a Cylindrical Shell	4-118
4.5.7	Nozzle in a Cylindrical Shell Oriented at an Angle from the Longitudinal Axis	4-118
4.5.8	Radial Nozzle in a Conical Shell	4-118
4.5.9	Nozzle in a Conical Shell.....	4-119
4.5.10	Radial Nozzle in a Spherical Shell or Formed Head.....	4-119
4.5.11	Hillside or Perpendicular Nozzle in a Formed Head	4-123
4.5.12	Circular Nozzles in a Flat Head.....	4-123
4.5.13	Spacing Requirements for Nozzles	4-124
4.5.14	Strength of Nozzle Attachment Welds	4-125
4.5.15	Local Stresses in Nozzles in Shells and Formed Heads from External Loads.....	4-128
4.5.16	Inspection Openings	4-129
4.5.17	Reinforcement of Openings Subject to Compressive Stress.....	4-130
4.5.18	Nomenclature.....	4-131
4.5.19	Tables.....	4-134
4.5.20	Figures	4-135
4.6	Design Rules for Flat Heads.....	4-142
4.6.1	Scope	4-142
4.6.2	Flat Unstayed Circular Heads.....	4-142
4.6.3	Flat Unstayed Non-Circular Heads.....	4-143
4.6.4	Integral Flat Head With A Centrally Located Opening	4-143
4.6.5	Nomenclature.....	4-145
4.6.6	Tables.....	4-147
4.6.7	Figures	4-153
4.7	Design Rules for Spherically Dished Bolted Covers.....	4-154
4.7.1	Scope	4-154
4.7.2	Type A Head Thickness Requirements.....	4-154
4.7.3	Type B Head Thickness Requirements.....	4-154
4.7.4	Type C Head Thickness Requirements.....	4-155
4.7.5	Type D Head Thickness Requirements.....	4-156

4.7.6	Nomenclature.....	4-160
4.7.7	Tables.....	4-162
4.7.8	Figures.....	4-163
4.8	Design Rules for Quick Actuating (Quick Opening) Closures.....	4-166
4.8.1	Scope.....	4-166
4.8.2	Definitions.....	4-166
4.8.3	General Design Requirements.....	4-166
4.8.4	Specific Design Requirements.....	4-167
4.8.5	Alternative Designs for Manually Operated Closures.....	4-167
4.8.6	Supplementary Requirements for Quick-Actuating (Quick-Opening) Closures.....	4-167
4.9	Design Rules for Braced and Stayed Surfaces.....	4-168
4.9.1	Scope.....	4-168
4.9.2	Required Thickness of Braced and Stayed Surfaces.....	4-168
4.9.3	Required Dimensions and Layout of Staybolts and Stays.....	4-168
4.9.4	Requirements for Welded-in Staybolts and Welded Stays.....	4-168
4.9.5	Nomenclature.....	4-170
4.9.6	Tables.....	4-171
4.9.7	Figures.....	4-172
4.10	Design Rules for Ligaments.....	4-173
4.10.1	Scope.....	4-173
4.10.2	Ligament Efficiency.....	4-173
4.10.3	Ligament Efficiency and the Weld Joint Factor.....	4-174
4.10.4	Nomenclature.....	4-174
4.10.5	Figures.....	4-175
4.11	Design Rules for Jacketed Vessels.....	4-179
4.11.1	Scope.....	4-179
4.11.2	Design of Jacketed Shells and Jacketed Heads.....	4-179
4.11.3	Design of Closure Member of Jacket to Vessel.....	4-180
4.11.4	Design of Penetrations Through Jackets.....	4-180
4.11.5	Design of Partial Jackets.....	4-181
4.11.6	Design of Half-Pipe Jackets.....	4-181
4.11.7	Nomenclature.....	4-182
4.11.8	Tables.....	4-183
4.11.9	Figures.....	4-194
4.12	Design Rules for NonCircular Vessels.....	4-197
4.12.1	Scope.....	4-197
4.12.2	General Design Requirements.....	4-197
4.12.3	Requirements for Vessels With Reinforcement.....	4-198
4.12.4	Requirements for Vessels With Stays.....	4-200
4.12.5	Requirements for Rectangular Vessels With Small Aspect Ratios.....	4-201
4.12.6	Weld Joint Factors and Ligament Efficiency.....	4-201
4.12.7	Design Procedure.....	4-204
4.12.8	Noncircular Vessels Subject to External Pressure.....	4-205
4.12.9	Rectangular Vessels With Two or More Compartments of Unequal Size.....	4-206
4.12.10	Fabrication.....	4-206
4.12.11	Nomenclature.....	4-207
4.12.12	Tables.....	4-210
4.12.13	Figures.....	4-246
4.13	Design Rules for Layered Vessels.....	4-261
4.13.1	Scope.....	4-261
4.13.2	Definitions.....	4-261
4.13.3	General.....	4-261
4.13.4	Design for Internal Pressure.....	4-261
4.13.5	Design for External Pressure.....	4-262
4.13.6	Design of Welded Joints.....	4-262
4.13.7	Nozzles and Nozzle Reinforcement.....	4-263
4.13.8	Flat Heads.....	4-264
4.13.9	Bolted and Studded Connections.....	4-264

4.13.10	Attachments and Supports	4-264
4.13.11	Vent Holes	4-264
4.13.12	Shell Tolerances.....	4-265
4.13.13	Nomenclature.....	4-267
4.13.14	Figures	4-268
4.14	Evaluation of Vessels Outside of Tolerance.....	4-281
4.14.1	Shell Tolerances.....	4-281
4.14.2	Local Thin Areas	4-281
4.14.3	Marking and Reports	4-281
4.14.4	Figures	4-282
4.15	Design Rules for Supports and Attachments	4-283
4.15.1	Scope	4-283
4.15.2	Design of Supports	4-283
4.15.3	Saddle Supports for Horizontal Vessels	4-283
4.15.4	Skirt Supports for Vertical Vessels.....	4-290
4.15.5	Lug And Leg Supports.....	4-291
4.15.6	Nomenclature.....	4-292
4.15.7	Tables.....	4-293
4.15.8	Figures	4-295
4.16	Design Rules for Flanged Joints.....	4-303
4.16.1	Scope	4-303
4.16.2	Design Considerations	4-303
4.16.3	Flange Types.....	4-304
4.16.4	Flange Materials	4-304
4.16.5	Gasket Materials	4-305
4.16.6	Design Bolt Loads	4-305
4.16.7	Flange Design Procedure	4-306
4.16.8	Split Loose Type Flanges	4-308
4.16.9	Noncircular Shaped Flanges with a Circular Bore.....	4-308
4.16.10	Flanges with Nut Stops.....	4-308
4.16.11	Joint Assembly Procedures.....	4-308
4.16.12	Nomenclature.....	4-309
4.16.13	Tables.....	4-312
4.16.14	Figures	4-324
4.17	Design Rules for Clamped Connections.....	4-332
4.17.1	Scope	4-332
4.17.2	Design Considerations	4-332
4.17.3	Flange Materials	4-332
4.17.4	Design Bolt Loads	4-333
4.17.5	Flange and Clamp Design Procedure.....	4-334
4.17.6	Nomenclature.....	4-337
4.17.7	Tables.....	4-340
4.17.8	Figures	4-342
4.18	Design Rules for Shell and Tube Heat Exchangers	4-344
4.18.1	Scope	4-344
4.18.2	Terminology	4-344
4.18.3	General Design Considerations	4-344
4.18.4	General Conditions of Applicability for Tubesheets	4-344
4.18.5	Tubesheet Flanged Extension	4-345
4.18.6	Tubesheet Characteristics	4-345
4.18.7	Rules for the Design of U-Tube Tubesheets.....	4-347
4.18.8	Rules for the Design of Fixed Tubesheets	4-352
4.18.9	Rules for the Design of Floating Tubesheets	4-365
4.18.10	Tube-to-Tubesheet Welds.....	4-375
4.18.11	Thin-Walled Expansion Joints.....	4-378
4.18.12	Thick-Walled Expansion Joints.....	4-378
4.18.13	Pressure Test Requirements.....	4-379
4.18.14	Heat Exchanger Marking and Reports.....	4-379

4.18.15	Nomenclature.....	4-381
4.18.16	Tables.....	4-386
4.18.17	Figures.....	4-390
4.19	Design Rules for Thin-Wall Expansion Joints	4-404
4.19.1	Scope	4-404
4.19.2	Conditions of Applicability	4-404
4.19.3	Design Considerations.....	4-404
4.19.4	Materials	4-406
4.19.5	Design of U-Shaped Unreinforced Bellows.....	4-406
4.19.6	Design of U-Shaped Reinforced Bellows	4-409
4.19.7	Design of Toroidal Bellows.....	4-410
4.19.8	Bellows Subject to Axial, Lateral or Angular Displacements	4-411
4.19.9	Fabrication	4-414
4.19.10	Examination.....	4-414
4.19.11	Pressure Test Requirements.....	4-414
4.19.12	Marking and Reports	4-414
4.19.13	Specification Sheet for Expansion Joints.....	4-415
4.19.14	Nomenclature.....	4-416
4.19.15	Tables.....	4-418
4.19.16	Figures.....	4-428
4.19.17	Specification Sheets.....	4-438

Annex 4.A Currently Not Used

Annex 4.B Guide For The Design And Operation Of Quick-Actuating (Quick-Opening) Closures

4.B.1	Introduction	4-441
4.B.2	Responsibilities	4-441
4.B.3	Design.....	4-441
4.B.4	Installation.....	4-442
4.B.5	Inspection	4-443
4.B.6	Training.....	4-443
4.B.7	Administrative Controls	4-443

Annex 4.C Basis For Establishing Allowable Loads For Tube-To-Tubesheet Joints

4.C.1	General	4-444
4.C.2	Maximum Axial Loads.....	4-445
4.C.3	Shear Load Test.....	4-445
4.C.4	Acceptance Standards for Joint Efficiency Factor Determined By Test.....	4-447
4.C.5	Acceptance Standards for Proposed Operating Temperatures Determined By Test	4-447
4.C.6	Nomenclature	4-448
4.C.7	Tables	4-450
4.C.8	Figures.....	4-451

PART 5 - DESIGN BY ANALYSIS REQUIREMENTS

5.1	General Requirements	5-3
5.1.1	Scope	5-3
5.1.2	Numerical Analysis	5-3
5.1.3	Loading Conditions	5-4
5.2	Protection Against Plastic Collapse.....	5-5
5.2.1	Overview	5-5
5.2.2	Elastic Stress Analysis Method.....	5-5
5.2.3	Limit-Load Analysis Method.....	5-8
5.2.4	Elastic-Plastic Stress Analysis Method.....	5-9
5.3	Protection Against Local Failure.....	5-11
5.3.1	Overview	5-11
5.3.2	Elastic Analysis	5-11
5.3.3	Elastic-Plastic Analysis.....	5-11

5.4	Protection Against Collapse From Buckling	5-12
5.4.1	Design Factors	5-12
5.4.2	Numerical Analysis	5-13
5.5	Protection Against Failure From Cyclic Loading	5-13
5.5.1	Overview	5-13
5.5.2	Screening Criteria for Fatigue Analysis	5-14
5.5.3	Fatigue Assessment – Elastic Stress Analysis and Equivalent Stresses	5-17
5.5.4	Fatigue Assessment – Elastic-Plastic Stress Analysis and Equivalent Strains	5-20
5.5.5	Fatigue Assessment of Welds – Elastic Analysis and Structural Stress	5-22
5.5.6	Ratcheting Assessment – Elastic Stress Analysis	5-26
5.5.7	Ratcheting Assessment – Elastic-Plastic Stress Analysis	5-28
5.6	Supplemental Requirements for Stress Classification in Nozzle Necks	5-29
5.7	Supplemental Requirements for Bolts	5-30
5.7.1	Design Requirements	5-30
5.7.2	Service Stress Requirements	5-30
5.7.3	Fatigue Assessment Of Bolts	5-30
5.8	Supplemental Requirements for Perforated Plates	5-31
5.9	Supplemental Requirements for Layered Vessels	5-31
5.10	Experimental Stress Analysis	5-31
5.11	Fracture Mechanic Evaluations	5-31
5.12	Definitions	5-32
5.13	Nomenclature	5-34
5.14	Tables	5-40
5.15	Figures	5-53

Annex 5.A Linearization Of Stress Results For Stress Classification

5.A.1	Scope	5-56
5.A.2	General	5-56
5.A.3	Selection of Stress Classification Lines	5-56
5.A.4	Stress Integration Method	5-57
5.A.4.1	Continuum Elements	5-57
5.A.4.2	Shell Elements	5-58
5.A.5	Structural Stress Method Based on Nodal Forces	5-59
5.A.5.1	Overview	5-59
5.A.5.2	Continuum Elements	5-59
5.A.5.3	Shell Elements	5-60
5.A.6	Structural Stress Method Based on Stress Integration	5-60
5.A.7	Nomenclature	5-61
5.A.8	Tables	5-62
5.A.9	Figures	5-64

Annex 5.B Histogram Development And Cycle Counting For Fatigue Analysis

5.B.1	General	5-75
5.B.2	Definitions	5-75
5.B.3	Histogram Development	5-75
5.B.4	Cycle Counting Using the Rainflow Method	5-76
5.B.5	Cycle Counting Using Max-Min Cycle Counting Method	5-76
5.B.6	Nomenclature	5-78

Annex 5.C Alternative Plasticity Adjustment Factors And Effective Alternating Stress For Elastic Fatigue Analysis

5.C.1	General	5-79
5.C.2	Effective Alternating Stress for Elastic Fatigue Analysis	5-79
5.C.3	Nomenclature	5-84

Annex 5.D Stress Indices

5.D.1	General	5-86
5.D.2	Stress Indices for Radial Nozzles	5-86

5.D.3	Stress Indices for Laterals	5-88
5.D.4	Nomenclature	5-89
5.D.5	Tables	5-90
5.D.6	Figures	5-92

Annex 5.E Design Methods For Perforated Plates Based On Elastic Stress Analysis

5.E.1	Overview	5-95
5.E.2	Stress Analysis of the Equivalent Solid Plate.....	5-95
5.E.3	Stiffness Effects of the Tubes.....	5-96
5.E.4	Effective Material Properties for the Equivalent Solid Plate.....	5-96
5.E.5	Pressure Effects in Tubesheet Perforations	5-98
5.E.6	Protection Against Plastic Collapse.....	5-98
5.E.7	Protection Against Cyclic Loading.....	5-99
5.E.8	Nomenclature	5-103
5.E.9	Tables	5-107
5.E.10	Figures.....	5-132

Annex 5.F Experimental Stress Analysis

5.F.1	Overview	5-137
5.F.2	Strain Measurement Test Procedure for Stress Components.....	5-137
5.F.3	Protection Against Cyclic Loading.....	5-138
5.F.4	Nomenclature	5-142
5.F.5	Figures.....	5-144

PART 6 - FABRICATION REQUIREMENTS

6.1	General Fabrication Requirements	6-3
6.1.1	Materials	6-3
6.1.2	Forming	6-4
6.1.3	Base Metal Preparation.....	6-6
6.1.4	Fitting and Alignment.....	6-7
6.1.5	Cleaning of Surfaces to Be Welded	6-8
6.1.6	Alignment Tolerances for Edges to Be Butt Welded.....	6-8
6.2	Welding Fabrication Requirements	6-9
6.2.1	Welding Processes.....	6-9
6.2.2	Welding Qualifications and Records	6-9
6.2.3	Precautions to Be Taken Before Welding.....	6-11
6.2.4	Specific Requirements for Welded Joints.....	6-11
6.2.5	Miscellaneous Welding Requirements	6-13
6.2.6	Summary of Joints Permitted and Their Examination	6-15
6.2.7	Repair of Weld Defects.....	6-15
6.2.8	Special Requirements for Welding Test Plates for Titanium Materials.....	6-15
6.3	Special Requirements for Tube-To-Tubesheet Welds.....	6-16
6.3.1	Material Requirements.....	6-16
6.3.2	Holes in Tubesheets.....	6-16
6.3.3	Weld Design and Joint Preparation.....	6-16
6.3.4	Qualification of Welding Procedure	6-16
6.4	Preheating and Heat Treatment of Weldments	6-16
6.4.1	Requirements for Preheating of Welds	6-16
6.4.2	Requirements for Postweld Heat Treatment	6-16
6.4.3	Procedures for Postweld Heat Treatment.....	6-18
6.4.4	Operation of Postweld Heat Treatment.....	6-20
6.4.5	Postweld Heat Treatment after Repairs	6-20
6.4.6	Postweld Heat Treatment of Nonferrous Materials	6-21
6.5	Special Requirements For Clad or Weld Overlay Linings, and Lined Parts	6-22
6.5.1	Materials	6-22
6.5.2	Joints In Corrosion Resistant Clad or Weld Metal Overlay Linings.....	6-23
6.5.3	Welding Procedures.....	6-23

6.5.4	Methods to Be Used In Attaching Applied Linings.....	6-23
6.5.5	Postweld Heat Treatment of Clad and Lined Weldments.....	6-23
6.5.6	Requirements for Base Material With Corrosion Resistant Integral or Weld Metal	
	Overlay Cladding.....	6-23
6.5.7	Examination Requirements.....	6-24
6.5.8	Inspection and Tests	6-24
6.5.9	Stamping and Reports.....	6-24
6.6	Special Requirements for Tensile Property Enhanced Q and T Ferritic Steels	6-24
6.6.1	General.....	6-24
6.6.2	Marking on Plates and Other Materials	6-24
6.6.3	Requirements for Heat Treating After Forming	6-24
6.6.4	Minimum Thickness after Forming	6-24
6.6.5	Welding Requirements	6-25
6.6.6	Postweld Heat Treatment.....	6-27
6.6.7	Heat Treatment Certification Tests.....	6-28
6.6.8	Examination Requirements.....	6-29
6.6.9	Inspection and Tests	6-29
6.6.10	Stamping and Reports.....	6-29
6.7	Special Requirements for Forged Fabrication	6-29
6.7.1	General.....	6-29
6.7.2	Ultrasonic Examination	6-29
6.7.3	Toughness Requirements.....	6-29
6.7.4	Tolerances on Cylindrical Forgings.....	6-29
6.7.5	Methods of Forming Forged Heads	6-30
6.7.6	Heat Treatment Requirements for Forged Fabrication	6-30
6.7.7	Welding For Fabrication.....	6-31
6.7.8	Repair of Defects in Material.....	6-32
6.7.9	Threaded Connections to Vessel Walls, Forged Necks, and Heads.....	6-33
6.7.10	Inspection, Examination, and Testing.....	6-33
6.7.11	Stamping and Reports for Forged Vessels.....	6-34
6.7.12	Pressure Relief Devices	6-34
6.8	Special Fabrication Requirements for Layered Vessels	6-34
6.8.1	General.....	6-34
6.8.2	General Fabrication Requirements	6-34
6.8.3	Welding Fabrication Requirements	6-34
6.8.4	Welding Qualification and Records.....	6-34
6.8.5	Specific Requirements for Welded Joints.....	6-35
6.8.6	Nondestructive Examination of Welded Joints.....	6-36
6.8.7	Welded Joint Efficiency.....	6-36
6.8.8	Contact between Layers.....	6-36
6.8.9	Vent Holes	6-37
6.8.10	Heat Treatment of Weldments	6-37
6.9	Nomenclature	6-38
6.10	Tables	6-39
6.11	Figures.....	6-65

PART 7 - INSPECTION AND EXAMINATION REQUIREMENTS

7.1	General	7-3
7.2	Responsibilities and Duties	7-3
7.2.1	Responsibilities and Duties of the Manufacturer and Inspector	7-3
7.2.2	Access for Inspector	7-3
7.2.3	Notification of Work Progress.....	7-3
7.3	Verification and Examination Prior To Welding.....	7-3
7.3.1	Compliance of Material with Requirements and Marking.....	7-3
7.3.2	Dimensional Check of Component Parts	7-3
7.3.3	Verification of Heat Treatment Practice	7-3
7.3.4	Verification of Welding Procedure Specification.....	7-3

7.3.5	Verification of Welder and Welding Operator Performance Qualification	7-4
7.4	Examination of Welded Joints.....	7-4
7.4.1	Nondestructive Examination Requirements.....	7-4
7.4.2	Examination Groups for Pressure Vessels.....	7-4
7.4.3	Extent of Nondestructive Examination.....	7-4
7.4.4	Selection of Examination Method for Internal (Volumetric) Flaws.....	7-6
7.4.5	Selection of Examination Method for Surface Flaws.....	7-6
7.4.6	Surface Condition and Preparation.....	7-6
7.4.7	Supplemental Examination for Cyclic Service.....	7-6
7.4.8	Examination and Inspection of Vessels with Protective Linings and Cladding.....	7-6
7.4.9	Examination and Inspection of Tensile Property Enhanced Q and T Vessels.....	7-7
7.4.10	Examination and Inspection of Integrally Forged Vessels.....	7-8
7.4.11	Examination and Inspection of Fabricated Layered Vessels.....	7-9
7.5	Examination Method and Acceptance Criteria.....	7-11
7.5.1	General.....	7-11
7.5.2	Visual Examination.....	7-11
7.5.3	Radiographic Examination.....	7-12
7.5.4	Ultrasonic Examination.....	7-14
7.5.5	Ultrasonic Examination Used in Lieu of Radiographic Examination.....	7-15
7.5.6	Magnetic Particle Examination (MT).....	7-17
7.5.7	Liquid Penetrant Examination (PT).....	7-19
7.5.8	Eddy Current Surface Examination Procedure Requirements (ET).....	7-20
7.5.9	Evaluation and Retest for Partial Examination.....	7-23
7.6	Final Examination of Vessel.....	7-23
7.6.1	Surface Examination after Hydrotest.....	7-23
7.6.2	Inspection of Lined Vessel Interior after Hydrotest.....	7-23
7.7	Leak Testing.....	7-23
7.8	Acoustic Emission.....	7-23
7.9	Tables.....	7-24
7.10	Figures.....	7-36

Annex 7.A Responsibilities And Duties For Inspection And Examination Activities

7.A.1	General.....	7-50
7.A.2	Manufacturer's Responsibility.....	7-50
7.A.2.1	The Manufacturer.....	7-50
7.A.2.2	Inspection and Examination Duties.....	7-50
7.A.3	Inspector's Responsibility.....	7-51
7.A.3.1	The Inspector.....	7-51
7.A.3.2	Inspection and Examination Duties.....	7-51
7.A.4	Tables.....	7-53

PART 8 - PRESSURE TESTING REQUIREMENTS

8.1	General Requirements.....	8-2
8.1.1	Selection of Pressure Test Methods.....	8-2
8.1.2	Precautions.....	8-2
8.1.3	Requirements for Vessels of Specific Construction.....	8-3
8.1.4	Pressure Gages.....	8-4
8.2	Hydrostatic Testing.....	8-5
8.2.1	Test Pressure.....	8-5
8.2.2	Preparation for Testing.....	8-5
8.2.3	Test Fluid.....	8-5
8.2.4	Test Procedures.....	8-5
8.2.5	Test Examination and Acceptance Criteria.....	8-6
8.3	Pneumatic Testing.....	8-6
8.3.1	Test Pressure.....	8-6
8.3.2	Preparation for Testing.....	8-6
8.3.3	Test Fluid.....	8-6

8.3.4	Test Procedures.....	8-7
8.3.5	Test Examination and Acceptance Criteria.....	8-7
8.4	Alternative Pressure Testing.....	8-7
8.4.1	Hydrostatic–Pneumatic Tests	8-7
8.4.2	Leak Tightness Testing.....	8-7
8.5	Documentation	8-8
8.6	Nomenclature	8-8

PART 9 - PRESSURE VESSEL OVERPRESSURE PROTECTION

9.1	General Requirements	9-2
9.1.1	Protection Against Overpressure	9-2
9.1.2	Types of Overpressure Protection.....	9-2
9.1.3	Required Relieving Capacity and Allowable Overpressure.....	9-2
9.1.4	Pressure Setting of Pressure Relief Devices	9-3
9.2	Pressure Relief Valves.....	9-3
9.3	Non-Reclosing Pressure Relief Devices.....	9-3
9.3.1	Rupture Disk Devices	9-3
9.3.2	Breaking Pin Devices	9-3
9.3.3	Spring Loaded Non-Reclosing Pressure Relief Devices.....	9-3
9.4	Calculation Of Rated Capacity For Different Relieving Pressures And/Or Fluids.....	9-3
9.4.1	General.....	9-3
9.4.2	Prorating of Certified Capacity for Different Pressures.....	9-3
9.4.3	Conversion of Certified Capacity for Different In-Service Fluids.....	9-4
9.5	Marking and Stamping	9-4
9.6	Provisions for Installation of Pressure Relieving Devices.....	9-4
9.6.1	General.....	9-4
9.6.2	Inlet Piping for Pressure Relief Devices	9-4
9.6.3	Discharge Lines from Pressure Relief Devices.....	9-4
9.6.4	Pressure Drop, Non-Reclosing Pressure Relief Devices.....	9-4
9.7	Overpressure Protection by Design	9-4
9.7.1	Requirements	9-4
9.7.2	Documentation.....	9-5
9.7.3	Manufacturer’s Data Report	9-5

Annex 9.A Best Practices For The Installation And Operation Of Pressure Relief Devices

9.A.1	Introduction	9-6
9.A.2	Provisions for the Installation of Stop Valves in the Relief Path.....	9-6
9.A.3	Inlet Piping Pressure Drop for Pressure Relief Valves.....	9-9
9.A.4	Discharge Lines from Pressure Relief Devices	9-9
9.A.5	Cautions Regarding Pressure Relief Device Discharge into a Common Header.....	9-10
9.A.6	Pressure Differentials (Operating Margin) for Pressure Relief Valves	9-10
9.A.7	Pressure Relief Valve Orientation	9-10
9.A.8	Reaction Forces and Externally Applied Piping Loads	9-10
9.A.9	Sizing of Pressure Relief Devices for Fire Conditions	9-12
9.A.10	Use of Pressure Indicating Devices to Monitor Pressure Differential	9-12