

**SECTION III**  
Rules for Construction of  
Nuclear Facility Components

**2017** ASME Boiler and  
Pressure Vessel Code  
An International Code

**Division 3**

Containment Systems for Transportation  
and Storage of Spent Nuclear Fuel  
and High-Level Radioactive Material

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AN INTERNATIONAL CODE

# 2017 ASME Boiler & Pressure Vessel Code

2017 Edition

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## RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

### Division 3

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## Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material

ASME Boiler and Pressure Vessel Committee  
on Construction of Nuclear Facility Components



The American Society of  
Mechanical Engineers

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# TABLE OF CONTENTS

List of Sections .....	xv
Foreword .....	xvii
Statement of Policy on the Use of the Certification Mark and Code Authorization in Advertising .....	xix
Statement of Policy on the Use of ASME Marking to Identify Manufactured Items .....	xix
Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees .....	xx
Personnel .....	xxiii
Organization of Section III .....	xlii
Summary of Changes .....	xlv
List of Changes in Record Order Number .....	1
Cross-Referencing and Stylistic Changes in the Boiler and Pressure Vessel Code .....	li
<b>Subsection WA</b>	
<b>General Requirements</b> .....	1
<b>Article WA-1000</b>	
<b>Scope of Division 3</b> .....	1
WA-1100	1
WA-1110	1
WA-1120	1
WA-1130	1
WA-1140	1
WA-1150	2
WA-1200	2
WA-1210	2
WA-1220	2
WA-1230	2
<b>Article WA-2000</b>	
<b>Design Basis</b> .....	3
WA-2100	3
WA-2110	3
WA-2120	3
WA-2130	4
<b>Article WA-3000</b>	
<b>Responsibilities and Duties</b> .....	5
WA-3100	5
WA-3110	5
WA-3120	5
WA-3130	6
WA-3300	7
WA-3320	7
WA-3330	7
WA-3340	7
WA-3350	7
WA-3360	9
WA-3370	9
WA-3380	9
WA-3390	10
WA-3400	10
WA-3420	10
WA-3430	10
WA-3440	10
WA-3450	10
WA-3460	10

WA-3470	Data Report .....	10
WA-3800	Metallic Material .....	10
WA-3810	Scope and Applicability .....	10
WA-3820	Material Organizations .....	11
<b>Article WA-4000</b>	<b>Quality Assurance</b> .....	12
WA-4100	Requirements .....	12
WA-4110	Scope and Applicability .....	12
WA-4120	Definitions .....	12
WA-4130	Establishment and Implementation .....	12
<b>Article WA-5000</b>	<b>Authorized Inspection</b> .....	14
WA-5100	Introduction .....	14
WA-5110	Applicability .....	14
WA-5120	Performance of Inspection .....	14
WA-5130	Access for Inspection Agency Personnel .....	14
WA-5200	Duties of Inspector .....	14
WA-5210	General Inspection Duties .....	14
WA-5220	Categories of Inspector's Duties .....	15
WA-5230	Scope of Work, Design Specifications, Design Reports, and Fabrication Specifications .....	15
WA-5240	Quality Assurance Programs .....	15
WA-5250	Qualification Records .....	15
WA-5260	Materials, Parts, and Heat Treatment .....	16
WA-5270	Examinations and Tests .....	16
WA-5280	Final Tests .....	16
WA-5290	Data Reports .....	16
WA-5300	Responsibilities of the Authorized Inspection Agency .....	16
<b>Article WA-7000</b>	<b>Reference Standards</b> .....	17
WA-7100	General Requirements .....	17
<b>Article WA-8000</b>	<b>Certificates of Authorization, Nameplates, Certification Mark, and Data Reports</b> .....	19
WA-8100	Authorization to Perform Code Activities .....	19
WA-8110	General .....	19
WA-8120	Scope of Authorization .....	19
WA-8130	Inspection Agreement Required .....	19
WA-8140	Quality Assurance Program Requirements .....	20
WA-8150	Application for Authorization .....	20
WA-8160	Evaluation for Authorization .....	20
WA-8170	Issuance of Authorization .....	20
WA-8180	Renewal of Authorization .....	20
WA-8200	Nameplates and Stamping With Certification Mark .....	20
WA-8210	General Requirements .....	20
WA-8220	Nameplates .....	21
WA-8230	Nameplates for Certification Mark With NPT Designator Items .....	21
WA-8300	Certification Mark .....	21
WA-8310	General Requirements .....	21
WA-8330	Removable Items .....	22
WA-8400	Data Reports .....	22
WA-8410	General Requirements .....	22
<b>Article WA-9000</b>	<b>Glossary</b> .....	29
WA-9100	Introduction .....	29
WA-9200	Definitions .....	29

<b>Subsection WB</b>	<b>Class TC Transportation Containments</b> .....	31
<b>Article WB-1000</b>	<b>Introduction</b> .....	31
WB-1100	Scope .....	31
WB-1120	Limits of Rules for Class TC Transportation Containments .....	31
WB-1130	Boundaries of Jurisdiction .....	31
<b>Article WB-2000</b>	<b>Material</b> .....	33
WB-2100	General Requirements for Material .....	33
WB-2110	Scope of Principal Terms Employed .....	33
WB-2120	Containment Material .....	33
WB-2130	Certification of Material .....	34
WB-2140	Welding Material .....	34
WB-2150	Material Identification .....	34
WB-2160	Deterioration of Material in Service .....	35
WB-2170	Heat Treatment to Enhance Impact Properties .....	35
WB-2180	Procedures for Heat Treatment of Material .....	35
WB-2190	Material Not Performing a Containment Function .....	35
WB-2200	Material Test Coupons and Specimens for Ferritic Steel Material and Ductile Cast Iron	35
WB-2210	Heat Treatment Requirements .....	35
WB-2220	Procedure for Obtaining Test Coupons and Specimens for Quenched and Tempered Material and for Ductile Cast Iron .....	36
WB-2300	Fracture Toughness Requirements for Material .....	37
WB-2310	Material to Be Toughness Tested .....	37
WB-2320	Impact Test Procedures .....	37
WB-2330	Test Requirements and Acceptance Standards .....	38
WB-2340	Number of Toughness Tests Required .....	40
WB-2350	Retests .....	41
WB-2360	Calibration of Instruments and Equipment .....	41
WB-2400	Welding Material .....	41
WB-2410	General Requirements .....	41
WB-2420	Required Tests .....	41
WB-2430	Weld Metal Tests .....	42
WB-2440	Storage and Handling of Welding Material .....	45
WB-2500	Examination and Repair of Containment Material .....	45
WB-2510	Examination of Containment Material .....	45
WB-2520	Examination After Quenching and Tempering .....	46
WB-2530	Examination and Repair of Plate .....	46
WB-2540	Examination and Repair of Forgings and Bars .....	47
WB-2550	Examination and Repair of Seamless and Welded Tubular Products and Fittings ...	49
WB-2570	Examination and Repair of Cast Products .....	52
WB-2580	Examination of Bolts, Studs, and Nuts .....	53
WB-2600	Material Organization's Quality System Programs .....	55
WB-2610	Documentation and Maintenance of Quality System Programs .....	55
WB-2700	Dimensional Standards .....	55
<b>Article WB-3000</b>	<b>Design</b> .....	56
WB-3100	General Design .....	56
WB-3110	Loading Criteria .....	56
WB-3120	Special Considerations .....	57
WB-3130	General Design Rules .....	57
WB-3200	Design of Containments .....	61
WB-3210	Design Criteria .....	61
WB-3220	Stress Limits for Other Than Bolts .....	64
WB-3230	Stress Limits for Bolts .....	74
WB-3240	Nozzles or Openings .....	75
WB-3250	Design of Welded Construction .....	76

WB-3260	Special Containment Requirements .....	79
WB-3700	Strain-Based Acceptance Criteria .....	79
<b>Article WB-4000</b>	<b>Fabrication</b> .....	<b>81</b>
WB-4100	General Requirements .....	81
WB-4110	Introduction .....	81
WB-4120	Certification of Materials and Fabrication by Certificate Holder .....	81
WB-4130	Repair of Material .....	82
WB-4200	Forming, Fitting, and Aligning .....	82
WB-4210	Cutting, Forming, and Bending .....	82
WB-4220	Forming Tolerances .....	83
WB-4230	Fitting and Aligning .....	85
WB-4240	Requirements for Weld Joints in Containments .....	87
WB-4300	Welding Qualifications .....	92
WB-4310	General Requirements .....	92
WB-4320	Welding Qualifications, Records, and Identifying Stamps .....	92
WB-4330	General Requirements for Welding Procedure Qualification Tests .....	94
WB-4400	Rules Governing Making, Examining, and Repairing Welds .....	97
WB-4410	Precautions to Be Taken Before Welding .....	97
WB-4420	Rules for Making Welded Joints .....	97
WB-4430	Welding of Attachments .....	98
WB-4450	Repair of Weld Metal Defects .....	99
WB-4600	Heat Treatment .....	101
WB-4610	Welding Preheat Requirements .....	101
WB-4620	Postweld Heat Treatment .....	101
WB-4630	Heat Treatment of Welds Other Than the Final Postweld Heat Treatment .....	111
WB-4700	Mechanical Joints .....	111
WB-4710	Bolting and Threading .....	111
WB-4720	Bolting Flanged Joints .....	111
<b>Article WB-5000</b>	<b>Examination</b> .....	<b>112</b>
WB-5100	General Requirements for Examination .....	112
WB-5110	Procedures, Qualifications, and Evaluation .....	112
WB-5120	Time of Examination of Welds and Weld Metal Cladding .....	112
WB-5130	Examination of Weld Edge Preparation Surfaces .....	114
WB-5140	Examination of Adjacent Base Material .....	114
WB-5200	Required Examination of Welds .....	114
WB-5210	Category A Welded Joints .....	114
WB-5220	Category B Welded Joints .....	114
WB-5230	Category C Welded Joints .....	114
WB-5240	Category D Welded Joints .....	114
WB-5260	Fillet, Partial Penetration, Socket, and Attachment Welded Joints .....	115
WB-5270	Special Welded Joints .....	115
WB-5300	Acceptance Standards .....	115
WB-5320	Radiographic Acceptance Standards .....	115
WB-5330	Ultrasonic Acceptance Standards .....	116
WB-5340	Magnetic Particle Acceptance Standards .....	116
WB-5350	Liquid Penetrant Acceptance Standards .....	116
WB-5400	Final Examination of Containments .....	116
WB-5410	Examination After Hydrostatic Test .....	116
WB-5500	Qualifications and Certification of Nondestructive Examination Personnel .....	117
WB-5510	General Requirements .....	117
WB-5520	Personnel Qualification, Certification, and Verification .....	117
WB-5530	Records .....	118
<b>Article WB-6000</b>	<b>Testing</b> .....	<b>119</b>
WB-6100	General Requirements .....	119
WB-6110	Scope .....	119



WB-6120	Testing of Containments .....	119
WB-6130	Preparation for Testing .....	119
WB-6200	Hydrostatic Tests .....	120
WB-6210	Hydrostatic Test Procedure .....	120
WB-6220	Hydrostatic Test Pressure Requirements .....	120
WB-6300	Pneumatic Tests .....	120
WB-6310	Pneumatic Testing Procedures .....	120
WB-6320	Pneumatic Test Pressure Requirements .....	120
WB-6400	Test Gages .....	121
WB-6410	.....	121
WB-6600	Special Test Pressure Situations .....	121
WB-6610	Containments Designed for External Pressure .....	121
WB-6620	Testing of Combination Units .....	121
WB-6700	Leak Testing .....	121
WB-6710	Helium Leak Testing .....	121
<b>Article WB-8000</b>	<b>Nameplates, Stamping With Certification Mark, and Reports .....</b>	<b>122</b>
WB-8100	General Requirements .....	122
<b>Subsection WC</b>	<b>Class SC Storage Containments .....</b>	<b>123</b>
<b>Article WC-1000</b>	<b>Introduction .....</b>	<b>123</b>
WC-1100	Scope .....	123
WC-1120	Limits of Rules for Class SC Storage Containments .....	123
WC-1130	Boundaries of Jurisdiction .....	123
<b>Article WC-2000</b>	<b>Material .....</b>	<b>125</b>
WC-2100	General Requirements for Material .....	125
WC-2110	Scope of Principal Terms Employed .....	125
WC-2120	Containment Material .....	125
WC-2130	Certification of Material .....	126
WC-2140	Welding Materials .....	127
WC-2150	Material Identification .....	127
WC-2160	Deterioration of Material in Service .....	127
WC-2170	Heat Treatment to Enhance Impact Properties .....	127
WC-2180	Procedures for Heat Treatment of Material .....	127
WC-2190	Attachment Material .....	127
WC-2200	Material Test Coupons and Specimens for Ferritic Steel Material and Ductile Cast Iron .....	127
WC-2210	Heat Treatment Requirements .....	127
WC-2220	Procedure for Obtaining Test Coupons and Specimens for Quenched and Tempered Material and for Ductile Cast Iron .....	128
WC-2300	Fracture Toughness Requirements for Material .....	129
WC-2310	Material to Be Impact Tested .....	129
WC-2320	Impact Test Procedures .....	130
WC-2330	Test Requirements and Acceptance Standards .....	131
WC-2340	Number of Impact Tests Required .....	132
WC-2350	Retests .....	133
WC-2360	Calibration of Instruments and Equipment .....	133
WC-2400	Welding Material .....	133
WC-2410	General Requirements .....	133
WC-2420	Required Tests .....	134
WC-2430	Weld Metal Tests .....	135
WC-2440	Storage and Handling of Welding Material .....	137
WC-2500	Examination and Repair of Containment Material .....	137
WC-2510	Containment Material .....	137
WC-2530	Examination and Repair of Plate .....	137
WC-2540	Examination and Repair of Forgings and Bars .....	139

WC-2550	Examination and Repair of Seamless and Welded (Without Filler Metal) Tubular Products and Fittings .....	140
WC-2560	Examination and Repair of Tubular Products and Fittings Welded With Filler Metal .....	142
WC-2570	Examination and Repair of Cast Products .....	143
WC-2580	Examination of Bolts, Studs, and Nuts .....	144
WC-2600	Material Organizations' Quality System Programs .....	145
WC-2610	Documentation and Maintenance of Quality System Programs .....	145
WC-2700	Dimensional Standards .....	145
<b>Article WC-3000</b>	<b>Design</b> .....	146
WC-3100	General Design .....	146
WC-3110	Loading Criteria .....	146
WC-3120	Special Considerations .....	147
WC-3130	General Design Rules .....	147
WC-3200	Design Rules for Containments .....	150
WC-3210	General Requirements .....	150
WC-3220	Design Consideration .....	153
WC-3230	Openings and Reinforcement .....	160
WC-3250	Design of Welded Construction .....	161
WC-3260	Special Containment Requirements .....	164
WC-3700	Strain-Based Acceptance Criteria .....	165
<b>Article WC-4000</b>	<b>Fabrication</b> .....	166
WC-4100	General Requirements .....	166
WC-4110	Introduction .....	166
WC-4120	Certification of Materials and Fabrication by Certificate Holder .....	166
WC-4130	Repair of Material .....	167
WC-4200	Forming, Cutting, and Aligning .....	167
WC-4210	Cutting, Forming, and Bending .....	167
WC-4220	Forming Tolerances .....	168
WC-4230	Fitting and Aligning .....	171
WC-4260	Requirements for Weld Joints in Containments .....	172
WC-4300	Welding Qualifications .....	175
WC-4310	General Requirements .....	175
WC-4320	Welding Qualifications, Records, and Identifying Stamps .....	180
WC-4330	General Requirements for Welding Procedure Qualification Tests .....	181
WC-4400	Rules Governing Making, Examining, and Repairing Welds .....	183
WC-4410	Precautions to Be Taken Before Welding .....	183
WC-4420	Rules for Making Welded Joints .....	183
WC-4430	Welding of Attachments .....	184
WC-4450	Repair of Weld Metal Defects .....	187
WC-4500	Brazing .....	188
WC-4510	Rules for Brazing .....	188
WC-4520	Brazing Qualification Requirements .....	188
WC-4530	Fitting and Aligning of Parts to Be Brazed .....	189
WC-4540	Examination of Brazed Joints .....	189
WC-4600	Heat Treatment .....	189
WC-4610	Welding Preheat Requirements .....	189
WC-4620	Postweld Heat Treatment .....	189
WC-4630	Heat Treatment of Welds Other Than the Final Postweld Heat Treatment .....	199
WC-4700	Mechanical Joints .....	199
WC-4710	Bolting and Threading .....	199
WC-4720	Bolting Flanged Joints .....	200
<b>Article WC-5000</b>	<b>Examination</b> .....	201
WC-5100	General Requirements for Examination .....	201
WC-5110	Procedures, Qualifications, and Evaluation .....	201
WC-5120	Time of Examination of Welds and Weld Metal Cladding .....	201

WC-5130	Examination of Weld Edge Preparation Surfaces .....	203
WC-5140	Examination of Adjacent Base Material .....	203
WC-5200	Required Examination of Welds .....	203
WC-5210	Category A Longitudinal Welded Joints .....	203
WC-5220	Category B Circumferential Welded Joints .....	203
WC-5230	Category C Welded Joints .....	203
WC-5240	Category D Welded Joints .....	203
WC-5250	Examination of Containment Closure Welds .....	204
WC-5260	Fillet, Partial Penetration, Socket, and Attachment Welded Joints .....	204
WC-5270	Special Welds and Brazed Joints .....	204
WC-5300	Acceptance Standards .....	205
WC-5320	Radiographic Acceptance Standards .....	205
WC-5330	Ultrasonic Acceptance Standards .....	205
WC-5340	Magnetic Particle Acceptance Standards .....	205
WC-5350	Liquid Penetrant Acceptance Standards .....	205
WC-5360	Visual Acceptance Standards for Brazed Joints .....	206
WC-5400	Final Examination of Containments .....	206
WC-5410	Examination After Pressure Test .....	206
WC-5500	Qualifications and Certification of Nondestructive Examination Personnel .....	206
WC-5510	General Requirements .....	206
WC-5520	Personnel Qualification, Certification, and Verification .....	206
WC-5530	Records .....	207
<b>Article WC-6000</b>	<b>Testing .....</b>	<b>208</b>
WC-6100	General Requirements .....	208
WC-6110	Scope .....	208
WC-6120	Testing of Containments .....	208
WC-6130	Preparation for Testing .....	208
WC-6200	Hydrostatic Tests .....	209
WC-6210	Hydrostatic Test Procedure .....	209
WC-6220	Hydrostatic Test Pressure Requirements .....	209
WC-6300	Pneumatic Tests .....	209
WC-6310	Pneumatic Testing Procedures .....	209
WC-6320	Pneumatic Test Pressure Requirements .....	209
WC-6400	Test Gages .....	210
WC-6410	.....	210
WC-6600	Special Test Pressure Situations .....	210
WC-6610	Containments Designed for External Pressure .....	210
WC-6620	Pressure Testing of Combination Units .....	210
WC-6700	Leak Testing .....	210
WC-6710	Helium Leak Testing .....	210
WC-6720	Containment Closures .....	211
<b>Article WC-8000</b>	<b>Nameplates, Stamping With Certification Mark, and Reports .....</b>	<b>212</b>
WC-8100	General Requirements .....	212
<b>Subsection WD</b>	<b>Class ISS Internal Support Structures .....</b>	<b>213</b>
<b>Article WD-1000</b>	<b>Introduction .....</b>	<b>213</b>
WD-1100	Scope and General Requirements .....	213
WD-1110	Scope .....	213
WD-1120	Limits of Rules for Class ISS Internal Support Structures .....	213
WD-1130	Boundaries of Jurisdiction .....	213
<b>Article WD-2000</b>	<b>Material .....</b>	<b>215</b>
WD-2100	General Requirements for Material .....	215
WD-2110	Scope of Principal Terms Employed .....	215
WD-2120	Material for Internal Support Structures .....	215
WD-2130	Certification of Material .....	216

WD-2140	Welding Material .....	216
WD-2150	Material Identification .....	216
WD-2160	Deterioration of Material in Service .....	216
WD-2170	Heat Treatment to Enhance Impact Properties .....	216
WD-2180	Procedures for Heat Treatment of Material .....	216
WD-2190	Temporary Attachment Material .....	216
WD-2200	Material Test Coupons and Specimens for Ferritic Steel Material .....	216
WD-2210	Heat Treatment Requirements .....	216
WD-2220	Procedure for Obtaining Test Coupons and Specimens for Quenched and Tempered Material .....	217
WD-2300	Fracture Toughness Requirements for Material .....	218
WD-2310	Material to Be Impact Tested .....	218
WD-2320	Impact Test Procedures .....	218
WD-2330	Test Requirements and Acceptance Standards .....	219
WD-2340	Number of Impact Tests Required .....	220
WD-2350	Retests .....	221
WD-2360	Calibration of Instruments and Equipment .....	221
WD-2400	Welding Material .....	221
WD-2410	General Requirements .....	221
WD-2420	Required Tests .....	221
WD-2430	Weld Metal Tests .....	222
WD-2440	Storage and Handling of Welding Material .....	225
WD-2500	Examination and Repair of Internal Support Structure Material .....	225
WD-2510	Examination of Internal Support Structure Material .....	225
WD-2520	Examination After Quenching and Tempering .....	226
WD-2530	Examination and Repair of Plate .....	226
WD-2540	Examination and Repair of Forgings and Bars .....	227
WD-2550	Examination and Repair of Seamless and Welded Tubular Products and Fittings ...	228
WD-2580	Examination of Bolting .....	229
WD-2600	Material Organizations' Quality System Programs .....	230
WD-2610	Documentation and Maintenance of Quality System Programs .....	230
<b>Article WD-3000</b>	<b>Design</b> .....	231
WD-3100	General Requirements for Design .....	231
WD-3110	Loading Criteria .....	231
WD-3120	Special Considerations .....	232
WD-3130	General Design Rules .....	232
WD-3200	Design Rules for Plate- and Shell-Type Internal Support Structures .....	233
WD-3210	General Requirements .....	233
WD-3220	Design by Analysis Requirements for Plate- and Shell-Type Internal Support Structure Members .....	236
WD-3230	Design Requirements for Plate- and Shell-Type Internal Support Structure Bolted Joints .....	247
WD-3240	Design Requirements for Plate- and Shell-Type Internal Support Structure Welded Joints .....	251
WD-3300	Design Rules for Linear-Type Internal Support Structures .....	254
WD-3310	General Requirements .....	254
<b>Article WD-4000</b>	<b>Fabrication</b> .....	255
WD-4100	General Requirements .....	255
WD-4110	Introduction .....	255
WD-4120	Certification of Material and Fabrication by Certificate Holder .....	255
WD-4130	Repair of Material .....	255
WD-4200	Forming, Fitting, and Aligning .....	256
WD-4210	Cutting, Forming, and Bending .....	256
WD-4230	Fitting and Aligning .....	257



WD-4300	Welding Qualifications .....	257
WD-4310	General Requirements .....	257
WD-4320	Welding Qualifications, Records, and Identifying Stamps .....	258
WD-4330	General Requirements for Welding Procedure Qualification Tests .....	258
WD-4400	Rules Governing Making, Examining, and Repairing Welds .....	261
WD-4410	Precautions to Be Taken Before Welding .....	261
WD-4420	Rules for Making Welded Joints .....	261
WD-4430	Welding of Attachments .....	262
WD-4440	Special Requirements for Welding .....	263
WD-4450	Repair of Weld Metal Defects .....	264
WD-4500	Brazing .....	265
WD-4600	Heat Treatment .....	265
WD-4610	Welding Preheat and Interpass Requirements .....	265
WD-4620	Postweld Heat Treatment .....	265
WD-4630	Heat Treatment of Welds Other Than the Final Postweld Heat Treatment .....	269
WD-4650	Heat Treatment After Bending or Forming .....	269
WD-4700	Mechanical Joints .....	269
WD-4710	Bolting and Threading .....	269
WD-4720	Bolting .....	269
<b>Article WD-5000</b>	<b>Examination .....</b>	<b>271</b>
WD-5100	General Requirements for Examination .....	271
WD-5110	Procedures, Qualifications, and Evaluation .....	271
WD-5120	Time of Examination of Welds .....	271
WD-5130	Examination of Weld Edge Preparation Surfaces .....	271
WD-5140	Examination of Adjacent Base Material .....	272
WD-5200	Required Examination of Welds .....	272
WD-5210	Permissible Examination Methods .....	272
WD-5220	Requirements for Radiography or Ultrasonic and Liquid Penetrant or Magnetic Particle Examination .....	273
WD-5230	Requirements for Liquid Penetrant or Magnetic Particle Examination .....	273
WD-5260	Requirements for Surface Visual Examination .....	273
WD-5270	Special Welded Joints .....	273
WD-5300	Acceptance Standards .....	274
WD-5320	Radiographic Acceptance Standards .....	274
WD-5330	Ultrasonic Acceptance Standards .....	274
WD-5340	Magnetic Particle Acceptance Standards .....	274
WD-5350	Liquid Penetrant Acceptance Standards .....	274
WD-5360	Visual Examination Acceptance Standards .....	275
WD-5500	Qualifications and Certification of Nondestructive Examination Personnel .....	275
WD-5510	General Requirements .....	275
WD-5520	Personnel Qualification, Certification, and Verification .....	275
WD-5530	Records .....	276
<b>Article WD-8000</b>	<b>Nameplates, Stamping With Certification Mark, and Report .....</b>	<b>277</b>
WD-8100	General Requirements .....	277
 <b>FIGURES</b>		
WA-8212-1	Form of Stamping .....	21
WB-2433.1-1	Weld Metal Delta Ferrite Content .....	45
WB-2552.1-1	Axial Propagation of Sound in Tube Wall .....	50
WB-3221-1	Stress Categories and Limits of Stress Intensity for Design Loadings .....	67
WB-3222-1	Stress Categories and Limits of Stress Intensity for Normal Loadings .....	68
WB-3224.1-1	Stress Categories and Limits of Stress Intensity for Accident Loadings for Elastic Analysis .....	72
WB-3251-1	Welded Joint Locations Typical of Categories A, B, C, and D .....	76
WB-3252-1	Typical Butt Joints .....	77

WB-3261-1	Categories A and B Joints Between Sections of Unequal Thickness .....	80
WB-4221.1-1	Maximum Difference in Cross-Sectional Diameters .....	84
WB-4221.2(a)-1	Maximum Permissible Deviation $e$ From a True Circular Form .....	85
WB-4221.2(a)-2	Maximum ARC Length for Determining Plus or Minus Deviation .....	86
WB-4233(a)-1	Butt Weld Alignment and Mismatch Tolerances for Unequal I.D. and O.D. When Items Are Welded From One Side and Fairing Is Not Performed .....	87
WB-4243-1	Acceptable Full Penetration Weld Details for Category C Joints .....	88
WB-4243-2	Typical Flat Heads With Hubs .....	89
WB-4244(a)-1	Nozzles Attached by Full Penetration Butt Welds .....	90
WB-4244(b)-1	Nozzles Attached by Full Penetration Corner Welds .....	91
WB-4244(c)-1	Deposited Weld Metal Used as Reinforcement of Openings for Nozzles .....	93
WB-4244(d)-1	Nozzles Attached by Partial Penetration Welds .....	94
WB-4427-1	Fillet Weld Details .....	99
WB-4433-1	Types of Attachment Welds .....	100
WB-4622.9(c)(8)-1	Temper Bead Weld Repair and Weld Temper Bead Reinforcement .....	105
WB-4622.9(c)(8)-2	Temper Bead Reinforcement .....	106
WB-4622.9(f)-1	Qualification Test Plate .....	107
WB-4622.11(c)(6)-1	Temper Bead Weld Repair and Weld Temper Bead Reinforcement of Dissimilar Metal Welds or Buttering .....	110
WC-2433.1-1	Weld Metal Delta Ferrite Content .....	138
WC-3224.6-1	Design Curves for Torispherical Heads and 2:1 Ellipsoidal Heads for Use With <a href="#">WC-3224.8</a> and <a href="#">WC-3224.6</a> .....	155
WC-3225-1	Typical Flat Heads .....	157
WC-3225-2	Some Acceptable Types of Unstayed Flat Heads and Covers .....	158
WC-3225-3	Attachment of Flat Heads to Containment Shell .....	159
WC-3232.2-1	Chart for Determining the Value of $F$ .....	161
WC-3251-1	Welded Joint Locations Typical of Categories A, B, C, and D .....	162
WC-3251-2	Typical Butt Joints .....	163
WC-3261-1	Categories A and B Joints Between Sections of Unequal Thickness .....	165
WC-4221.1-1	Maximum Difference in Cross-Sectional Diameters .....	169
WC-4221.2(a)-1	Maximum Permissible Deviation $e$ From a True Circular Form .....	170
WC-4221.2(a)-2	Maximum ARC Length for Determining Plus or Minus Deviation .....	171
WC-4233-1	Butt Weld Alignment and Mismatch Tolerances for Unequal I.D. and O.D. When Items Are Welded From One Side and Fairing Is Not Performed .....	173
WC-4265-1	Acceptable Full Penetration Weld Details for Category C Joints .....	174
WC-4265-2	Typical Partial Penetration Weld Detail for Category C Flat Head Closure Joints ...	175
WC-4265-3	Typical Flat Heads .....	176
WC-4266(a)-1	Nozzles Attached by Full Penetration Butt Welds .....	177
WC-4266(b)-1	Full Penetration Corner-Welded Attachments .....	178
WC-4266(c)-1	Deposited Weld Metal Used as Reinforcement of Openings for Nozzles .....	179
WC-4266(d)-1	Fittings With Internal Threads .....	179
WC-4266(e)-1	Partial Penetration Weld Connections .....	180
WC-4427-1	Fillet and Socket Weld Details and Dimensions .....	185
WC-4433-1	Typical Types of Attachment Welds .....	186
WC-4433-2	Typical Attachments .....	187
WC-4622.10(c)(7)-1	Temper Bead Weld Repair and Weld Temper Bead Reinforcement .....	194
WC-4622.10(c)(7)-2	Temper Bead Reinforcement .....	195
WC-4622.10(f)-1	Qualification Test Plate .....	196
WC-4622.12(c)(6)-1	Temper Bead Weld Repair and Weld Temper Bead Reinforcement of Dissimilar Metal Welds or Buttering .....	198
WD-1131-1	Jurisdictional Boundary Between the Internal Support Structure and the Containment .....	214
WD-2433.1-1	Weld Metal Delta Ferrite Content .....	225
WD-3221-1	Stress Categories and Limits of Stress Intensities for Design Loadings .....	238
WD-3222-1	Stress Categories and Limits of Stress Intensities for Normal Loadings .....	239
WD-3224-1	Stress Categories and Limits of Stress Intensities for Off-Normal Loadings .....	243

WD-4427-1	Fillet Weld Details and Dimensions .....	263
WD-4441-1	Weld Inlay and Overlay Specifications .....	264

**TABLES**

WA-4134.17-1	Lifetime Quality Assurance Records .....	13
WA-4134.17-2	Nonpermanent Quality Assurance Records .....	13
WA-7100-1	Dimensional Standards .....	17
WA-7100-2	Standards and Specifications Referenced in Division 3 .....	18
WA-8100-1	Authorizations and Certification Mark Issued by the Society for the Construction of Transportation and Storage Components and Parts .....	19
WB-2331.2-1	Required LST-RT <sub>NDT</sub> Values for Ferritic Steel Material for Containment Material .....	39
WB-2331.2-2	Required Fracture Toughness Values for Ferritic Steel Material for Containments Having a Specified Yield Strength of 50 ksi (350 000 kPa) or Less at 100°F (38°C) .....	39
WB-2332(a)-1	Required C <sub>v</sub> Values for Piping .....	40
WB-2333-1	Required C <sub>v</sub> Values for Bolting Material .....	40
WB-2432.1-1	Sampling of Welding Materials for Chemical Analysis .....	43
WB-2432.2-1	Chemical Analysis for Welding Material .....	44
WB-3133.4-1	Values of Spherical Radius Factor, K <sub>1</sub> .....	59
WB-3217-1	Classification of Stress Intensity in Containments for Some Typical Cases .....	65
WB-4232-1	Maximum Allowable Offset in Final Welded Joints .....	86
WB-4622.1-1	Mandatory Requirements for Postweld Heat Treatment of Welds .....	102
WB-4622.4(c)-1	Alternative Holding Temperatures and Times .....	102
WB-4622.7(b)-1	Exemptions to Mandatory PWHT .....	103
WB-5111-1	Thickness, IQI Designations, Essential Holes, and Wire Diameters .....	113
WC-2311(a)-1	Exemptions From Impact Testing Under <a href="#">WC-2311(a)(7)</a> .....	130
WC-2332.1-1	Required C <sub>v</sub> Lateral Expansion Values for Containment Material Other Than Bolting ...	131
WC-2332.1-2	Required C <sub>v</sub> Energy Values for Containment Material Other Than Bolting .....	132
WC-2332.3-1	Required C <sub>v</sub> Values for Bolting Material Tested in Accordance With <a href="#">WC-2332.3</a> .....	132
WC-2432.1-1	Sampling of Welding Materials for Chemical Analysis .....	136
WC-2432.2-1	Welding Material Chemical Analysis .....	137
WC-3133.4-1	Values of Spherical Radius Factor, K <sub>1</sub> .....	149
WC-3217-1	Stress Intensity <i>k</i> Factors for Design and Operating Load Combinations .....	152
WC-3262-1	Stress Reduction Factors and Examinations for Closure Welds .....	165
WC-4232(a)-1	Maximum Allowable Offset in Final Welded Joints .....	172
WC-4524-1	Maximum Design Temperatures for Brazing Filler Metal, °F (°C) .....	189
WC-4622.1-1	Mandatory Requirements for Postweld Heat Treatment of Welds .....	190
WC-4622.4(c)-1	Alternative Holding Temperatures and Times .....	191
WC-4622.7(b)-1	Exemptions to Mandatory PWHT .....	192
WC-5111-1	Thickness, IQI Designations, Essential Holes, and Wire Diameters .....	202
WD-2331(a)-1	Required C <sub>v</sub> Values for Internal Support Structure Material With 2 in. (50 mm) Maximum Thickness (Other Than Bolting) .....	219
WD-2333-1	Required C <sub>v</sub> Values for Bolting Material .....	220
WD-2432.1-1	Sampling of Welding Materials for Chemical Analysis .....	224
WD-2432.2-1	Welding Material Chemical Analysis .....	224
WD-3217-1	Classification of Stress Intensities for Some Typical Cases .....	237
WD-3229.2-1	Values of <i>K</i> for Various Boundary Conditions and <i>a/b</i> Ratios .....	247
WD-3234-1	Stress Limit Factors for Bolt Design by Analysis .....	248
WD-3234.1(d)-1	Effective Slip Coefficient Versus Surface Condition .....	249
WD-3234.2-1	Maximum Sizes of Bolt Holes .....	250
WD-3234.3(a)-1	Minimum Edge Distances .....	250
WD-3234.4-1	Increment C1 for Minimum Spacing Between Oversized and Slotted Holes .....	251
WD-3235.4-1	Classification of Loading Conditions .....	251
WD-3235.5-1	Stress Categories .....	252
WD-3235.6-1	Allowable Stress Ranges .....	252
WD-3240-1	Permissible Welded Joints and Design Factors .....	253
WD-4622.1-1	Mandatory Requirements for Postweld Heat Treatment (PWHT) of Welds .....	266

WD-4622.4(c)-1	Alternative Holding Temperatures and Times .....	267
WD-4622.7(b)-1	Exemptions to Mandatory PWHT .....	268
WD-5111-1	Thickness, IQI Designations, Essential Holes, and Wire Diameters .....	272

**FORMS**

N-7	Nuclear Containments .....	23
N-8	For Class SC or TC Closure Welds .....	25
N-9	Shop Fabricated Parts .....	26
N-11	Certificate Holder's Data Report for Internal Support Structures .....	28

<b>ENDNOTES</b> .....	279
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# LIST OF SECTIONS

(17)

## SECTIONS

- I Rules for Construction of Power Boilers
- II Materials
  - Part A — Ferrous Material Specifications
  - Part B — Nonferrous Material Specifications
  - Part C — Specifications for Welding Rods, Electrodes, and Filler Metals
  - Part D — Properties (Customary)
  - Part D — Properties (Metric)
- III Rules for Construction of Nuclear Facility Components
  - Subsection NCA — General Requirements for Division 1 and Division 2
  - Appendices
  - Division 1<sup>\*</sup>
    - Subsection NB — Class 1 Components
    - Subsection NC — Class 2 Components
    - Subsection ND — Class 3 Components
    - Subsection NE — Class MC Components
    - Subsection NF — Supports
    - Subsection NG — Core Support Structures
  - Division 2 — Code for Concrete Containments
  - Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
  - Division 5 — High Temperature Reactors
- IV Rules for Construction of Heating Boilers
- V Nondestructive Examination
- VI Recommended Rules for the Care and Operation of Heating Boilers
- VII Recommended Guidelines for the Care of Power Boilers
- VIII Rules for Construction of Pressure Vessels
  - Division 1
  - Division 2 — Alternative Rules
  - Division 3 — Alternative Rules for Construction of High Pressure Vessels
- IX Welding, Brazing, and Fusing Qualifications
- X Fiber-Reinforced Plastic Pressure Vessels
- XI Rules for Inservice Inspection of Nuclear Power Plant Components
- XII Rules for Construction and Continued Service of Transport Tanks

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<sup>\*</sup> The 2015 Edition of Section III was the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, was published. The requirements located within Subsection NH were moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

## **INTERPRETATIONS**

Interpretations are issued in real time in ASME's Interpretations Database at <http://go.asme.org/Interpretations>. Historical BPVC interpretations may also be found in the Database.

## **CODE CASES**

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2017 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Supplements will be sent or made available automatically to the purchasers of the Code Cases books up to the publication of the 2019 Code.

# FOREWORD\*

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

- (a) Committee on Power Boilers (I)
- (b) Committee on Materials (II)
- (c) Committee on Construction of Nuclear Facility Components (III)
- (d) Committee on Heating Boilers (IV)
- (e) Committee on Nondestructive Examination (V)
- (f) Committee on Pressure Vessels (VIII)
- (g) Committee on Welding, Brazing, and Fusing (IX)
- (h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
- (i) Committee on Nuclear Inservice Inspection (XI)
- (j) Committee on Transport Tanks (XII)
- (k) Technical Oversight Management Committee (TOMC)

Where reference is made to “the Committee” in this Foreword, each of these committees is included individually and collectively.

The Committee’s function is to establish rules of safety relating only to pressure integrity, which govern the construction\*\* of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the

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\* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI’s requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

\*\* *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at <http://go.asme.org/BPVCPublicReview> to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of an ASME Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.



## **STATEMENT OF POLICY ON THE USE OF THE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING**

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not “approve,” “certify,” “rate,” or “endorse” any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities “are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code,” or “meet the requirements of the ASME Boiler and Pressure Vessel Code.” An ASME corporate logo shall not be used by any organization other than ASME.

The Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the Certification Mark. General usage is permitted only when all of a manufacturer’s items are constructed under the rules.

## **STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS**

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Certification Mark described in the governing Section of the Code.

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME” or the Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

# (17) SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES

## 1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the applicable Boiler and Pressure Vessel (BPV) Standards Committee (hereinafter referred to as the Committee). See the guidelines on approval of new materials under the ASME Boiler and Pressure Vessel Code in Section II, Part D for requirements for requests that involve adding new materials to the Code. See the guidelines on approval of new welding and brazing materials in Section II, Part C for requirements for requests that involve adding new welding and brazing materials (“consumables”) to the Code.

Technical inquiries can include requests for revisions or additions to the Code requirements, requests for Code Cases, or requests for Code Interpretations, as described below:

(1) *Code Revisions.* Code revisions are considered to accommodate technological developments, to address administrative requirements, to incorporate Code Cases, or to clarify Code intent.

(2) *Code Cases.* Code Cases represent alternatives or additions to existing Code requirements. Code Cases are written as a Question and Reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all regulators, jurisdictions, or Owners automatically accept Code Cases. The most common applications for Code Cases are as follows:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit use of a new material for Code construction

(-c) to gain experience with new materials or alternative requirements prior to incorporation directly into the Code

(3) *Code Interpretations*

(-a) Code Interpretations provide clarification of the meaning of existing requirements in the Code and are presented in Inquiry and Reply format. Interpretations do not introduce new requirements.

(-b) If existing Code text does not fully convey the meaning that was intended, or conveys conflicting requirements, and revision of the requirements is required to support the Interpretation, an Intent Interpretation will be issued in parallel with a revision to the Code.

(b) Code requirements, Code Cases, and Code Interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or Owners to choose any method of design or any form of construction that conforms to the Code requirements.

(c) Inquiries that do not comply with the following guidance or that do not provide sufficient information for the Committee’s full understanding may result in the request being returned to the Inquirer with no action.

## 2 INQUIRY FORMAT

Submittals to the Committee should include the following information:

(a) *Purpose.* Specify one of the following:

(1) request for revision of present Code requirements

(2) request for new or additional Code requirements

(3) request for Code Case

(4) request for Code Interpretation

(b) *Background.* The Inquirer should provide the information needed for the Committee’s understanding of the Inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda (if applicable), paragraphs, figures, and tables. Preferably, the Inquirer should provide a copy of, or relevant extracts from, the specific referenced portions of the Code.

(c) *Presentations.* The Inquirer may desire to attend or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the Inquiry. Attendance at a BPV Standards Committee meeting shall be at the expense of the Inquirer. The Inquirer's attendance or lack of attendance at a meeting will not be used by the Committee as a basis for acceptance or rejection of the Inquiry by the Committee. However, if the Inquirer's request is unclear, attendance by the Inquirer or a representative may be necessary for the Committee to understand the request sufficiently to be able to provide an Interpretation. If the Inquirer desires to make a presentation at a Committee meeting, the Inquirer should provide advance notice to the Committee Secretary, to ensure time will be allotted for the presentation in the meeting agenda. The Inquirer should consider the need for additional audiovisual equipment that might not otherwise be provided by the Committee. With sufficient advance notice to the Committee Secretary, such equipment may be made available.

### 3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions should include the following information:

(a) *Requested Revisions or Additions.* For requested revisions, the Inquirer should identify those requirements of the Code that they believe should be revised, and should submit a copy of, or relevant extracts from, the appropriate requirements as they appear in the Code, marked up with the requested revision. For requested additions to the Code, the Inquirer should provide the recommended wording and should clearly indicate where they believe the additions should be located in the Code requirements.

(b) *Statement of Need.* The Inquirer should provide a brief explanation of the need for the revision or addition.

(c) *Background Information.* The Inquirer should provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request, that will allow the Committee to adequately evaluate the requested revision or addition. Sketches, tables, figures, and graphs should be submitted, as appropriate. The Inquirer should identify any pertinent portions of the Code that would be affected by the revision or addition and any portions of the Code that reference the requested revised or added paragraphs.

### 4 CODE CASES

Requests for Code Cases should be accompanied by a statement of need and background information similar to that described in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure) should be described. In addition, it is important that the request is in connection with equipment that will bear the Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and should be written as a Question and a Reply, in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Editions and Addenda (if applicable) to which the requested Code Case applies.

### 5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations should be accompanied by the following information:

(1) *Inquiry.* The Inquirer should propose a condensed and precise Inquiry, omitting superfluous background information and, when possible, composing the Inquiry in such a way that a "yes" or a "no" Reply, with brief limitations or conditions, if needed, can be provided by the Committee. The proposed question should be technically and editorially correct.

(2) *Reply.* The Inquirer should propose a Reply that clearly and concisely answers the proposed Inquiry question. Preferably, the Reply should be "yes" or "no," with brief limitations or conditions, if needed.

(3) *Background Information.* The Inquirer should provide any need or background information, such as described in 3(b) and 3(c), respectively, for Code revisions or additions, that will assist the Committee in understanding the proposed Inquiry and Reply.

If the Inquirer believes a revision of the Code requirements would be helpful to support the Interpretation, the Inquirer may propose such a revision for consideration by the Committee. In most cases, such a proposal is not necessary.

(b) Requests for Code Interpretations should be limited to an Interpretation of a particular requirement in the Code or in a Code Case. Except with regard to interpreting a specific Code requirement, the Committee is not permitted to consider consulting-type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements

- (2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation
- (3) a request seeking the rationale for Code requirements

## 6 SUBMITTALS

(a) *Submittal.* Requests for Code Interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at <http://go.asme.org/InterpretationRequest>. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt. If the Inquirer is unable to use the online form, the Inquirer may mail the request to the following address:

Secretary  
ASME Boiler and Pressure Vessel Committee  
Two Park Avenue  
New York, NY 10016-5990

All other Inquiries should be mailed to the Secretary of the BPV Committee at the address above. Inquiries are unlikely to receive a response if they are not written in clear, legible English. They must also include the name of the Inquirer and the company they represent or are employed by, if applicable, and the Inquirer's address, telephone number, fax number, and e-mail address, if available.

(b) *Response.* The Secretary of the appropriate Committee will provide a written response, via letter or e-mail, as appropriate, to the Inquirer, upon completion of the requested action by the Committee. Inquirers may track the status of their Interpretation Request at <http://go.asme.org/Interpretations>.

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January 1, 2017

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 J. Johnston, Jr.

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 M. Lashley  
 K. A. Manoly  
 D. P. Munson  
 T. M. Musto  
 J. E. O'Sullivan  
 V. Rohatgi  
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 R. W. Barnes

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**Special Working Group on Industry Experience for New Plants  
(BPV III & BPV XI)**

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E. L. Pleins, <i>Chair</i>	Y.-S. Kim
J. Ossmann, <i>Secretary</i>	K. Matsunaga
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P. J. Hennessey	D. W. Sandusky
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J. Honcharik	R. M. Wilson
E. V. Imbro	S. M. Yee
C. G. Kim	

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A. Cardillo	R. R. Stevenson
P. J. Coco	R. Troficanto
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J. P. Chicoine	D. Picart, <i>Delegate</i>
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B. J. Iske	S. V. Voorhees, <i>Contributing Member</i>
J. Klug	J. L. Kleiss, <i>Alternate</i>
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**Subgroup on Water Heaters (BPV IV)**

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J. P. Chicoine	T. E. Trant
C. Dinic	R. D. Troutt
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**Subgroup on Welded Boilers (BPV IV)**

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B. Calderon	R. D. Troutt
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A. F. Garbolevsky	C. Vorwald
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R. J. Basile	S. Terada
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F. L. Brown	R. A. Whipple
D. Chandiramani	K. Xu
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R. D. Dixon	P. Prueter
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R. Mahadeen	D. A. Swanson
U. R. Miller	J. P. Swezy, Jr.
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D. B. DeMichael	D. B. Stewart
M. Faulkner	D. A. Swanson
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P. Bunch	S. K. Parimi
J. Ellens	M. Sarzynski
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X. Kaculi	D. T. Peters, <i>Contributing Member</i>
K. Karpanan	

**Subgroup on High Pressure Vessels (BPV VIII)**

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R. T. Hallman	K.-J. Young
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J. F. Grubb	M. Katcher, <i>Contributing Member</i>
M. Kowalczyk	J. A. McMaster, <i>Contributing Member</i>
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P. Angelini	L. Moracchioli
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R. D. Dixon	J. L. Traud
L. Fridlund	R. Wink
R. T. Hallman	Y. Xu
K. Karpanan	F. Kirkemo, <i>Contributing Member</i>
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N. McKie	D. M. Fryer, <i>Honorary Member</i>
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Y. Chen	X. Qian
Z. Chen	B. Wang
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W. Guo	K. Zhang
B. Han	Y. Zhang
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H. Hui	G. Zhu

**Working Group on Materials (BPV VIII Div. 3)**

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J. Cameron	D. B. Stewart
R. D. Dixon	P. L. Sturgill
M. Kowalczyk	D. A. Swanson
D. L. Kurle	J. P. Swezy, Jr.
M. D. Lower	J. Vattappilly
R. Mahadeen	P. G. Wittenbach
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J. Burgess	T. Patel
S. Cammeresi	M. Poehlmann
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E. Suarez, <i>Staff Secretary</i>	D. Arrigo, <i>Alternate</i>
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# ORGANIZATION OF SECTION III

## 1 GENERAL

Section III consists of Division 1, Division 2, Division 3, and Division 5. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter “N” for Division 1, by the letter “C” for Division 2, by the letter “W” for Division 3, and by the letter “H” for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1<sup>\*</sup>
  - Subsection NB — Class 1 Components
  - Subsection NC — Class 2 Components
  - Subsection ND — Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
  - Subsection WD — Class ISS Internal Support Structures
- Division 5 — High Temperature Reactors
  - Subsection HA — General Requirements
    - Subpart A — Metallic Materials
    - Subpart B — Graphite Materials
    - Subpart C — Composite Materials
  - Subsection HB — Class A Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HC — Class B Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HF — Class A and B Metallic Supports
    - Subpart A — Low Temperature Service
  - Subsection HG — Class A Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class A Nonmetallic Core Support Structures
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

## 2 SUBSECTIONS

Subsections are divided into Articles, subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

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<sup>\*</sup> The 2015 Edition of Section III was the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, was published. The requirements located within Subsection NH were moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.



### 3 ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection, except NCA, in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping With Certification Mark, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

### 4 SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

### 5 SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

### 6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

### 7 SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

### 8 SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

### 9 REFERENCES

References used within Section III generally fall into one of the following four categories:

(a) *References to Other Portions of Section III.* When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to Article NB-3000 includes all material in Article NB-3000; reference to NB-3100 includes all material in subarticle NB-3100; reference to NB-3110 includes all paragraphs, NB-3111 through NB-3113.

(b) *References to Other Sections.* Other Sections referred to in Section III are the following:

(1) *Section II, Materials.* When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

(2) *Section V, Nondestructive Examination.* Section V references begin with the letter “T” and relate to the nondestructive examination of material or welds.

(3) *Section IX, Welding and Brazing Qualifications.* Section IX references begin with the letter “Q” and relate to welding and brazing requirements.

(4) *Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components.* When a reference is made to inservice inspection, the rules of Section XI shall apply.

(c) *Reference to Specifications and Standards Other Than Published in Code Sections*

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials (ASTM). At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E94 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute. \*\* When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME (<https://www.asme.org/>).

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-89-2003.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 Doral Boulevard, Suite 130, Doral, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix “SF,” for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-605. When documents so designated are referred to in Section III, for example API-605-1988, they are standards published by the American Petroleum Institute and are listed in Table NCA-7100-1.

(d) *References to Appendices.* Section III uses two types of appendices that are designated as either Section III Appendices or Subsection Appendices. Either of these appendices is further designated as either Mandatory or Nonmandatory for use. Mandatory Appendices are referred to in the Section III rules and contain requirements that must be followed in construction. Nonmandatory Appendices provide additional information or guidance when using Section III.

(1) Section III Appendices are contained in a separate book titled “Appendices.” These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-1210. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

(2) Subsection Appendices are specifically applicable to just one subsection and are contained within that subsection. Subsection-specific mandatory and nonmandatory appendices are numbered in the same manner as Section III Appendices, but with a subsection identifier (e.g., NF, NH, D2, etc.) preceding either the Roman numeral or the capital letter for a unique designation. For example, NF-II-1100 or NF-A-1200 would be part of a Subsection NF mandatory or nonmandatory appendix, respectively. For Subsection CC, D2-IV-1120 or D2-D-1330 would be part of a Subsection CC mandatory or nonmandatory appendix, respectively.

(3) It is the intent of this Section that the information provided in both Mandatory and Nonmandatory Appendices may be used to meet the rules of any Division or Subsection. In case of conflict between Appendix rules and Division/Subsection rules, the requirements contained in the Division/Subsection shall govern. Additional guidance on Appendix usage is provided in the front matter of Section III Appendices.

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\*\* The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix “ASA” followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix “USAS” followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

## SUMMARY OF CHANGES

Errata to the BPV Code may be posted on the ASME Web site to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published by ASME at <http://go.asme.org/BPVCerrata>.

Changes given below are identified on the pages by a margin note, **(17)**, placed next to the affected area.

The Record Numbers listed below are explained in more detail in “List of Changes in Record Number Order” following this Summary of Changes.

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
xv	List of Sections	Updated
xx	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	Revised in its entirety (13-2222)
xxiii	Personnel	Updated
xlii	Organization of Section III	(1) In “1 General,” title of Section III, Division 3 revised (13-1594) (2) In “1 General,” for Section III, Division 3, Subsection WD added (3) In “1 General,” entry for Subsection NH deleted and footnote editorially revised (4) In “9 References,” subparas. (a) and (d)(1) revised (16-148)
1	WA-1110	(1) Title and paragraphs revised (13-1594) (2) Former endnote 2 deleted from Endnotes (15-2548)
1	WA-1130	Subparagraph (b) revised (13-1594, 15-2548)
1	WA-1140	Title and subparas. (a), (b), (d), and (d)(1) through (d)(3) revised (13-1594)
2	WA-1210	Revised (13-1594)
2	WA-1221	Revised (13-1594)
2	WA-1230	Revised (13-1594)
3	Article WA-2000	Title revised (13-1594)
3	WA-2100	(1) WA-2110, WA-2121, WA-2122, WA-2123(e), WA-2123.4, WA-2124, and WA-2130 revised (13-1594) (2) Former endnote 4 incorporated into WA-2121(c) and WA-2123(c) and deleted from Endnotes (15-2548) (3) Former endnote 5 incorporated into WA-2123.4(b) and deleted from Endnotes (15-2548)
5	WA-3110	Revised (13-1594)
5	WA-3111	Revised (13-1594)
5	WA-3112	Revised (13-1594)
5	WA-3113	In subpara. (a), first sentence revised (13-1594)
6	WA-3123	Revised in its entirety (14-2159)
6	WA-3124	Added (14-2159)

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
7	WA-3320	Subparagraphs (d) and (f) revised (13-1594)
7	WA-3330	Revised (13-1594)
7	WA-3340	Revised (13-1594)
7	WA-3351	WA-3351.1, WA-3351.2(d), WA-3351.2(g), WA-3351.2(h), WA-3351.2(i), WA-3351.3, and WA-3351.4 revised (13-1594, 15-209)
8	WA-3352.1	Subparagraphs (a), (b), (d), and (e) revised (13-1594)
8	WA-3356	Revised in its entirety (13-1594, 15-209)
9	WA-3357	Subparagraph (c) revised (13-1594)
9	WA-3361	(1) WA-3361.1, WA-3361.2, and WA-3361.4 revised (13-1594) (2) WA-3361.3 revised (13-1594, 15-209)
10	WA-3461	Revised (13-1594)
10	WA-3800	(1) WA-3810 and WA-3812 revised (13-1594, 16-2075) (2) WA-3811(b) and WA-3820 revised (16-2075)
12	WA-4110	In subpara. (a), first sentence revised (13-1594)
12	WA-4120	(1) New subpara. (b) added (15-226) (2) Former subpara. (b) redesignated as (c) and (d) (15-226)
13	Table WA-4134.17-1	Revised (13-1594)
13	Table WA-4134.17-2	Revised (13-1594)
14	WA-5122	Revised (13-1594)
14	WA-5125	Subparagraph (a) revised (13-1594)
14	WA-5210	Subparagraph (b) revised (13-1594)
15	WA-5230	Subparagraph (c) revised (15-209)
16	WA-5262	Subparagraph (c) revised (13-1594)
17	Article WA-7000	Revised in its entirety (13-1594)
19	Table WA-8100-1	Revised (13-1594)
20	WA-8150	WA-8151, WA-8152, and WA-8154 revised (13-1594)
20	WA-8161	In subpara. (b), last sentence revised (13-1594, 15-209)
20	WA-8211	Subparagraphs (a) and (a)(5) revised (13-1594)
21	Figure WA-8212-1	Revised (13-1594, 16-961)
21	WA-8220	(1) Subparagraph (b) revised (13-1594) (2) Subparagraph (c) added (16-961)
21	WA-8230	Second sentence revised (13-1594)
21	WA-8300	(1) WA-8310(b) revised (13-1594) (2) In WA-8311, first paragraph and subpara. (b) revised (13-1594)
23	Form N-7	Revised (13-1594)
25	Form N-8	Revised (13-1594)
26	Form N-9	Revised (13-1594)
28	Form N-11	Added (13-1594)

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
29	WA-9200	(1) Definitions of <i>component, containment, containment closure weld, disposal, energy-limited dynamic event, internal support structure, qualified source material, regulatory authority, source material, storage, and transportation</i> revised (13-1594, 16-2075) (2) Definition of <i>Certification Mark</i> deleted (13-1594) (3) Definitions of <i>Class ISS, Containment Systems, and Lowest Service Temperature (LST)</i> added (13-1594, 15-2548)
31	WB-1100	Subparagraphs (a) and (b) revised (13-1594, 16-148, 16-1537)
31	WB-1120	(1) Title revised (14-1895) (2) Former subparagraph (a) deleted and former subpara. (c) redesignated as (a) and revised (14-1895)
33	WB-2122	First sentence revised (16-2075)
34	WB-2123	Last line revised (16-2075)
34	WB-2150	First sentence revised (16-2075)
35	WB-2211	(1) Title revised (15-2548) (2) Former endnote 8 incorporated into paragraph and deleted from Endnotes (15-2548)
36	WB-2222.2	Fraction " $\frac{1}{2}$ " corrected by errata to " $\frac{1}{4}$ " (13-140)
36	WB-2222.3	Fraction " $\frac{1}{2}$ " corrected by errata to " $\frac{1}{4}$ " (13-140)
36	WB-2223.1	Fraction " $\frac{1}{2}$ " corrected by errata to " $\frac{1}{4}$ " (13-140)
38	WB-2321.3	Revised and former endnote 9 deleted from Endnotes (15-2548)
38	WB-2321.4	Revised and former endnote 9 deleted from Endnotes (15-2548)
38	WB-2331.1	Subparagraph (a) revised (15-2548)
39	WB-2331.2	Subparagraph (a) revised (15-2548)
39	WB-2332	Subparagraphs (a)(1) and (b) revised (15-2548)
40	WB-2333	Revised (15-2548)
41	WB-2360	Subparagraphs (a) and (b) revised (16-2075)
42	WB-2431.1	Former endnote 8 incorporated into subpara. (c) and deleted from Endnotes (15-2548)
43	WB-2432.1	Former endnote 12 incorporated into subpara. (c) and deleted from Endnotes (15-2548)
49	WB-2551	Former endnote 13 incorporated into subpara. (a) and deleted from Endnotes (15-2548)
53	WB-2581	Revised (14-1396)
53	WB-2582	Revised (14-1396)
55	WB-2610	Subparagraph (b) revised (16-2075)
56	WB-3113	Former endnote 15 deleted from Endnotes (15-2548)
59	Table WB-3133.4-1	Reformatted editorially
63	WB-3215	Former endnote 18 added after last paragraph as in-text Note and deleted from Endnotes (15-2548)
66	WB-3222.4	First sentence revised (16-336)

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
69	WB-3222.6	Former endnote 19 added as in-text Note and deleted from Endnotes (15-2548)
69	WB-3222.9	Former endnote 21 incorporated into subpara. (d)(3) and deleted from Endnotes (15-2548)
71	WB-3222.11	In subpara. (a), former endnote 22 added as in-text Note below nomenclature <i>y'</i> and deleted from Endnotes (15-2548)
71	WB-3224.1	Subparagraphs (c) and (e) revised (15-2529)
73	WB-3224.2	Revised (15-2529)
75	WB-3234	Subparagraph (a) revised (15-2529)
76	WB-3251.1	Former endnote 23 deleted from Endnotes (15-2548)
81	WB-4121.1	Revised (16-2106)
83	WB-4221.1	Revised (13-542)
84	WB-4221.3	Last two lines revised (15-209)
84	WB-4222.1	Revised (13-542)
87	WB-4243	Former endnote 24 incorporated into subpara. (c)(1) and deleted from Endnotes (15-2548)
97	WB-4335.2(e)(1)	Revised (15-2548)
99	Figure WB-4427-1	Editorially updated
101	WB-4622.1	Former endnote 8 incorporated into paragraph and deleted from Endnotes (15-2548)
123	WC-1100	(1) In subpara. (a), last line revised (13-1594) (2) In subpara. (b), first sentence revised (16-148, 16-1537)
123	WC-1120	(1) Title revised (14-1895) (2) Former subpara. (a) deleted and former subpara. (c) redesignated as (a) and revised (14-1895)
125	WC-2122	In first paragraph, first sentence revised (16-2075)
126	WC-2124	In first paragraph, first sentence revised (16-2075)
126	WC-2125	Former endnote 31 added as second paragraph and deleted from Endnotes (16-2075)
127	WC-2150	First sentence revised (16-2075)
127	WC-2211	Former endnote 8 added to the end of the paragraph and deleted from Endnotes (15-2548)
129	WC-2311	Subparagraphs (a)(7), (a)(8), and (b) revised (15-2548)
130	WC-2321.3	Revised (15-2548)
131	WC-2331	Subparagraphs (a)(1) and (a)(2) revised and former endnote 33 deleted from Endnotes (15-2548)
131	WC-2332	(1) Title and WC-2332.3 revised (15-2548) (2) Former endnote 35 incorporated into the first paragraph of WC-2332.1 and WC-2332.2 and deleted from Endnotes (15-2548) (3) WC-2332.3 revised (15-2548)

<i>Page</i>	<i>Location</i>	<i>Change (Record Number)</i>
133	WC-2360	References to NCA revised (16-2075)
135	WC-2431.1	Former endnote 8 incorporated into subpara. (c) and deleted from Endnotes (15-2548)
136	WC-2432.1	Former endnote 12 incorporated into subpara. (c) and deleted from Endnotes (15-2548)
141	WC-2552	Former endnote 13 added as new paragraph and deleted from Endnotes (15-2548)
144	WC-2582	Revised (14-1396)
149	Table WC-3133.4-1	Reformatted editorially
150	WC-3211.1	In subpara. (a), first sentence revised (13-1594)
151	WC-3216.3	In subparas. (a)(2) and (c), references to Section III Appendices revised (16-148)
152	Table WC-3217-1	Notes (3) and (4) revised (15-2529, 16-148)
152	WC-3217.2	Last line and endnote 19 (formerly 36) revised (16-148)
153	WC-3219.1	Reference to Section III Appendices revised (16-148)
153	WC-3219.1.2	Revised in its entirety (16-148)
154	WC-3224.6	Reference to Section III Appendices revised (16-148)
154	WC-3224.8	Reference to Section III Appendices revised (16-148)
156	WC-3224.9	Reference to Section III Appendices revised (16-148)
157	Figure WC-3225-1	In the callout for sketches (a), (b), and (c), "0.2" corrected by errata to "0.20" (17-335)
158	Figure WC-3225-2	In the callout for sketches (b) through (e), "0.2" corrected by errata to "0.20" (17-335)
159	Figure WC-3225-3	In the callout for sketches (a), (b), and (d) through (g), "0.2" corrected by errata to "0.20" (17-335)
156	WC-3225.2	Former endnote 39 added as subpara. (c) and deleted from Endnotes (15-2548)
161	WC-3251.1	Reference to endnote 23 deleted (15-2548)
166	WC-4121.1	Cross-reference revised (16-2106)
167	WC-4130	Subparagraph (d) revised (13-1594)
168	WC-4221.1	Revised (13-542)
169	WC-4222.1	Revised (13-542)
174	WC-4265	Former endnote 24 incorporated into subpara. (d)(1) and deleted from Endnotes (15-2548)
182	WC-4335.2	Subparagraphs (b)(1) and (c)(1) revised (15-2548)
189	WC-4622.1	Former endnote 8 incorporated into paragraph and deleted from Endnotes (15-2548)
213	Subsection WD	Added (13-1593, 14-1895, 16-960, 16-2106)

## LIST OF CHANGES IN RECORD ORDER NUMBER

Record Number	Change
13-140	Errata corrections. See Summary of Changes for details.
13-542	Revised WB/WC-4221.1 and WB/WC-4222.1 to clearly establish the equations for U.S. Customary and SI units, to be consistent across BPVC Divisions and book Sections.
13-1593	Added new Subsection WD.
13-1594	Revised the Organization of Section III to address the incorporation of a new proposed Subsection WD that addresses internal support structures.
13-2222	Revised the front guidance on interpretations in its entirety.
14-1396	Revised WB-2581, WB-2582, and WC-2582 Visual Examination and added references to ASTM F788 and ASTM F812.
14-1895	Revised to eliminate statements regarding whether components shall be constructed to Division 3 rules, also revised to make WB/WC/WD-1000 more consistent.
14-2159	Revised WA-3123 and added WA-3124 to allow approval of subcontracted calibration and testing services by acceptance of International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Agreement (MRA) approved laboratories.
15-209	Revised the term "Registered Professional Engineer" to "Certifying Engineer" and added requirements to be consistent with changes in Mandatory Appendix XXIII.
15-226	Revised WA-4120(b) to clarify applicability of NQA-1 definitions.
15-2529	Updated cross references as a result of revision of Nonmandatory Appendix F as a Mandatory Appendix.
15-2548	Updated Subsections WA/WB/WC, as well as the Division 3-related Nonmandatory Appendix EE, to incorporate and delete some endnotes into the text.
16-148	Revised numerous sections of text related to incorporation of revised Mandatory Appendix XIII.
16-336	Revised WB-3222.4 to evaluate normal loads.
16-960	Revised Table WD-2331(a)-1 so that the maximum thickness matches that established in WD-2331 and WD-2332. Clarified Table WD-2331(a)-1 column heads as being applicable to all material (not just pipe or shells) by deleting "wall," and added an additional stress limit to WD-3229.2(c) to address those situations when buckling is not a limiting issue.
16-961	Revised WA-8220 to add alternative nameplate requirements and revised Figure WA-8212-1, removing date info since this is not mentioned in the WA requirements.
16-1537	Revised WB/WC-1100(b) for clarity.
16-2075	Made numerous revisions in WA-3810, WA-3811, WA-3812, and WA-3820 to change references to NCA-385X to NCA-425X, based on the proposed revisions identified in Record 16-341.
16-2106	Revised WB/WC/WD-4121.1 to align the phrasing of Division 1 with Divisions 2 and 3 for consistency.
17-335	Errata corrections. See Summary of Changes for details.



# CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

## Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

## Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

## Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

*Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees* has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

## Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
  - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

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# SUBSECTION WA

## GENERAL REQUIREMENTS

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### ARTICLE WA-1000

#### SCOPE OF DIVISION 3

#### WA-1100 SCOPE

(17) **WA-1110 NATURE OF THESE RULES AND CONTAINMENT SYSTEMS TO WHICH THEY ARE APPLICABLE**

(a) The rules of Division 3 contain the requirements for the construction of individual components (and parts where appropriate) that comprise Containment Systems ([Article WA-9000](#)). Division 3 Containment Systems are used for the transportation and/or storage, including disposal,<sup>1</sup> of spent nuclear fuel and high-level radioactive material.

(b) As used in Division 3, Containment Systems may be comprised of one or more components, such as containments and internal support structures. Containment System components for which Division 3 provides rules are as follows:

(1) the transportation containment ([Subsection WB](#) — Class TC)

(2) the storage containment ([Subsection WC](#) — Class SC)

(3) the internal support structure ([Subsection WD](#) — Class ISS)

#### WA-1120 DEFINITIONS

Definitions of key terms used in this Division are included in [Article WA-9000](#).

(17) **WA-1130 LIMITS OF THESE RULES**

(a) The rules of this Division provide requirements for new construction including consideration of mechanical and thermal stresses due to cyclic operation. They do not cover deterioration which may occur in service as a result of radiation effects, corrosion, erosion, or instability of the material. These effects shall be addressed in the Design Specification by requiring appropriate measures to be included in the design.

(b) The rules are intended to be applicable to any item that serves a containment or internal support structure function.

#### WA-1140 USE OF CODE EDITIONS AND CASES (17)

(a) The Design Specification shall establish the Code Edition.

(b) The Certificate Holder shall construct the components or parts under the provisions of a Quality Assurance Program which has been accepted by the Society. The Quality Assurance Program shall be updated to meet the requirements of the latest Division 3 Edition within 6 months of issuance.

(c) Code Cases are permissible and may be used beginning with the date of approval by the ASME Council. Only Code Cases that are specifically identified as being applicable to this Division may be used. Code Cases may only be used by mutual consent of the parties involved.

(d) Materials produced and certified in accordance with Code Editions and Addenda, if applicable, other than the one specified in the Design Specification may be used, provided all of the following requirements are satisfied.

(1) The material ([WA-1220](#)) meets the applicable requirements of a material specification permitted by [WB-2121](#), [WC-2121](#), or [WD-2121](#), as appropriate, of the Edition specified for construction.

(2) The material meets all the requirements of [Article WB-2000](#), [Article WC-2000](#), or [Article WD-2000](#), as appropriate, of the Edition specified for construction.

(3) The material was produced under the provisions of a Quality System Program which had been accepted by the Society or qualified by a party other than the Society (NCA-3820), in accordance with the requirements of the latest Edition and Addenda, if applicable, issued at the time the material was produced. Material exempted from portions of the provisions of NCA-3800 by [WB-2610](#), [WC-2610](#), or [WD-2610](#), as appropriate, may be used, provided the requirements of (1) and (2) above are met.

**WA-1150 UNITS OF MEASURE**

Either U.S. Customary or SI units may be used for compliance with all requirements of this edition, but one system shall be used consistently throughout for all phases of construction.

Either the U.S. Customary units or SI units that are listed in Section III Appendices, Mandatory Appendix XXIV shall be used consistently for all phases of construction (e.g., materials, design, fabrication, and reports). Since values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary units and SI units.

When SI units are selected, U.S. Customary values in referenced specifications that do not contain SI units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

With the publication of the 2004 Edition, Section II, Part D is published as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for construction.

**WA-1200 GENERAL REQUIREMENTS****(17) WA-1210 VALVES**

Valves may form part of the Class TC or Class SC containment boundary. If valves are included in the containment, they shall be designed and constructed in accordance with Section III, Division 1, Class 1 for transportation containments, or Class 1 or Class 2 for storage containments.

**WA-1220 MATERIALS****WA-1221 Metallic Materials****(17)**

Metallic materials shall be manufactured to an SA, SB, or SFA Specification,<sup>2</sup> or any other material specification permitted by [WB-2121](#), [WC-2121](#), or [WD-2121](#), as appropriate. Such material shall be manufactured, identified, and certified in accordance with the requirements of this Division. Tubular products and fittings welded with filler metal shall meet the requirements of Section III, Division 1, Class 1.

**WA-1222 Material, ASTM Specification**

Materials produced under an ASTM designation may be accepted as complying with the corresponding ASME Specification, provided the ASME Specification is designated as being identical with the ASTM Specification for the grade, class, or type produced and provided that the material is confirmed as complying with the ASTM Specification by a Certified Material Test Report, when permitted by NCA-3862.1(a), or Certificate of Compliance from the Material Manufacturer.

**WA-1223 Welding Material, AWS Specification**

Welding material produced under an AWS designation may be accepted as complying with the corresponding ASME Specification, provided the latter Specification is indicated to be identical with the AWS Specification and provided the welding material is confirmed as complying with the AWS Specification by a Certified Material Test Report or Certification from the Material Manufacturer.

**WA-1230 PARTS****(17)**

The Design Specification and Design Documents for parts shall meet the requirements of [WA-3350](#). If the fabrication of such parts is subcontracted to others, the subcontractor shall possess a valid and appropriate Certificate of Authorization for Section III, Division 3 construction.

# ARTICLE WA-2000

## DESIGN BASIS

(17)

### (17) WA-2100 GENERAL REQUIREMENTS

#### WA-2110 SCOPE

Rules for the design of components or parts used for transportation and storage as defined in [Article WA-1000](#) are provided in [Article WB-3000](#), [Article WC-3000](#), or [Article WD-3000](#). The N3 Certificate Holder shall be responsible for establishing a Design Specification that identifies design and safety criteria for the design of the component or part in accordance with the appropriate rules of this Division.

#### WA-2120 DESIGN BASIS

##### WA-2121 Consideration of Operating Conditions

(a) Transportation or storage components ([WA-1110](#)) are subject to operating and test conditions (when specified) that are required to be considered in the design in order to satisfy applicable safety criteria.

(b) Operating conditions for transportation or storage components are classified as either normal, off-normal [applicable only to storage uses ([Subsections WC](#) and/or [WD](#))], or accident conditions. Each condition shall be defined in the Design Specification.

(c) The selection of operating conditions, and the determination of their significance to the design and operability or functionality of the component, are beyond the scope of this Division. Appropriate guidance for the selection of operating conditions may be derived from safety criteria documents from the regulatory and enforcement authorities having jurisdiction.

##### WA-2122 Consideration of Test Conditions

(a) Components shall be subject to a test, when required by [Article WB-6000](#) or [Article WC-6000](#). The stress produced in the component during testing shall not exceed the limits provided in [WB-3225](#) or [WC-3218](#), as appropriate.

(b) Other tests may be specified in the Design Specification. Stresses produced in the component by such a test shall not exceed the test limits specified in the Design Specification.

##### WA-2123 Establishment of Loadings, Stresses, and Limits

(a) The Design Specification shall identify the loadings and combination of loadings and the applicable Service Limits for the stresses resulting from those loadings.

(b) Normal loadings result from normal conditions.

(c) Off-normal loadings result from off-normal conditions [applicable only to storage uses ([Subsections WC](#) and/or [WD](#))].

(d) Accident loadings result from accident conditions.

(e) Test loadings include pressure and leak tests required by [Article WB-6000](#) or [Article WC-6000](#) of this Division.

**WA-2123.1 Design Loadings.** Design Loadings for components shall be in accordance with (a), (b), and (c) below and the additional requirements of this Division.

(a) *Design Pressure.* The specified internal and external Design Pressure shall not be less than the maximum difference in pressure between the inside and outside of the item, or between any two chambers of a combination unit, which exists under the most severe loadings for which the Level A Service Limits are applicable. It shall include allowances for pressure surges and static pressure heads. Pressure loads are not applicable to internal support structures per [Article WD-3000](#).

(b) *Design Temperature.* The specified Design Temperature shall not be less than the expected maximum metal temperature through the thickness of the part under consideration for which Level A Service Limits are specified. Where a component is heated by internal heat generation the effects of such heat input shall be considered in establishing the Design Temperature.

(c) *Design Mechanical Loads.* The Design Mechanical Loads identified in the Design Specification shall include the weight of the component(s), contents, and other items such as operating equipment, impact limiting devices, shielding, insulation, and linings, as applicable.

**WA-2123.2 Operating Loadings.** When the Design Specification or applicable Subsection of this Division requires computation to demonstrate compliance with specified Service Limits, the Design Specification shall provide information from which the operating loadings can be identified (pressure, temperature, mechanical loads, cycles, etc.). The Design Specification shall designate the appropriate Service Limit ([WA-2123.4](#)) to be associated with each operating loading or combination of loadings.

##### WA-2123.3 Test Loadings.

(a) Test loadings include pressure tests required by this Division.

(b) Loads due to other types of tests as may be required by the Design Specification.

**WA-2123.4 Design, Service, and Test Limits.**

(a) *Design Limits.* The limits for Design Loadings shall meet the requirements of the appropriate Subsection of this Division.

(b) *Service Limits.* The Design Specification shall designate Service Limits as defined in (1) through (3). Level B Service Limits are not used in this Division.

(1) *Level A Service Limits.* Level A Service Limits are those sets of limits that must be satisfied for all normal loadings identified in the Design Specification to which the component may be subjected in the performance of its specified function. The component must withstand these loadings without damage requiring repair.

(2) *Level C Service Limits.* Level C Service Limits, which are applicable only to storage uses (Subsections WC and/or WD), are those sets of limits that must be satisfied for all off-normal loadings identified in the Design Specification for which these Service Limits are designated. These sets of limits permit large deformations in areas of structural discontinuity, which may necessitate removal of the component from service for inspection or repair of damage to the component. The selection of this limit shall be reviewed for compatibility with established safety criteria.

(3) *Level D Service Limits.* Level D Service Limits are those sets of limits that must be satisfied for all accident loadings identified in the Design Specification for which these Service Limits are designated. These sets of limits permit gross general deformation with some consequential loss of dimensional stability and damage requiring

repair, which may require removal of the component from service. The selection of this limit shall be reviewed for compatibility with established safety criteria.

(c) *Alternative Service Limits.* Components may be designed using more restrictive Service Limits than specified in the Design Specification. For example, Level C Service Limits may be used when Level D Service Limits have been specified.

**(d) Test Limits**

(1) The limits for Test Loadings shall meet the requirements of the appropriate Subsection of this Division.

(2) The selection of limits for other tests shall be included in the Design Specification.

**WA-2124 Acceptance Criteria**

(a) Components shall comply with the design rules established for design, operating, and test conditions in the appropriate Subsection of this Division.

(b) Design documentation shall be completed in accordance with the requirements of the Subsection applicable to the component.

**WA-2130 SPECIAL REQUIREMENTS**

Contractual arrangements between the Owner and the N3 Certificate Holder (WA-3111) that specify requirements in addition to, or more restrictive than, those specified by the rules of this Division may be applied, provided such requirements do not negate any rules of this Division. Such special contractual requirements are beyond the scope of this Division and shall not apply as conditional requirements for Code construction.

## ARTICLE WA-3000 RESPONSIBILITIES AND DUTIES

### WA-3100 GENERAL

#### (17) WA-3110 RESPONSIBILITIES VS. LEGAL LIABILITIES

The parties identified in [WA-3111](#), [WA-3112](#), and [WA-3113](#) are involved in the construction of transportation and storage components or items that come under the jurisdiction of this Division. Each party has specific duties and responsibilities as set forth in this Article. The responsibilities relate only to Code compliance and are not to be construed as involving contractual or legal liabilities. A single organization may perform one or more of the roles assigned to each party provided all the requirements of this Division are met.

#### (17) WA-3111 N3 Certificate Holder

(a) The N3 Certificate Holder is the organization that obtains a Certificate of Authorization issued by the Society. The N3 Certificate Holder prepares a Design Specification ([WA-3351](#)), determines the loads applied to the component, designs the component, demonstrates the adequacy of the design of the component, and issues a Design Report and other documents required by this Division.

(b) If there are site-specific design criteria that must be met to satisfy the requirements of this Division, then it is the responsibility of the N3 Certificate Holder to obtain these criteria for inclusion into the Design Documents required by this Division.

(c) The N3 Certificate Holder is responsible for the preparation and certification of the Fabrication Specification and its issuance to the component fabricator.

(d) The N3 Certificate Holder has the overall responsibility for the construction of the component in accordance with the requirements of this Division. In addition to obtaining a Certificate of Authorization from the Society, the N3 Certificate Holder completes the appropriate Data Report Form and applies the Certification Mark to completed components as required by this Division.

#### (17) WA-3112 Owner

The Owner, as used in this Division, is the organization that assumes title to the transportation or storage component upon delivery by the Certificate Holder.

### WA-3113 NPT Certificate Holder

(17)

(a) The NPT Certificate Holder is the organization that fabricates components and/or parts in accordance with the requirements of the Fabrication Specification. The NPT Certificate Holder obtains an N-type Certificate of Authorization issued by the Society, completes the appropriate Data Report Form, and applies a Certification Mark to the items they fabricate as required by this Division.

(b) N3 Certificate Holders may perform the duties of an NPT Certificate Holder provided these activities are within the scope of their Certificate of Authorization.

### WA-3120 AUTHORIZATION

#### WA-3121 Types of Authorization

[Table WA-8100-1](#) lists the types of certificates issued by the Society and indicates the responsibilities of each Certificate Holder.

### WA-3122 Subcontracted Services

(a) Services may be subcontracted that are both within and beyond the scope of this Division. There are no requirements for the subcontracting of services beyond the scope of this Division. Services covered by this Division may either be of a type for which the Society issues Certificates, or may be of the type for which the Society does not issue a Certificate. Subcontracts for activities for which Certificates are required shall be made only to Certificate Holders. The Certificate Holder may subcontract to another organization the surveying and auditing of his subcontractors and Material Organizations, but must retain the responsibility for these activities and for the qualification of these subcontractors and Material Organizations.

(b) An N3 Certificate Holder may subcontract the fabrication of parts to a Section III, Division 1 Class 1 NPT Certificate Holder provided the scope of work is included in the scope of the subcontractor's N-type Certificate of Authorization.

(c) The Certificate Holder shall describe in his Quality Assurance Manual the manner in which he controls and accepts the responsibility for the subcontracted activities that are not required by this Division to be subcontracted to a Certificate Holder.



**(17) WA-3123 Subcontracted Calibration Services**

As an alternative to survey and audit of suppliers of subcontracted calibration services, a Certificate Holder, Material Organization, or approved supplier may accept accreditation by accrediting bodies recognized by the International Laboratory Accreditation Cooperation (ILAC), Mutual Recognition Arrangement (MRA), provided the requirements of (a) through (d) are met.

(a) A documented review of the supplier's accreditation shall be performed and shall include verification

(1) that the accreditation is to ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories, from an accredited body recognized by the ILAC MRA

(2) that the published scope of accreditation for the calibration laboratory covers the needed measurement parameters, ranges, and uncertainties

(b) The procurement documents shall specify

(1) that the service must be provided in accordance with the accredited ISO/IEC 17025:2005 program and scope of accreditation

(2) that the calibration certificate/report shall include identification of the laboratory equipment/standards used

(3) that the calibration certificate/report shall include as-found calibration data when calibrated items are found to be out-of-tolerance

(4) that the service supplier shall not subcontract the service to any other supplier

(5) that the Certificate Holder, Material Organization, or approved supplier must be notified of any condition that adversely impacts the laboratory's ability to maintain the scope of accreditation

(6) additional technical and quality requirements, as necessary, based on a review of the procured scope of services, including but not limited to, tolerances, accuracies, ranges, and industry standards.

(c) At receipt inspection, the Certificate Holder, Material Organization, or approved supplier shall be responsible for validating that the supplier's documentation certifies

(1) that the subcontracted calibration was performed in accordance with the supplier's ISO/IEC 17025:2005 program and scope of accreditation

(2) conformance to the procurement document's requirements

(d) This activity shall be documented in the Certificate Holder's Quality Assurance Program, Material Organization's Quality System Program Manual, or approved supplier's quality program.

**(17) WA-3124 Subcontracted Testing Services**

As an alternative to survey and audit of suppliers of subcontracted services, a Certificate Holder, Material Organization, or approved supplier may accept accreditation by accrediting bodies recognized by the International

Laboratory Accreditation Cooperation (ILAC), Mutual Recognition Arrangement (MRA), provided the requirements of (a) through (d) are met.

(a) A documented review of the supplier's accreditation shall be performed and shall include verification

(1) that the accreditation is to ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories, from an accredited body recognized by the ILAC MRA

(2) that the published scope of accreditation for the testing laboratory covers the needed testing services including test methodology and tolerances/uncertainties

(b) The procurement documents shall specify

(1) that the service must be provided in accordance with the accredited ISO/IEC 17025:2005 program and scope of accreditation

(2) that the service supplier shall not subcontract the service to any other supplier

(3) that the Certificate Holder, Material Organization, or approved supplier must be notified of any condition that adversely impacts the laboratory's ability to maintain the scope of accreditation

(4) additional technical and quality requirements, as necessary, based on a review of the procured scope of services, including but not limited to, tolerances, accuracies, ranges, and industry standards

(c) At receipt inspection, the Certificate Holder, Material Organization, or approved supplier shall be responsible for validating that the supplier's documentation certifies

(1) that the subcontracted testing was performed in accordance with the supplier's ISO/IEC 17025:2005 program and scope of accreditation

(2) conformance to the procurement document's requirements

(d) This activity shall be documented in the Certificate Holder's Quality Assurance Program, Material Organization's Quality System Program Manual, or approved supplier's quality program.

**WA-3130 WELDING AND SUBCONTRACTING OF WELDING****WA-3131 Welding During Construction**

This Division requires that all welding during construction be done only by an organization holding the N-type Certificate of Authorization appropriate to the scope of welding to be performed. A Certificate Holder may engage individuals by contract for their services as welders or welding operators at the location shown on the Certificate, provided the conditions of (a) through (f) below are met. This is an acceptable method of complying with Section IX requirements concerning responsibility for welding.

(a) The work performed by such welders and welding operators is within the scope of the Certificate.



(b) The conditions governing the use of such welders and welding operators are contained in the Quality Assurance Manual of the Certificate Holder. The Quality Assurance Program (WA-3372 and WA-3460) shall include a requirement for direct supervision and direct technical control of the welders and welding operators by the Certificate Holder during such welding operations, and this program shall be acceptable to the Certificate Holder's Authorized Inspection Agency (WA-5121) performing the inspections.

(c) The welding procedures have been properly qualified by the Certificate Holder, and Code responsibility for such procedures is retained by the Certificate Holder.

(d) Welders and welding operators are qualified by the Certificate Holder to perform such procedures.

(e) The Certificate Holder shall have contractual control of the welding operation, including authority to assign or remove welders and welding operators at his discretion.

(f) The Certificate Holder shall be responsible for Code compliance of the completed item including stamping with the Certification Mark and providing the completed appropriate Data Report Form.

## **WA-3300 RESPONSIBILITIES OF AN N3 CERTIFICATE HOLDER**

### **(17) WA-3320 CATEGORIES OF THE N3 CERTIFICATE HOLDER'S RESPONSIBILITIES**

The N3 Certificate Holder's responsibilities include the following:

(a) obtaining an N3 Certificate of Authorization (WA-3330);

(b) compliance with this Division (WA-3340);

(c) achievement of structural integrity (WA-3340);

(d) establishing the Code Editions and Code Cases to be used in the Design Specification, and determining they are acceptable to the regulatory and jurisdictional authorities (WA-1140);

(e) developing and certifying a Design Specification (WA-3351);

(f) evaluating the loads applied to components;

(g) provision of a Design Report (WA-3350) including:

(1) stress analysis for parts (WA-3353)

(2) reconciliation of Design Drawing changes with the Design Report (WA-3355)

(3) certification of the Design Report (WA-3356);

(h) preparing and certifying the Fabrication Specification (WA-3360);

(i) providing the Certified Fabrication Specification to the fabricator (WA-3361.4);

(j) providing and correlating the Certified Design Specification, Certified Design Report and Certified Fabrication Specification to the Owner;

(k) making available the Certified Design Specification and documentation of review to the Inspector (WA-3358);

(l) making available to the Inspector the Certified Design Report and other documents required by this Division and those requested by the Inspector to assure compliance with Code requirements;

(m) obtaining an agreement with an Authorized Inspection Agency (WA-8130);

(n) establishing and maintaining a Quality Assurance Program (WA-4130):

(1) documenting a Quality Assurance Program (WA-3372);

(2) filing the Quality Assurance Program (WA-3373);

(3) qualification of Material Organizations and suppliers of subcontracted services (WA-3371);

(o) review of Certified Material Test Reports and Certificates of Compliance for materials used by him (WA-1220);

(p) documentation of the review and approval of materials used by him [WA-1140(d)];

(q) preparation, accumulation, control, and protection of required records while in his custody [WA-4134(b)];

(r) Data Reports (WA-3380);

(s) subcontracting (WA-3122) for materials, design, fabrication, examination, testing, and inspection. The N3 Certificate Holder shall retain overall responsibility, including certification and stamping;

(t) review of the Design Report (WA-3357).

### **WA-3330 OBTAINING A CERTIFICATE**

(17)

An N3 Certificate (WA-8100) shall be obtained for construction of components intended to be in compliance with the requirements of this Division and to be stamped with a Certification Mark with N3 Designator. The N3 Certificate Holder may do all the work of an NPT Certificate Holder, provided that the scope of work is included in this Certificate.

### **WA-3340 COMPLIANCE WITH THIS DIVISION**

(17)

The N3 Certificate Holder has the responsibility for assuring that the construction of a component to be stamped with the Certification Mark with N3 Designator meets all the requirements of this Division.

### **WA-3350 DESIGN DOCUMENTS**

#### **WA-3351 Design Specifications**

(17)

**WA-3351.1 Provision and Correlation.** It is the responsibility of the N3 Certificate Holder to prepare, certify and issue the Design Specification for a component. The N3 Certificate Holder shall also be responsible for the correlation of all Design Specifications. Separate Design Specifications are not required for parts that form part of a component when they are included in the Design Specification for the component (WA-1230).

**WA-3351.2 Contents of Design Specifications.** The Design Specifications shall contain sufficient detail to provide a complete basis for design and construction in accordance with this Division. Such requirements shall not result in design or construction that fails to conform with the rules of this Division. All Design Specifications shall include (a) through (i) below.

(a) the functions and boundaries of the items covered (WA-3351.3);

(b) the design requirements (Article WA-2000);

(c) the environmental conditions, including radiation;

(d) the Code classification(s) (TC, SC, both TC and SC, or ISS) of the components covered;

(e) material requirements including impact test requirements;

(f) examination and testing requirements for containment closure welds;

(g) the effective Code Edition and Code Cases to be used for construction;

(h) the maximum allowable leakage rate; and

(i) mechanical loads, such as drop and handling, that must be considered in the design.

**WA-3351.3 Boundaries of Jurisdiction.** In order to define the boundaries of components with respect to adjacent components and other structures, the Design Specifications shall include the boundary of the component as given in WB-1130, WC-1130, or WD-1130, as appropriate.

**WA-3351.4 Certification of the Design Specifications.** The Design Specifications shall be certified to be correct and complete and to be in compliance with the requirements of WA-3351 by one or more Certifying Engineers, competent in the applicable field of design and related transportation or storage component requirements and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII.

**WA-3351.5 Availability of the Design Specification.** The N3 Certificate Holder shall make a copy of the completed Design Specification available to the Inspector and the Owner.

## **WA-3352 Requirements for Design Documents**

### **(17) WA-3352.1 Design Documents.**

(a) The Design Report and the Design Drawings used for construction are the primary Design Documents. The design shown by the Design Drawings shall comply with the Design Specification and the rules of this Division and shall be in agreement with the other Design Documents. The Design Report shall demonstrate the adequacy of the design with regard to the structural integrity of the component.

(b) The N3 Certificate Holder may subcontract stress analysis or complete design of all or a portion of a component. However, the N3 Certificate Holder is responsible for the design of the component and for the Design Documents.

(c) The Design Drawings shall be in agreement with the Design Report before it is certified (WA-3356) and shall be identified and described in the Design Report.

(d) When the design includes parts, including piping that is to be purchased from an NPT Certificate Holder or valves that are to be purchased from a Division 1 N Certificate Holder, the N3 Certificate Holder shall incorporate the Design Documents for the purchased items into the Design Documents of the component.

(e) The N3 Certificate Holder shall demonstrate the adequacy of the design of any item comprising the boundary of the component to meet the requirements of the Design Specification and this Division. This demonstration shall be included in the Design Report for the component.

### **WA-3353 Design Output Documents for Parts**

When the N3 Certificate Holder purchases parts from an NPT Certificate Holder, it is the responsibility of the N3 Certificate Holder to provide or cause to be provided the calculations for the parts and to incorporate them into the Design Output Documents.

### **WA-3355 Modification of Document and Reconciliation With Design Report**

Any modification of any document used for design from the corresponding document used for design analysis, shall be reconciled with the Design Report by the person or organization responsible for the design. A revision or addenda to the Design Report shall be prepared and certified (WA-3356) to indicate the basis on which this has been accomplished. All such revised documentation shall be filed with the completed Design Report.

### **WA-3356 Certification of Design Report**

(17)

(a) The Design Report shall be certified to be correct and complete and to be in accordance with the requirements of WA-3352 by one or more Certifying Engineers competent in the applicable field of design and related transportation or storage component requirements and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII. The Design Report shall be certified only after all design requirements of this Division have been met. Such Certifying Engineers shall be other than the individuals certifying the Design Specification (WA-3351.4), and they are not required by these rules to be independent of the organization holding the Certificate.

(b) It is the intent of this Division that the certification of the Design Report shall in no way relieve the N3 Certificate Holder of the responsibility for ensuring that the design of the component meets the conditions stated in the Design Specification and this Division.

**(17) WA-3357 Review of Design Report**

(a) A review of the Design Report shall be made by the N3 Certificate Holder certifying the Design Specification to determine that all the design and loading conditions identified in the Design Specification have been considered, and that the acceptance criteria established in the Design Specification and this Division have been met. This review shall be made by individuals who did not prepare the Certified Design Report.

(b) Documentation shall be provided to the Owner to indicate that the review required by (a) above has been completed.

(c) A copy of the documentation required by (b) above shall be attached to, and become part of, the Design Report.

**WA-3358 Availability of Design Reports**

The N3 Certificate Holder shall make a copy of the completed Certified Design Report, including documentation of the review when required (WA-3357), and drawings used for construction available to the Inspector.

**WA-3360 FABRICATION SPECIFICATION****(17) WA-3361 Provisions of the Fabrication Specification**

**WA-3361.1 Responsibility.** It is the responsibility of the N3 Certificate Holder to prepare, certify, and issue the Fabrication Specification for components. The N3 Certificate Holder shall be responsible for the correlation of all Data Reports for the component. Separate Fabrication Specifications are not required for parts when they are included in the Fabrication Specification for the component.

**WA-3361.2 Contents of the Fabrication Specification.** The Fabrication Specification shall be based upon the Design Specification and the Design Output Documents, and shall contain sufficient detail, including forming and fabrication tolerances, to provide a complete basis for fabrication in accordance with this Division. Fabrication Specifications for components shall include the examination and testing requirements for closure welds. Such requirements shall not result in fabrication that fails to conform with the Design Specification, Design Documents and the rules of this Division.

**WA-3361.3 Certification of the Fabrication Specification.** The Fabrication Specification shall be certified to be correct and complete and to be in compliance with the requirements of WA-3361.2 by one or more Certifying Engineers, competent in the requirements of this Division and the field of Division 3 component fabrication and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII. Such Registered Professional Engineers are not required to be independent of the organization preparing the Fabrication Specification.

**WA-3361.4 Filing the Fabrication Specification.** Fabrication Specification in its entirety shall become the principal document governing fabrication and shall be available at the location of fabrication during the complete fabrication process.

**WA-3361.5 Availability of the Fabrication Specification.** The N3 Certificate Holder shall make a copy of the completed Fabrication Specification used for fabrication available to the Inspector and the Owner.

**WA-3370 RESPONSIBILITY FOR QUALITY ASSURANCE****WA-3371 Scope of Responsibilities**

The N3 Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services (WA-3122), including nondestructive examination contractors and Material Organizations. Material Organizations holding Quality System Certificates (Materials), and Certificate Holders whose scope includes the supply or manufacture of materials, need not be surveyed or audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate of Authorization need not be surveyed nor audited for work within the scope of the subcontractor's Certificate.

An N3 Certificate Holder may qualify vendors of subcontracted services (WA-3122) other than those requiring a Certificate of Authorization for another Certificate Holder doing work for that N3 Certificate Holder. The qualification documentation shall be supplied to the other Certificate Holder prior to their use of the subcontracted service.

**WA-3372 Documentation of Quality Assurance Program**

The N3 Certificate Holder shall be responsible for documenting its Quality Assurance Program (WA-4134).

**WA-3373 Filing of Quality Assurance Manual**

The N3 Certificate Holder shall file with the Authorized Inspection Agency (WA-5121) copies of the Quality Assurance Manual. The N3 Certificate Holder shall keep a copy on file available to the Inspector (WA-5123).

**WA-3380 DATA REPORTS**

The N3 Certificate Holder shall certify compliance with this Division by signing the appropriate Data Report and application of the Certification Mark (Article WA-8000).

**WA-3390 N3 CERTIFICATE HOLDER'S RESPONSIBILITY FOR RECORDS**

The N3 Certificate Holder shall be responsible for maintaining the records identified in [Tables WA-4134.17-1](#) and [WA-4134.17-2](#) during construction. Upon completion of construction, these records shall be transferred to the Owner.

**WA-3400 RESPONSIBILITIES OF AN NPT CERTIFICATE HOLDER****WA-3420 CATEGORIES OF AN NPT CERTIFICATE HOLDER'S RESPONSIBILITIES**

The responsibilities of an NPT Certificate Holder include the following:

- (a) obtaining an NPT Certificate ([WA-3430](#));
- (b) compliance with this Division ([WA-3440](#));
- (c) qualification of Material Organizations and suppliers of subcontracted services ([WA-3451](#));
- (d) establishing and maintaining a Quality Assurance Program ([WA-3460](#));
- (e) documenting a Quality Assurance Program ([WA-3460](#));
- (f) filing the Quality Assurance Manual ([WA-3461](#));
- (g) Data Reports ([WA-3470](#));
- (h) obtaining an agreement with an Authorized Inspection Agency ([WA-8130](#));
- (i) fabricating parts assigned to him in accordance with the Fabrication Specification(s) and this Division;
- (j) preparing fabrication procedures and shop drawings;
- (k) making available to the Inspector the documents specified by this Division and those requested by him to assure compliance with Code requirements;
- (l) review of Certified Material Test Reports and Certificates of Compliance for materials used by him ([WA-1220](#));
- (m) preparation, accumulation, control, and protection of required records while in his custody [[WA-4134\(b\)](#) and [NCA-4134.17](#)];
- (n) documentation of review and approval of material used by him as permitted by [WA-1140\(d\)](#).

**WA-3430 OBTAINING A CERTIFICATE**

An NPT Certificate ([WA-8100](#)), listing Division 3 in its scope, shall be obtained for the fabrication of any item intended to be in compliance with the requirements of this Division and to be stamped with a Certification Mark with NPT Designator.

**WA-3440 COMPLIANCE WITH THIS DIVISION**

The NPT Certificate Holder shall have all work performed in accordance with the applicable requirements of this Division.

**WA-3450 RESPONSIBILITY FOR QUALITY ASSURANCE****WA-3451 Scope of Responsibilities**

(a) The NPT Certificate Holder shall be responsible for surveying, qualifying, and auditing suppliers of subcontracted services ([WA-3122](#)) including nondestructive examination contractors and Material Organizations. Material Organizations holding Quality System Certificate (Materials), and Certificate Holders whose scope includes the supply or manufacture of materials, need not be surveyed or audited for work or material covered by the scope of their Certificate. Subcontractors holding an appropriate Certificate of Authorization need not be surveyed nor audited for work within the scope of the subcontractor's Certificate.

(b) An NPT Certificate Holder may qualify vendors of subcontracted services other than those requiring a Certificate for another Certificate Holder doing work for that NPT Certificate Holder. The qualification documentation shall be supplied to the other Certificate Holder prior to their use of the subcontracted service.

**WA-3460 DOCUMENTATION OF QUALITY ASSURANCE PROGRAM**

The NPT Certificate Holder shall be responsible for documenting its quality assurance program.

**WA-3461 Filing of Quality Assurance Program (17)**

The NPT Certificate Holder shall file with the Authorized Inspection Agency ([WA-5121](#)) copies of the Quality Assurance Manual. The NPT Certificate Holder shall keep a copy on file and available to the Inspector ([WA-5123](#)).

**WA-3470 DATA REPORT**

The NPT Certificate Holder shall certify compliance with this Division by signing the appropriate Data Report Form and applying the appropriate stamping ([Article WA-8000](#)).

**WA-3800 METALLIC MATERIAL (17)****WA-3810 SCOPE AND APPLICABILITY**

The requirements of [WA-3800](#) provide for various entities known as Certificate Holders, Material Organizations ([NCA-3820](#)), and approved suppliers ([NCA-4255.3](#)). These entities are involved in the performance of operations, processes, and services related to the procurement, manufacture and supply of material, source material, and unqualified source material, as defined in the Glossary ([NCA-9200](#)).

**WA-3811 Limitations**

The following limitations apply to approved suppliers:

(a) Approved suppliers shall not approve other suppliers of materials or services that affect materials.

(b) Approved suppliers may adopt a limited scope quality system program as approved by the Certificate Holder or Material Organization [NCA-4255.3(b)].

#### **WA-3812 Exclusions**

Material falling within the small products exclusion of [WB-2610](#), [WC-2610](#), or [WD-2610](#), as appropriate or material that is allowed by this Section to be furnished with a Certificate of Compliance, is exempted from the requirements of [WA-3800](#), except:

(a) Certified Material Test Reports or Certificates of Compliance shall meet the requirements of NCA-3862.1.

(b) For construction of components meeting the requirements of this Division, material identification and marking shall meet the requirements of NCA-4256.3.

#### **WA-3820 MATERIAL ORGANIZATIONS**

A Material Organization shall be certified or qualified in accordance with NCA-3820 through NCA-3842.2, and NCA-4250 through NCA-4259.2. Material Certification shall be in accordance with NCA-3860.



# ARTICLE WA-4000 QUALITY ASSURANCE

## WA-4100 REQUIREMENTS

### (17) WA-4110 SCOPE AND APPLICABILITY

(a) This Article sets forth the requirements for planning, managing, and conducting Quality Assurance Programs for controlling the quality of activities performed under this Division and the rules governing the evaluation of such Programs prior to the issuance of Certificates for construction of Division 3 components. The Quality Assurance requirements for Material Organizations are provided in [WA-3800](#). Certificate Holders are advised to consult other regulations for quality assurance requirements governing activities beyond the scope of this Division.

(b) N3 and NPT Certificate Holders shall comply with the requirements of ASME NQA-1, "Quality Assurance Requirements for Nuclear Facility Applications," Part I,<sup>3</sup> as modified and supplemented in [WA-4120\(d\)](#) and [WA-4134](#).

### (17) WA-4120 DEFINITIONS

- (a) The definitions in [Article WA-9000](#) shall apply.  
 (b) The definitions in Article NCA-9000 shall apply unless defined in [Article WA-9000](#)  
 (c) The terms and definitions of NQA-1 shall apply unless defined in [Article WA-9000](#) or Article NCA-9000.

(d) For the following terms, which are defined in both NQA-1 and [Article WA-9000](#) or Article NCA-9000, the definitions in [Article WA-9000](#) or Article NCA-9000 shall apply, as determined by (b).

- (1) item
- (2) Owner
- (3) quality assurance
- (4) repair
- (5) rework
- (6) service
- (7) use-as-is
- (8) nonconformance

## WA-4130 ESTABLISHMENT AND IMPLEMENTATION

### WA-4131 Material Organizations

The requirements of NCA-3800 and [WA-3800](#) apply.

### WA-4134 Division 3 Certificate Holders

- (a) Provisions of NCA-4134 apply to N3 and NPT Certificate Holders.  
 (b) For this Division, [Tables WA-4134.17-1](#) and [WA-4134.17-2](#) shall be used in place of [Tables NCA-4134.17-1](#) and [NCA-4134.17-2](#) to identify lifetime and nonpermanent records.

**Table WA-4134.17-1  
Lifetime Quality Assurance Records**

Record	Record
1. Index to lifetime records (NCA-4134.17)	9. Final nondestructive examination reports
2. Code Data Reports (WA-8400)	10. Repair records when required by Code (Article WB-4000, Article WC-4000, Article WD-4000)
3. Design Specification (WA-3300)	11. Weld procedures
4. Design Documents (WA-3300)	12. Audit and survey reports (NCA-4134.18)
5. As-built drawings (WA-3300)	13. Process sheets, travelers, or checklists
6. Certified Material Test Reports (CMTR) and documentation providing traceability to location used, if required (WB-4100, WC-4100, WD-4100)	14. Joint-welder identification records when such records are used in lieu of physical marking of welds (WB-4300, WC-4300, WD-4300)
7. Heat treatment records [Note (1)]	15. Fabrication Specification (WA-3300)
8. Final hydrostatic and pneumatic test results (Article WB-6000, Article WC-6000)	16. Casting Plan (WB-2126, WC-2126)

GENERAL NOTE: Nonconformance reports that affect those records listed shall be incorporated into the record or be retained with the records.

NOTE:

(1) Either heat treatment charts or certified summaries of time and temperature data may be provided. These data may be included as part of the CMTR.

**Table WA-4134.17-2  
Nonpermanent Quality Assurance Records**

Record	Retention Period
1. QA Program Manual	3 yr after superseded or invalidated
2. Design procurement and QA procedures (NCA-4134.5)	3 yr after superseded or invalidated
3. NDE procedures (WB-5112, WC-5112, WD-5112)	10 yr after superseded or invalidated
4. Personnel qualification records (WB-5520, WC-5520, WD-5520 and WB-4322, WC-4322, WD-4322)	3 yr after superseded or invalidated
5. Purchase orders	10 yr after superseded or invalidated
6. Final radiographs not covered in Table WA-4134.17-1	10 yr after completion
7. Calibration records (NCA-4134.12)	Until recalibrated

GENERAL NOTE: Nonconformance reports that affect those records listed and are not incorporated into the record shall be retained for the retention period applicable to the record the nonconformance report affects.

# ARTICLE WA-5000 AUTHORIZED INSPECTION

## WA-5100 INTRODUCTION

### WA-5110 APPLICABILITY

This Article provides the requirements for inspection by the Authorized Inspection Agency.

### WA-5120 PERFORMANCE OF INSPECTION

#### WA-5121 Authorized Inspection Agency

(a) The Authorized Inspection Agency shall be accredited by the Society in accordance with the provisions set forth in ASME QAI-1.

(b) The Authorized Inspection Agency shall notify the Society when it enters into an agreement with a Certificate Holder, or whenever an existing agreement is terminated.

Certificate Holder is actively engaged in Section III work. The Supervisor shall be available, as needed, for consultation and support of the local inspection staff. The Supervisor shall maintain supervisory control over one or more Authorized Nuclear Inspectors and shall perform all of the functions and maintain the records required of him in ASME QAI-1.

(b) The portion of a Certificate Holder's Quality Assurance Program that involves Material Organization activities [NCA-3820(c)] shall be audited by the Supervisor at least once each year.

#### WA-5130 ACCESS FOR INSPECTION AGENCY PERSONNEL

#### WA-5131 Access to the Certificate Holder's Facilities

(a) The Certificate Holder shall arrange for the Inspection Agency Personnel to have free access at all times to those locations where Code activities, including those concerned with supply or manufacture of materials, are being performed on an item, when so requested. The Certificate Holder shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when the item will be ready for any required tests or inspections.

(b) The Certificate Holder shall provide personnel to accompany the Authorized Nuclear Inspector Supervisor during his required audits.

## WA-5200 DUTIES OF INSPECTOR

### WA-5210 GENERAL INSPECTION DUTIES

(a) The Inspector who performs the detailed inspections in compliance with this Division shall witness or otherwise verify all examinations and make all inspections required by this Division. The Inspector shall also make any other inspections and witness or verify (including making measurements) any other examinations and additional investigations which, in the Inspector's judgment, are necessary to ascertain whether the item being inspected has been constructed (WA-1110) in compliance with the rules of this Division. Parts, including piping sub-assemblies, shall be in accordance with the accepted documents (WA-3300).

(b) The duties of the Inspector shall not be interpreted by virtue of these rules to extend to any construction requirements beyond those of this Division that may be set

#### (17) WA-5122 Authorized Nuclear Inspector Supervisor

The Authorized Inspection Agency shall employ Authorized Nuclear Inspection Supervisors, qualified in accordance with ASME QAI-1, to supervise the Inspectors.

#### WA-5123 Authorized Nuclear Inspector

The Authorized Inspection Agency shall also employ Authorized Nuclear Inspectors qualified in accordance with the latest revision of ASME QAI-1, to perform inspections required by this Division. The inspections required by this Division shall be performed by an Authorized Nuclear Inspector. Any reference to Inspector throughout this Division shall mean Authorized Nuclear Inspector. The Authorized Nuclear Inspector shall not be in the employ of a Certificate Holder.

#### (17) WA-5125 Duties of Authorized Nuclear Inspector Supervisors

(a) Supervisors, in conjunction with Inspectors employed by the same Authorized Inspection Agency (WA-5121), shall participate in the Society's review of the applicant's Quality Assurance Program (WA-8160). In those cases where the Supervisor performs the functions of the Inspector, he may represent both during the review of the Program. A Supervisor designated by the Authorized Inspection Agency shall review and accept any proposed modifications to Quality Assurance Manuals before they are put into effect. The Authorized Nuclear Inspector Supervisor shall audit the Inspector's performance at least twice per year at locations where the



forth in the Fabrication Specifications (WA-3360). However, such requirements shall not result in construction which fails to conform with the requirements of this Division.

#### **WA-5220 CATEGORIES OF INSPECTOR'S DUTIES**

The duties of the Inspector shall include but not necessarily be limited to those given in (a) through (i) below.

(a) verifying the scope of work to be performed [WA-5230(a)];

(b) monitoring of the Certificate Holder's Quality Assurance Program including subcontracted activities (WA-5240);

(c) reviewing of the Certificate Holder's qualification records (WA-5250);

(d) verifying materials (WA-5260);

(e) witnessing or verifying in-process fabrication, non-destructive examination, and tests (WA-5270);

(f) witnessing final testing (WA-5280);

(g) reviewing and signing Data Reports (WA-5290);

(h) reviewing drawings and inspecting in accordance with them;

(i) performing all other duties specifically required in ASME QAI-1.

#### **(17) WA-5230 SCOPE OF WORK, DESIGN SPECIFICATIONS, DESIGN REPORTS, AND FABRICATION SPECIFICATIONS**

(a) The Inspector shall verify that the scope stated in the N-type Certificate of Authorization includes the work to be performed.

(b) The Inspector shall verify that the Design Specification, Design Reports, and Fabrication Specifications, when required, are on file and that they have been properly certified in accordance with WA-3351.4, WA-3356, and WA-3361.3.

(c) The Inspector shall not be held responsible for the scope or adequacy of the Design Specifications, for the completeness or accuracy of the Design Report or calculations or for the qualification of Certifying Engineers certifying documents in compliance with the requirements of this Division.

#### **WA-5240 QUALITY ASSURANCE PROGRAMS**

##### **WA-5241 Stipulation of Inspections Prior to Issuance of Process Sheets or Controls**

Prior to the issuance of process sheets or controls required by NCA-4134.9, the Certificate Holder shall review them and the applicable drawings with the Inspector, who shall then stipulate the inspections he intends to make in order to fulfill the requirements of WA-5210.

#### **WA-5242 Monitoring of Quality Assurance Programs**

The Inspector shall monitor the performance of the Certificate Holder for conformity to the requirements of their Quality Assurance Program accepted by the Society. The Inspector shall verify that all changes to the Quality Assurance Manual have been accepted by the Authorized Inspection Agency before they are put into effect.

#### **WA-5243 Process Control Checklist**

The Inspector shall indicate on the Certificate Holder's process sheets or checklist his concurrence that compliance has been attained at each point stipulated by him (WA-5241).

#### **WA-5250 QUALIFICATION RECORDS**

##### **WA-5251 Review of Qualification Records**

The Inspector shall review the qualification records of the Certificate Holder.

#### **WA-5253 Welding Procedures**

The Inspector shall assure himself that the welding procedures employed in fabrication have been qualified under the provisions of this Division. The Certificate Holder shall submit evidence to the Inspector that these requirements have been met. When there is a specific reason to question the welding procedure, the Inspector may require requalification as a requirement for the procedure to be used on work subject to his inspection.

#### **WA-5254 Welders and Welding Operators**

The Inspector shall assure himself that all welding is performed by welders or welding operators qualified under the provisions of this Division. The Certificate Holder shall make available to the Inspector a certified copy of the record of performance qualification tests of each welder and welding operator as evidence that these requirements have been met. When there is a specific reason to question the ability of the welder or the welding operator to make welds that meet the requirements of the specification, the Inspector may require requalification before the welder or welding operator is permitted to continue welding on work subject to his inspection. The Inspector shall also assure himself that each welder and welding operator has been assigned an identifying symbol and that such symbols are regularly and consistently applied when required by this Division.

#### **WA-5255 Examination Procedures**

The Inspector shall assure himself that the examination and testing procedures required by this Division have been qualified. When there is a specific reason to question whether the examination or testing procedure requirements are being met, the Inspector may require requalification of the procedure.

### **WA-5256 Nondestructive Examination Personnel**

The Inspector has the duty to verify the qualification and certification of nondestructive examination personnel employed by the Certificate Holder and has the duty to monitor the nondestructive examination activities and require requalification of any personnel when there is reason to question the performance of that person. In addition, the Inspector shall monitor the Certificate Holder's Quality Assurance Program as it relates to the nondestructive examination activities of Material Organizations, and NDE subcontractors that the Certificate Holder qualified.

### **WA-5260 MATERIALS, PARTS, AND HEAT TREATMENT**

#### **WA-5261 Inspection of Materials for Compliance**

The Inspector shall assure himself that all materials used comply with all applicable requirements of this Division. The Certificate Holder shall make available to the Inspector certified reports of the results of all tests performed in accordance with (a) and (b) below:

(a) the material specifications;

(b) the requirements in the applicable materials Articles of this Division, including certified reports of the results of all required tests and examinations performed.

#### **(17) WA-5262 Dimensional Check**

The Inspector shall satisfy himself:

(a) that the item is being constructed within the tolerance required by the Design Specification, Design Drawings, and Fabrication Specifications, and this Division;

(b) that head and shell sections conform to the prescribed shape and meet the thickness requirements;

(c) that fittings and attachments to be welded to the component fit properly to the surface of that component. If required by the Inspector, the Certificate Holder shall make available accurately formed templates for his use.

#### **WA-5263 Check of Heat Treatment Practice**

The Inspector shall satisfy himself that all heat treatment operations required by this Division are correctly performed and that the temperature readings and gradients conform to the requirements.

### **WA-5270 EXAMINATIONS AND TESTS**

The Inspector shall witness in-process fabrication non-destructive examinations and destructive tests, when feasible; alternatively, he shall check the examination and test records to determine the acceptability of the items involved.

### **WA-5280 FINAL TESTS**

The Inspector shall witness final tests required by this Division and examinations performed during such tests by the Certificate Holder.

### **WA-5290 DATA REPORTS**

The appropriate Data Reports prepared by the Certificate Holder shall be reviewed and signed by the Inspector only after they have been certified by a responsible representative of the Certificate Holder and after he has satisfied himself that all requirements of this Division have been met and that each Data Report certified is a correct record.

### **WA-5300 RESPONSIBILITIES OF THE AUTHORIZED INSPECTION AGENCY**

The responsibilities of the Authorized Inspection Agency shall include but not necessarily be limited to those given in (a) through (j) below.

(a) Maintain a staff of Authorized Nuclear Inspectors and Authorized Nuclear Inspector Supervisors (WA-5122 and WA-5123).

(b) Make agreements with Certificate Holders for inspection service (WA-5121 and WA-8130). Notify the Society whenever such agreements are terminated (WA-5121).

(c) Provide for participation in the Society's review of the applicant's Quality Assurance Program (WA-5125).

(d) Provide for the review and acceptance of any proposed modifications to Quality Assurance Manuals before they are put into effect (WA-5125).

(e) Review and accept the Certificate Holder's method of securing the nameplate to components to which, because of size or other considerations, the nameplate cannot be directly attached [WA-8220(b)].

(f) Review and accept the Certificate Holder's alternative method of identification, including the unique method of marking of components to which, because of size or other considerations, nameplates cannot be directly attached [WA-8220(b)].

(g) Review and accept the Certificate Holder's alternative method of marking of parts (WA-8230).

(h) Review and accept the Certificate Holder's procedures for alternative stamping requirements (WA-8311).

(i) Determine by agreement with the Certificate Holder the sequence for stamping and the completion of the Code Data Report [WA-8310(c)].

(j) And all other duties specifically required in ASME QAI-1.

# ARTICLE WA-7000 REFERENCE STANDARDS

## WA-7100 GENERAL REQUIREMENTS

Dimensions of standard products shall comply with the dimensional standards listed in [Table WA-7100-1](#) when the standard is referenced in the Division 3 Subsection. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by [Article WB-3000](#), [Article WC-3000](#), or [Article WD-3000](#) for a specific component.

The standards and specifications referenced in the text of each Subsection are listed in [Table WA-7100-2](#). Where reference is made within Division 3 to requirements, that are part of the ASME Boiler and Pressure Vessel Code, they are not included in this Table.

**Table WA-7100-1  
Dimensional Standards**

Standard ID	Published Title	Section III Referenced Edition	Other Acceptable Editions
<b>Pipes and Tubes</b>			
ASME B36.10M	Welded and Seamless Wrought Steel Pipe	2004	2000, 1996, 1985
ASME B36.19M	Stainless Steel Pipe	2004	1985 (R1994)
<b>Fittings, Flanges, and Gaskets</b>			
ASME B16.5	Pipe Flanges and Flanged Fittings	2009	2003, 1998, 1988, 1981
ASME B16.9 <a href="#">[Note (1)]</a>	Factory-Made Wrought Butt-Welding Fittings	2007	2001, 1993, 1986, 1981
ASME B16.11	Forged Fittings, Socket-Welding and Threaded	2009	2001, 1996, 1980
ASME B16.20	Metallic Gaskets for Pipe Flanges: Ring-Joint Spiral Wound and Jacketed	2007	2000, 1998, 1984
ASME B16.21	Nonmetallic Flat Gaskets for Pipe Flanges	2005	1992
ASME B16.25	Butt-Welding Ends	1997	1986
ASME B16.47	Large Diameter Steel Flanges	2006	1998
MSS SP-43	Wrought and Fabricated Butt-Welding Fittings for Low Pressure, Corrosion Resistant Applications	2008	1991 (R1996)(R2001), 1982 (R1986), 1982
<b>Bolting</b>			
ASME B18.2.1 <a href="#">[Note (2)]</a>	Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head and Lag Screws	2010	1999, 1981
ASME/ANSI B18.2.2 <a href="#">[Note (2)]</a>	Square and Hex Nuts (Inch Series)	1987 (R1999)	1987, 1972 (R1983)
ASME B18.3 <a href="#">[Note (2)]</a>	Socket Cap, Shoulder, and Set Screws, Hex and Spine Keys (Inch Series)	2003	1998, 1986, 1982
<b>Threads</b>			
ASME B1.1 <a href="#">[Note (2)]</a>	Unified Inch Screw Threads (UN and UNR Thread Form)	2003 (R2008)	1989, 1982
ANSI/ASME B1.20.1 <a href="#">[Note (2)]</a>	Pipe Threads, General Purpose (Inch)	1983 (R2006)	1983 (R1992)
ANSI B1.20.3 <a href="#">[Note (2)]</a>	Dryseal Pipe Threads (Inch)	1976 (R2008)	1976 (R1981) (R1982) (R1991) (R1998)

NOTES:

(1) Analysis per ASME B16.9, para. 2.2, is acceptable only for caps and reducers.

(2) These standards are referenced for dimensional purposes only. Any manufacturing or inspection requirements contained in item are not mandatory. The SA or SB Material Specification specifies the applicable manufacturing and inspection requirements.

**Table WA-7100-2  
Standards and Specifications Referenced in Division 3**

Standard ID	Published Title	Section III Referenced Edition
<b>The American Society of Mechanical Engineers (ASME)</b>		
ASME NQA-1	Quality Assurance Requirements for Nuclear Facility Applications	2008, 2009a
ASME QAI-1	Qualifications for Authorized Inspection	Latest
<b>American Society for Nondestructive Testing (ASNT)</b>		
SNT-TC-1A	Personnel Qualification and Certification in Nondestructive Testing	2011
<b>American Society for Testing and Materials (ASTM)</b>		
ASTM E23	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials	2002a
ASTM E185	Standard Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels	2010
ASTM E186	Standard Reference Radiographs for Heavy-Walled (2 to 4 <sup>1</sup> / <sub>2</sub> -in.) [(51 to 114-mm)] Steel Castings	67, 73, 75, 79
ASTM E208	Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels	1991
ASTM E280	Standard Reference Radiographs for Heavy-Walled (4 <sup>1</sup> / <sub>2</sub> to 12-in.) [(114 to 305-mm)] Steel Castings	68, 72, 75
ASTM E399	Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials	1983, 1990
ASTM E446	Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness	72, 75, or 78
ASTM E604	Standard Test Method for Dynamic Tear Testing of Metallic Materials	1983
ASTM E1820	Standard Test Method for Measurement of Fracture Toughness	2001
ASTM F788	Standard Specification for Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series	2013
ASTM F812	Standard Specification for Surface Discontinuities of Nuts, Inch and Metric Series	2012
<b>American Welding Society (AWS)</b>		
AWS A4.2	Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel	1991
<b>American National Standards Institute (ANSI)</b>		
ANSI N14.5	Leakage Test on Packages for Transportation	1997, 2014

# ARTICLE WA-8000 CERTIFICATES OF AUTHORIZATION, NAMEPLATES, CERTIFICATION MARK, AND DATA REPORTS

**WA-8100 AUTHORIZATION TO PERFORM  
CODE ACTIVITIES**

**WA-8110 GENERAL**

Certificates of Authorization to use the official Certification Mark in [Table WA-8100-1](#) to certify work in this Division will be granted by the Society for a 3-yr period pursuant to the provisions set forth in this Article.

**WA-8120 SCOPE OF AUTHORIZATION**

(a) The Certificate of Authorization ([WA-3120](#)) will identify the facility covered and state the scope of activities for which authorization is granted. The Society may, at its discretion, limit or extend the scope of an authorization to any types or classes of items or to a specific location.

(b) The Society may, at any time, make regulations concerning the issuance and use of Certificates and the Certification Mark as it deems appropriate, and all regulations shall become binding upon the holders of a valid Certificate.

**WA-8130 INSPECTION AGREEMENT REQUIRED**

Certificate Holders shall possess an agreement with an ASME accredited Authorized Inspection Agency to provide inspection and audit services. The agreement with the Authorized Inspection Agency shall be made prior to application for a survey. Certificate Holders shall notify the Society whenever their agreements with an Authorized Inspection Agency are cancelled or changed to another Authorized Inspection Agency.

**Table WA-8100-1  
Authorizations and Certification Mark Issued by the Society for the Construction of Transportation  
and Storage Components and Parts**

(17)

Type of Organization (Code Division)	Scope	Division 1	Division 3	Data Report Form	Notes
N3 or NPT (Div. 3)	Transportation containments	...	Class TC	N-7	(1)
	Storage containments	...	Class SC	N-7	(1)
	Internal support structures	...	Class ISS	N-11	...
N3 or NPT (Div. 3)	Parts	...	Class TC, SC, or ISS	N-9	(1), (2)
	Field closure welds	...	Class TC or SC	N-8	(1)
NPT (Div. 1)	Tubular products welded with filler metal	Class 1 for transportation containments, Class 1 or 2 for storage containments	...	NM-1	(3)
N (Div. 1)	Line valves	Class 1 for transportation containments, Class 1 or 2 for storage containments	...	NPV-1	(4)

NOTES:

- (1) Completed Data Reports for closure welds of containments shall be forwarded to the Owner.
- (2) Data reports for parts shall be forwarded in duplicate to the Certificate Holder of the finished component.
- (3) Material ([WA-1220](#)) shall be documented on a Certified Material Test Report or a Certificate of Compliance in accordance with [Article WB-2000](#), [Article WC-2000](#), or [Article WD-2000](#), as appropriate.
- (4) Line valves shall meet the requirements of Division 1 in their entirety.

**WA-8140 QUALITY ASSURANCE PROGRAM REQUIREMENTS**

It is a requirement that a Certificate Holder have a Quality Assurance Program ([Article WA-4000](#)) that has been evaluated and accepted by the Society.

**(17) WA-8150 APPLICATION FOR AUTHORIZATION**

An Organization desiring a Certificate of Authorization shall apply to the Society upon forms issued by the Society describing the scope of Code activities to be performed.

**WA-8151 Field Operations**

The N3 or NPT Certificate of Authorization may be extended to include field operations such as the completion or repair of components and parts constructed under that authorization. Except as permitted in [WA-8152](#), the Society requires a survey of each field site to assure that the Quality Assurance Program described in the Manual is implemented and enforced.

**WA-8152 Field Operations for Containment Closure Welds**

The N3 or NPT Certificates may be extended to field locations for making final closure welds to loaded spent nuclear fuel or high-level radioactive material containments without a site survey by the Society, provided

(a) the control of materials, special processes, examinations, inspections, tests, and certification at field locations shall be described in the Certificate Holders Quality Assurance Manual, including involvement of the Inspector;

(b) the Certificate Holders Quality Assurance Program has been reviewed and accepted by the Authorized Inspection Agency to confirm (a) above prior to any welding at field locations;

(c) unique identifiers are permanently marked on each of the containment parts that are to be assembled together;

(d) the welds are to be made in accordance with the requirements of the Fabrication Specification; and

(e) the Data Report for each containment includes the unique identifiers of (c) above.

**WA-8153 Shop Assembly**

Shop assembly of components, or components to piping or other items, may be by N-type Certificate Holders if such activities are included within the scope of their N-type Certificate of Authorization.

**WA-8154 Code Activities Prior to Certification**

Code activities performed prior to issuance of an N3 or NPT Certificate of Authorization shall be subject to the acceptance of the Inspector.

**WA-8160 EVALUATION FOR AUTHORIZATION****WA-8161 Evaluation for Certificate of Authorization**

(17)

(a) Applicants for a new or renewed N3 or NPT Certificate of Authorization for construction require a survey of their facilities. The purpose of the survey is to evaluate the applicant's Quality Assurance Manual and the implementation of the Quality Assurance Program.

(b) The extent of the survey will be determined by the Society based on a review of the applicant's intended scope of Code activities described in the application. The acceptance by the Society of the Quality Assurance Program shall not be interpreted to mean endorsement of technical capability to perform design work such as system design or stress analysis. Such capability is implied for the specific component involved by the certification of Design Reports ([WA-3356](#)) by a Certifying Engineer.

(c) Authorization to certify a Data Report or apply a Certification Mark to an item will be granted only after a survey by the Society has satisfactorily demonstrated the adequacy and implementation of the Quality Assurance Program.

**WA-8170 ISSUANCE OF AUTHORIZATION**

Each Certificate Holder shall have agreed that each Certificate and Certification Mark (if one is issued) is at all times the property of the Society, that it will be used according to the rules and regulations of this Division, and that the Certificate and Certification Mark will be promptly returned to the Society upon demand, or when the Certificate Holder discontinues the scope of Code activities covered by his Certificate. The holder of a Certification Mark shall not permit any other party to use its Certificate or Certification Mark. The Society reserves the absolute right to cancel or refuse to renew such authorization, returning fees paid for the prorated unexpired term.

**WA-8180 RENEWAL OF AUTHORIZATION**

Not later than 6 months prior to the date of expiration of any Certificate, the Certificate Holder shall apply for a renewal of such authorization and the issuance of a new Certificate.

**WA-8200 NAMEPLATES AND STAMPING WITH CERTIFICATION MARK****WA-8210 GENERAL REQUIREMENTS****WA-8211 Nameplates**

(17)

(a) Each component or part to which a Certification Mark is applied shall have a nameplate, except as otherwise permitted by this subarticle. Marking shall be as required by (1) through (5) below.



- (1) the applicable official Certification Mark, as shown in [Table WA-8100-1](#);
  - (2) Class of construction and Designator;
  - (3) the statement “Certified by”;
  - (4) Certificate Holder’s name;
  - (5) Serial number and, if applicable, National Board number and/or Canadian registration number.
- (b) Valves fabricated by a Division 1 Certificate Holder shall be stamped in accordance with Article NCA-8000.

**WA-8212 Stamping With the Certification Mark**

The Certification Mark shall be stamped on a nameplate attached to an item, except as otherwise permitted by this subarticle. The arrangement of markings shall be as shown in [Figure WA-8212-1](#). The data shall be in characters not less than  $\frac{3}{32}$  in. (2.5 mm) high. The selected method shall not result in any harmful contamination or sharp discontinuities. Stamping directly on items, when used, shall be done with blunt-nosed continuous or blunt-nose interrupted dot die stamps.

**WA-8213 Attachment of Nameplates**

- (a) The nameplate shall be attached by a method that will not affect the structural integrity of the item.
- (b) If the nameplate is marked before it is attached, the Certificate Holder shall assure that the nameplate with the correct marking has been attached and the Inspector shall verify that this has been done.

(17) **WA-8220 NAMEPLATES**

- (a) The markings required by [WA-8210](#) shall be applied to a separate nameplate attached to the item. The nameplate shall be of a visible, permanent type and not detrimental to the item. The type, method, and manner of marking shall be described in the Certificate Holder’s Quality Assurance Program or Procedure.
- (b) If, because of size or other considerations, the nameplates cannot be directly attached to the component or part, the Certificate Holder may secure the nameplate in a manner acceptable to the Authorized Inspection

Agency. The use of this alternative method of identification, including the method of marking, shall be reviewed by and found acceptable to the Authorized Inspection Agency ([WA-5121](#)) prior to implementation by the Certificate Holder.

(c) For internal support structures, if because of size, geometric constraints, or other considerations the nameplate cannot be directly attached to the component, an alternative method of identification may be used. The alternative method is to be acceptable to the Authorized Inspection Agency and includes application of a unique identification mark to the component that will serve to identify the component with the appropriate Data Report. The marking shall be of a visible, permanent type and not detrimental to the component. That type, method, and manner of marking shall be described in the Certificate Holder’s Quality Assurance Program or Procedure. The use of this alternative method of marking shall be reviewed by and found acceptable to the Authorized Inspection Agency ([WA-5121](#)) prior to the implementation by the Certificate Holder.

**WA-8230 NAMEPLATES FOR CERTIFICATION MARK WITH NPT DESIGNATOR ITEMS** (17)

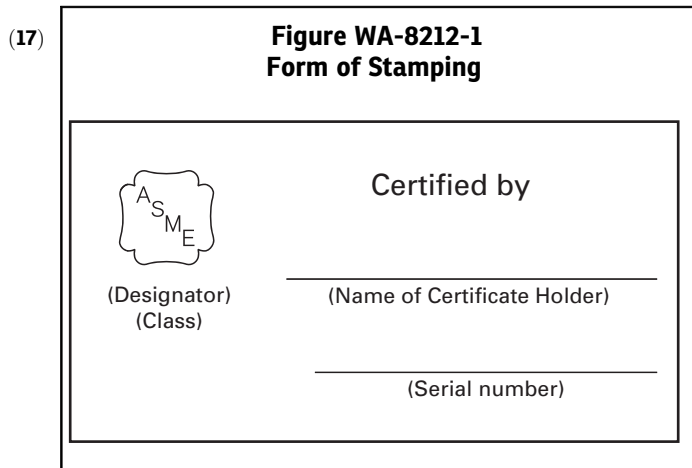
Parts shall have a separate nameplate equivalent to that required for completed items when the size and use of the item will accommodate such a nameplate. When the size or use of the item will not permit the installation of a nameplate, the marking shall consist of suitable identification of the item until it has been incorporated into the finished component or other Certification Mark with NPT Designator item. This alternative method of marking shall be reviewed with and found acceptable to the Authorized Inspection Agency before being used by the Certificate Holder.

**WA-8300 CERTIFICATION MARK** (17)

**WA-8310 GENERAL REQUIREMENTS**

(a) The Certification Mark shall be applied by the Certificate Holder only with authorization of the Inspector. In any case, the Certification Mark shall not be applied until completion of the required examination and testing, except as permitted in [WA-8311](#).

(b) [Table WA-8100-1](#) provides Certification Mark requirements as related to type of certificates, scope of work, and class of construction. The class of construction shall be indicated by the letters TC, SC, TC and SC, or ISS stamped below and outside the official Certification Mark. For construction of components, parts, or welds to be certified as meeting a Section III Edition or Addenda before the 2011 Addenda, the ASME Certification Mark is equivalent to and may be used in lieu of the N3 or NPT Stamp shown in the Section III Edition and Addenda used for construction.



(c) The completed Code Data Report certifies that the Inspector has inspected the item and authorized the application of the Certification Mark. The sequence for stamping and the completion of the Code Data Report shall be determined by agreement between the Authorized Inspection Agency and the Certificate Holder.

#### **WA-8311 Alternative Stamping Requirements**

For containments where final closure welds are not completed until after spent nuclear fuel or high-level radioactive materials are loaded into the containment, the organization assuming overall responsibility for the containment may apply the Certification Mark with N3 Designator prior to completion of the final closure welds, provided

(a) unique identifiers are permanently marked on each of the containment parts that are to be assembled together;

(b) the Data Report for each component includes the assigned unique identifiers; and

(c) the procedure for controlling, and the use of, the unique identifiers shall be included in the Certificate Holders Quality Assurance Program and accepted by the Certificate Holders Authorized Inspection Agency prior to use.

#### **WA-8330 REMOVABLE ITEMS**

Removable items that form part of a containment boundary shall have unique markings identifiable to an individual component.

#### **WA-8400 DATA REPORTS**

##### **WA-8410 GENERAL REQUIREMENTS**

The appropriate Data Report,<sup>4</sup> as specified in [Table WA-8100-1](#), shall be filled out by the Certificate Holder and shall be signed by the Certificate Holder and the Inspector for each item (except as provided elsewhere in this Article) to be marked with a Certification Mark. Any quantity to which units apply shall be entered on the Manufacturer's Data Report with the chosen units.

##### **WA-8412 Availability of Data Reports**

All Data Reports and referenced supporting material shall be available to the Inspector, Owner, and enforcement, or regulatory authority having jurisdiction.



**FORM N-7 NUCLEAR CONTAINMENTS**  
**As Required by the Provisions of the ASME Code, Section III, Division 3**

1. Manufactured and certified by \_\_\_\_\_
2. Manufactured for \_\_\_\_\_
3. Transport and/or Storage \_\_\_\_\_  
(name and address)
4. Type \_\_\_\_\_  
(horizontal or vertical) (Containment serial no.) (Certificate Holder's serial no.) (CRN) (National Bd. no.) (year built)
5. ASME Code, Section III, Division 3 \_\_\_\_\_  
(edition) (class) (Code Case no.)
6. Shell \_\_\_\_\_  
(material spec. no.) (tensile strength) (nominal thickness) (diameter ID) (length (overall))
7. Seams Long \_\_\_\_\_ ; girth \_\_\_\_\_  
(type) (HT) (RT or UT) (joint eff. %) (type) (HT) (RT or UT) (joint eff. %)
8. Heads \_\_\_\_\_  
[(a) material spec. no.] (tensile strength) [(b) material spec. no.] (tensile strength)  
[(c) material spec. no.] (tensile strength) [(d) material spec. no.] (tensile strength)

	Location (top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (convex or concave)
(a)									
(b)									
(c)									
(d)									

If removable, bolts used; \_\_\_\_\_. If quick opening closure or other fastening, describe in detail \_\_\_\_\_

9. Design pressure \_\_\_\_\_ at \_\_\_\_\_. Min. pressure-test temp. \_\_\_\_\_. Pneu., hydro., or comb. test pressure \_\_\_\_\_  
 He leak test \_\_\_\_\_  
[maximum acc. leak rate (from fab. spec.)]
10. Supports \_\_\_\_\_ Lugs \_\_\_\_\_ Legs \_\_\_\_\_ Other \_\_\_\_\_ Attached \_\_\_\_\_  
(yes or no) (quantity) (quantity) (describe) (where and how)

11. Nozzles

Purpose	Quantity	Diameter or Size	Type	How Attached	Material	Thickness	Reinforcement Material	Location

12. Parts supplied by others (Data Reports attached).

- (a) Part \_\_\_\_\_ (b) Serial No. \_\_\_\_\_ (c) CRN No. \_\_\_\_\_ (d) National Bd. No. \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

13. For containments list identifying markings of matching items to be joined in the field by welding.

\_\_\_\_\_ to be welded to \_\_\_\_\_  
(closure plates, heads) (shell assembly)

14. Remarks \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

FORM N-7 (Back — Pg. 2 of \_\_\_\_)

Certificate Holder's Serial No. \_\_\_\_\_

CERTIFICATION OF DESIGN

Design Specification on file at \_\_\_\_\_
Design Specification certified by \_\_\_\_\_ P.E. State or Prov. \_\_\_\_\_ Reg. No. \_\_\_\_\_
Design Report on file at \_\_\_\_\_
Design Report certified by \_\_\_\_\_ P.E. State or Prov. \_\_\_\_\_ Reg. No. \_\_\_\_\_
Fabrication Specification on file at \_\_\_\_\_
Fabrication Specification certified by \_\_\_\_\_ P.E. State or Prov. \_\_\_\_\_ Reg. No. \_\_\_\_\_

CERTIFICATE OF COMPLIANCE FOR OVERALL RESPONSIBILITY

Following completion of the above, the Certificate of Authorization Holder accepting overall responsibility for this Division 3 containment shall complete the following statement:
We certify that the statements made by this report are correct and that construction of the items described in this Data Report conforms to the rules of the construction of the ASME Code, Section III, Division 3.
N3 Certificate of Authorization No. \_\_\_\_\_ Expires \_\_\_\_\_
Date \_\_\_\_\_ N3 Certificate Holder \_\_\_\_\_ Signed \_\_\_\_\_ (authorized representative)

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by \_\_\_\_\_ of \_\_\_\_\_ have compared the statements described on this Data Report with those described in the attached Certificate Holder's Data Reports and to the best of my knowledge and belief, the described items have been constructed in accordance with the ASME Code, Section III, Division 3.
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the items described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.
Date \_\_\_\_\_ Signed \_\_\_\_\_ (Authorized Nuclear Inspector) Commission \_\_\_\_\_ [National Board Number and Endorsement]

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that this nuclear containment conforms to the rules for construction of the ASME Code, Section III, Division 3.
Certificate of Authorization Type and No. \_\_\_\_\_ Expires \_\_\_\_\_
Date \_\_\_\_\_ Name \_\_\_\_\_ (N3 Certificate Holder) Signed \_\_\_\_\_ (authorized representative)

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by \_\_\_\_\_ of \_\_\_\_\_ have inspected the component described in this Data Report on \_\_\_\_\_, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this component in accordance with the ASME Code, Section III, Division 3.
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the component described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.
Date \_\_\_\_\_ Signed \_\_\_\_\_ (Authorized Nuclear Inspector) Commission \_\_\_\_\_ [National Board Number and Endorsement]

**FORM N-8 FOR CLASS SC OR TC CLOSURE WELDS**  
**As Required by the Provisions of the ASME Code, Section III, Division 3**

- 1. Welds made by \_\_\_\_\_  
(name and address of certificate holder)
- 2. Welds made for \_\_\_\_\_  
(owner's name and address)
- 3. Location of installation \_\_\_\_\_  
(name and address)
- 4. Welds were made in accordance with Fabrication Specification No. \_\_\_\_\_  
Revision \_\_\_\_\_ Date \_\_\_\_\_
- 5. Containment Serial No. \_\_\_\_\_ National Bd. No. \_\_\_\_\_ CRN No. \_\_\_\_\_  
Year Built \_\_\_\_\_ Identification Markings of Items to be Joined \_\_\_\_\_  
Welded to \_\_\_\_\_  
(heads, covers) (shell assy.)
- 6. ASME Code, Section III, Division 3 \_\_\_\_\_  
(class) (Code Case no.) (editions)
- 7. Testing: Hydro., pneu., or comb. pressure test at \_\_\_\_\_  
He leak test \_\_\_\_\_ of Welds \_\_\_\_\_  
(max. acceptable leak rate)
- 8. Remarks: \_\_\_\_\_

**CERTIFICATE OF COMPLIANCE**

We certify that the statements made in this report are correct and that these closure welds conform to the rules of construction of the ASME Code, Section III, Division 3, and the Fabrication Specification listed on this Data Report.

Certificate of Authorization Type and No. \_\_\_\_\_ Expires \_\_\_\_\_  
Date \_\_\_\_\_ Name \_\_\_\_\_ Signed \_\_\_\_\_  
(Certificate Holder) (authorized representative)

**CERTIFICATE OF INSPECTION**

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by \_\_\_\_\_ of \_\_\_\_\_ have inspected these items described in this Data Report on \_\_\_\_\_, and state that to the best of my knowledge and belief, the Certificate Holder has fabricated these parts in accordance with the ASME Code, Section III, Division 3. Each part listed has been authorized for stamping on the date shown above.  
By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the equipment described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or loss of any kind arising from or connected with this inspection.

Date \_\_\_\_\_ Signed \_\_\_\_\_ Commission \_\_\_\_\_  
(Authorized Nuclear Inspector) [National Board Number and Endorsement]

(17)

**FORM N-9 SHOP FABRICATED PARTS**  
**As Required by the Provisions of the ASME Code, Section III, Division 3**

Pg. 1 of \_\_\_\_\_

1. Manufactured and certified by \_\_\_\_\_  
(name and address of N Certificate Holder)

2. Manufactured for \_\_\_\_\_  
(name and address of Purchaser)

3. Transport and/or Storage \_\_\_\_\_

4. Type \_\_\_\_\_  
(horizontal or vertical) (Serial no.) (Certificate Holder's serial no.) (CRN) (National Bd. no.) (year built)

5. ASME Code, Section III, Division 3 \_\_\_\_\_  
(edition) (class) (Code Case no.)

6. Shell \_\_\_\_\_  
(material spec. no.) (tensile strength) (nominal thickness) (diameter ID) (length (overall))

7. Seams Long \_\_\_\_\_ ; girth \_\_\_\_\_  
(type) (HT) (RT or UT) (joint eff. %) (type) (HT) (RT or UT) (joint eff. %)

8. Heads \_\_\_\_\_  
[(a) material spec. no.] (tensile strength) [(b) material spec. no.] (tensile strength)  
[(c) material spec. no.] (tensile strength) [(d) material spec. no.] (tensile strength)

	Location (top, bottom, ends)	Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (convex or concave)
(a)										
(b)										
(c)										
(d)										

If removable, bolts used \_\_\_\_\_. If quick opening closure or other fastening, describe in detail \_\_\_\_\_

9. Design pressure \_\_\_\_\_ at \_\_\_\_\_. Min. pressure-test temp. \_\_\_\_\_. Pneu., hydro., or comb. test pressure \_\_\_\_\_  
 He leak test \_\_\_\_\_  
[maximum acc. leak rate (from fab. spec.)]

10. Supports \_\_\_\_\_ Lugs \_\_\_\_\_ Legs \_\_\_\_\_ Other \_\_\_\_\_ Attached \_\_\_\_\_  
(yes or no) (quantity) (quantity) (describe) (where and how)

11. Nozzles

Purpose	Quantity	Diameter or Size	Type	How Attached	Material	Thickness	Reinforcement Material	Location

12. Parts supplied by others (Data Reports attached).  
 (a) Part \_\_\_\_\_ (b) Serial No. \_\_\_\_\_ (c) CRN No. \_\_\_\_\_ (d) National Bd. No. \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

13. For components list identifying markings of matching items to be joined in the field by welding.  
 \_\_\_\_\_ to be welding to \_\_\_\_\_  
(closure plates, heads) (shell assembly)

14. List of Drawings (with last revision and date) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

15. Remarks \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

FORM N-9 (Back — Pg. 2 of \_\_\_\_)

Certificate Holder's Serial No. \_\_\_\_\_

16. Fabrication specification used for the manufacture of this item \_\_\_\_\_  
revision no. \_\_\_\_\_ prepared by \_\_\_\_\_  
Certified by \_\_\_\_\_ P.E. State or Prov. \_\_\_\_\_ Reg. No. \_\_\_\_\_

**CERTIFICATE OF SHOP COMPLIANCE**

We certify that the statements made by this report are correct and that this (these) \_\_\_\_\_  
conforms to the rules of the construction of the ASME Code, Section III, Division 3  
Certificate of Authorization Type and No. \_\_\_\_\_ Expires \_\_\_\_\_  
Date \_\_\_\_\_ Name \_\_\_\_\_ Signed \_\_\_\_\_  
(NPT Certificate Holder) (authorized representative)

**CERTIFICATE OF SHOP INSPECTION**

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by \_\_\_\_\_  
of \_\_\_\_\_ have inspected these items described in this Data Report on \_\_\_\_\_, and state that to the  
best of my knowledge and belief, the Certificate Holder has fabricated these parts in accordance with the ASME Code, Section III, Division 3. Each  
part listed has been authorized for stamping on the date shown above.  
By signing this certificate, neither the inspector nor his employer makes any warranty, expressed or implied, concerning the equipment described  
in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage  
or a loss of any kind arising from or connected with this inspection.  
Date \_\_\_\_\_ Signed \_\_\_\_\_ Commission \_\_\_\_\_  
(Authorized Nuclear Inspector) [National Board Number and Endorsement]

(17)

**FORM N-11 CERTIFICATE HOLDER'S DATA REPORT FOR INTERNAL SUPPORT STRUCTURES\***  
**As Required by the Provisions of the ASME Code, Section III, Division 3** Pg. 1 of \_\_\_\_

1. Manufactured and certified by \_\_\_\_\_  
(name and address of Certificate Holder)
2. Manufactured for \_\_\_\_\_  
(name and address of Purchaser)
3. Applicable Installation(s) \_\_\_\_\_  
(specific identifiers)
4. Type \_\_\_\_\_  
(Transportation, storage, or both) (C.H.'s serial no.) (CRN) (drawing no.) (National Bd. no.) (year built)
5. ASME Code, Section III, Division 3 \_\_\_\_\_  
(edition) (class) (Code Case no.)
6. Manufactured in accordance with specification \_\_\_\_\_ Rev. \_\_\_\_\_ Date \_\_\_\_\_  
(Fabrication Specification)
7. List of Drawings (with last revision and date) \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
8. Remarks \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

CERTIFICATION OF DESIGN AND FABRICATION		
Design Specification certified by _____	P.E. State _____	Reg. no. _____
Design Report certified by _____	P.E. State _____	Reg. no. _____
Fabrication Specification certified by _____	P.E. State _____	Reg. no. _____

CERTIFICATE OF INTERNAL SUPPORT STRUCTURES	
The undersigned, having a valid Certification of Authorization, certify that the construction of the internal support structure will not adversely affect the integrity of the containment.	
N3 Certificate of Authorization No. _____	Expires _____
Date _____ Name _____	Signed _____
<small>(Certificate Holder) (authorized representative)</small>	

CERTIFICATE OF SHOP COMPLIANCE	
We certify that the statements made in this report are correct and that this internal support structure conforms to the rules of construction of the ASME Code, Section III, Division 3.	
Certificate of Authorization Type and No. _____	Expires _____
Date _____ Name _____	Signed _____
<small>(Certificate Holder) (authorized representative)</small>	

CERTIFICATE OF INSPECTION	
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by _____	
have inspected the internal support structure described in this Data Report on _____, and state that to the best of my knowledge and belief, the Certificate Holder has constructed this item in accordance with the ASME Code, Section III, Division 3. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the item described in this Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.	
Date _____ Signed _____	Commission _____
<small>(Authorized Nuclear Inspector) [National Board Number and Endorsement]</small>	

\* Supplemental sheets in the form of lists, sketches, or drawings may be used provided: (1) size is 8 1/2 x 11; (2) information in items 1 through 4 on this Data Report is included on each sheet; and (3) each sheet is numbered and the number of sheets is recorded at the top of this form.

(07/17)

# ARTICLE WA-9000

## GLOSSARY

### WA-9100 INTRODUCTION

This Article defines selected terms used in this Division. The definitions in this Glossary shall prevail should a conflict exist with definitions found elsewhere in this Division or other documents referenced in this Division. Unless defined below, the definitions of Article NCA-9000 shall apply.

### (17) WA-9200 DEFINITIONS

*Authorized Nuclear Inspector:* an Authorized Nuclear Inspector is an employee of an Authorized Inspection Agency who has qualifications for and has been properly qualified for Division 3.

*Authorized Nuclear Inspector Supervisor:* an Authorized Nuclear Inspector Supervisor is an employee of an Authorized Inspection Agency who has been assigned by that agency to oversee and direct the work of one or more Authorized Nuclear Inspectors and who has qualifications for and has been properly qualified for Division 3.

*Class ISS:* the Division 3 classification assigned to internal support structures.

*Class SC:* the Division 3 classification assigned to storage containments.

*Class TC:* the Division 3 classification assigned to transportation containments.

*Code Class:* the classification, specified in the Design Specification, which establishes the rules for design and construction of items.

*component:* a containment or internal support structure that is designed, constructed, and stamped in accordance with the rules of Division 3.

*construction (as used in Division 3):* an all-inclusive term comprising materials, design, fabrication, examination, testing, inspection, and certification required in the manufacture of an item.

*containment:* an enclosure that serves as a barrier for spent nuclear fuel or high-level radioactive material within a prescribed volume for transportation or storage.

*containment closure weld:* a weld made to close the containment after spent nuclear fuel or high-level radioactive material has been loaded into the containment.

*Containment Systems:* a collective term for one or more components whose construction requirements are addressed by Division 3. Division 3 does not require nor prohibit any Containment System component to be used in conjunction with another Containment System component.

*Design Documents:* documents used to establish the design requirements, which include those criteria, parameters, bases, or other design requirements upon which detailed final design is based. For this Division, these include the Design Specifications and any other documents referenced by them. Additionally, Design Documents are the output of the above and provide the technical description of the item; these include Certified Design Reports, drawings, calculations, and Fabrication Specifications.

*Design Specification (Division 3):* a document prepared by the N3 Certificate Holder which provides a complete basis for design in accordance with this Division.

*disposal:* the permanent placement of spent nuclear fuel or high-level radioactive material in a repository.

*energy-limited dynamic event:* a time-dependent, nonrepeating event characterized by an impact or other mechanical loading with a known level of energy content.

*examination:* specific actions by qualified personnel using qualified procedures to verify that items and fabrication processes are in conformance with specified requirements. This term, when used in conjunction with qualification of personnel to perform quality-related activities, shall mean a written examination.

*Fabrication Specification:* a document, or set of documents, prepared by the N3 Certificate Holder that establishes the requirements for fabrication.

*Inspector:* the Authorized Nuclear Inspector as defined in [WA-5123](#).

*internal support structure:* a component used within transportation or storage containments that performs a combination of structural and configuration control and other functions as described by the Design Specification (e.g., heat transfer and criticality).

*item:* a product constructed under a Certificate of Authorization ([WA-3120](#)) or material ([WA-1220](#)).

*Lowest Service Temperature (LST)*: the lowest temperature that the metal may experience in service as detailed in the Design Specification.

*material*: for Section III, Division 3, metallic materials manufactured to an SA, SB, SFA, or any other material specification permitted by this Division.

*modification*: a change to an item made necessary by, or resulting in, a change in design requirements.

*N3 Certificate Holder (Division 3)*: the organization that causes a Design Specification, Design Report, and Fabrication Specification to be developed. This organization assumes responsibility for Code compliance with respect to materials, design, fabrication, examination, testing, inspection, certification, and stamping of items constructed to the requirements of this Division.

*Owner*: the organization that takes legal ownership of a Division 3 component.

*qualified source material*: metallic products produced by an approved supplier, Material Organization, or Certificate Holder in accordance with the requirements of WA-3800, or the output of the qualification process requirements of NCA-4255.5.

*quality control*: measurement of the characteristics of an item or process to determine conformance to specified requirements.

*Quality System Certificate*: a Certificate issued by the Society that permits an organization to perform specified Material Organization activities in accordance with Code requirements.

*regulatory authority*: a Federal Government Agency, such as the United States Nuclear Regulatory Commission, empowered to issue and enforce regulations concerning the design and construction of components used for transportation and/or storage of spent nuclear fuel and high-level radioactive material.

*shop drawings*: drawings which describe fabrication details, physical dimensions, arrangements, and any significant engineering features needed to establish conformance to the Fabrication Specification, and this Division.

*source material*: metallic products used by a Material Organization or Certificate Holder in a product form conversion process in the manufacture of material [NCA-4251.2(a)(1)], or in a qualification process based on test and examination to the requirements of the material specification [NCA-4255.5(a)(2) and (3)]. Source material may be qualified or unqualified.

*special process*: a process, the results of which are highly dependent on the control of the process or skill of the operator, or both.

*storage*: the interim placement of spent fuel or high-level radioactive material in a Section III, Division 3, Class SC containment in accordance with specified requirements.

*supplier*: any individual or organization that furnishes materials or services in accordance with a procurement document.

*survey*: a documented evaluation of an organization's ability to perform Code activities as verified by a determination of the adequacy of the organization's quality program and by a review of the implementation of that program at the location of the work.

*testing*: an element of verification for the determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions.

*traceability*: the ability to verify the history, location, or application of an item by means of recorded identification.

*transportation*: the conveyance of spent nuclear fuel or high-level radioactive material over public access routes in a Section III, Division 3, Class TC containment in accordance with specified requirements.

*unqualified source material*: source material not produced by a Certificate Holder, Material Organization, or approved supplier in accordance with the requirements of [WA-3800](#).

*use-as-is*: only applicable requirements of this Division have been met.

*verification*: a review to ensure that activities have been performed and documented in accordance with applicable requirements.



# SUBSECTION WB CLASS TC TRANSPORTATION CONTAINMENTS

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## ARTICLE WB-1000 INTRODUCTION

### (17) WB-1100 SCOPE

(a) *Subsection WB* contains rules for the material, design, fabrication, examination, testing, marking, stamping, and preparation of reports by the Certificate Holder for Class TC transportation containments for spent nuclear fuel and high-level radioactive material.

(b) The rules of *Subsection WB* cover the strength and containment integrity of items where their failure could breach the containment boundary. The rules cover load stresses but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of containment materials. *WA-1130* further limits the rules of this Subsection.

### (17) WB-1120 LIMITS OF RULES FOR CLASS TC TRANSPORTATION CONTAINMENTS

(a) *Subsection WB* does not contain rules to cover all details of construction of Class TC containments. Where complete details are not provided in this Subsection, it is intended that the N3 Certificate Holder, subject to review by the Inspector (*Article WA-5000*), shall provide the details of construction which will be consistent with those provided by the rules of this Subsection.

(b) Valves, classified as part of the containment by the Design Specification, shall be classified as Class 1 and shall meet the requirements of Division 1 in lieu of all other requirements of this Division.

### WB-1130 BOUNDARIES OF JURISDICTION

#### WB-1131 Boundary of Containments

The Design Specification shall define the boundary of a containment. The containment includes the vessel and any penetrations attached to the vessel.

### WB-1132 Boundary Between a Containment and Attachments

#### WB-1132.1 Attachments.

(a) An *attachment* is an element in contact with or connected to the inside or outside of a containment, which may perform a containment function, and either a structural or nonstructural function.

(b) Attachments that do not perform a containment function include items such as stiffeners or containment opening reinforcement.

(c) Attachments with a noncontainment function include items in the containment support load path such as support and shear lugs, brackets, trunnions and skirts.

(d) Attachments with a structural function (structural attachments) perform a containment function or are in the containment support load path.

(e) Attachments with a nonstructural function (non-structural attachments) do not perform a containment function nor are they in the containment support load path. Nonstructural attachments include items such as nameplates and lifting lugs.

**WB-1132.2 Jurisdictional Boundary.** The jurisdictional boundary between a containment and an attachment defined in the Design Specification shall not be any closer to the containment than as defined in (a) through (g) below.

(a) Attachments forged with the containment or weld buildup on the containment surface shall be considered part of the containment.

(b) Attachments, welds, and fasteners having a containment function shall be considered part of the containment.

(c) Except as provided in (d) and (e) below, the boundary between a containment and an attachment not having a containment function shall be at the surface of the containment.

*(d)* The first connecting weld of a structural attachment that does not perform a containment function to a containment shall be considered part of the containment.

*(e)* The first connecting weld of a welded nonstructural attachment to a containment shall be considered part of the attachment.

*(f)* Mechanical fasteners used to connect an attachment that does not perform a containment function to the containment shall be considered part of the attachment.

*(g)* The boundary may be located further from the containment portion of the containment than as defined in (a) through (f) above when specified in the Design Specification.

## ARTICLE WB-2000 MATERIAL

### WB-2100 GENERAL REQUIREMENTS FOR MATERIAL

#### WB-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in [Article WA-9000](#). The term *Material Organization* is defined in Article NCA-9000.

(b) The term *containment material* as used in this Subsection applies to items such as containment shells and heads; reinforcement around openings and penetrations such as leak testing and drainage ports, and structural reinforcements required by design to maintain structural integrity.

(c) The requirements of this Article make reference to the term *thickness t*. For the purpose intended, the following definitions of nominal thickness apply.

(1) *plate*: the thickness is the dimension of the short transverse direction.

(2) *forgings*: the thickness is the dimension defined as follows:

(-a) *hollow forgings*: the nominal thickness is measured between the inside and outside surfaces (radial thickness)

(-b) *disk forgings* (axial length less than the outside diameter): the nominal thickness is the axial length

(-c) *flat ring forgings* (axial length less than the radial thickness): for axial length  $\leq 2$  in. (50 mm), the axial length is the nominal thickness. For axial length  $> 2$  in. (50 mm), the radial thickness is the nominal thickness.

(-d) *rectangular solid forgings*: the least rectangular dimension is the nominal thickness

(3) *castings*: thickness for fracture toughness testing and heat treatment purposes is defined as the wall thickness of the containment.

#### WB-2120 CONTAINMENT MATERIAL

#### WB-2121 Permitted Material Specifications

(a) Containment material and material welded thereto, except as permitted in [WB-4435](#), and except for welding and hard surfacing metals and cladding which is 10% or less of the thickness of the base material ([WB-3122](#)), shall conform to the requirements of one of the specifications for material given in Section II, Part D, Tables 2A, 2B, and 4, including all applicable footnotes in the table, and to all of the special requirements of this Article which

apply to the product form in which the material is used. As an additional control, only the following materials shall be used:

(1) materials whose P-Numbers are listed in [Table WB-4622.1-1](#)

(2) ductile cast iron castings per specifications SA-874 or SA/JIS G5504

(b) The requirements of this Article do not apply to seals and gaskets.

(c) Material for instrument line fittings, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, Tables 2A and 2B, provided that the material is determined to be adequate for the service conditions by the containment designer.

(d) Welding material used in the manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to material used as backing rings or backing strips in welded joints.

#### WB-2122 Special Requirements Conflicting With Permitted Material Specifications (17)

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (NCA-4256). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in [WB-2500](#). Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in [WB-4121](#). Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested as part of the containment pressure test in accordance with [WB-6100](#), except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

(17) **WB-2123 Size Ranges**

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-4256).

**WB-2124 Fabricated Hubbed Flanges**

Fabricated hubbed flanges shall be in accordance with the following:

(a) Hubbed flanges may be machined from a hot rolled or forged billet. The axis of the finished flange shall be parallel to the long axis of the original billet. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric.)

(b) Hubbed flanges, except as permitted in (a) above, shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

(1) in a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange (this is not intended to imply that the original plate surface must be present in the finished flange);

(2) the joints in the ring are welded butt joints that conform to the requirements of this Division. Thickness to be used to determine postweld heat treatment and radiography requirements shall be the lesser of  $t$ , or  $(A - B)/2$ , where these symbols are as defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

(c) The back of the flange and the outer surface of the hub shall be examined by the magnetic particle method or the liquid penetrant method in accordance with [WB-2540](#) to ensure that these surfaces are free from defects.

**WB-2125 Bolting Material**

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

**WB-2126 Ductile Cast Iron for Containment**

The containment body shall be cast by a single pouring controlled by a casting plan to ensure reproducibility. The casting plan shall be agreed upon between the manufacturer and purchaser and shall become a lifetime quality assurance record in accordance with [WA-4134](#).

**WB-2127 Additional Requirements When Strain-Based Acceptance Criteria Have Been Implemented**

In order to satisfy the strain-based acceptance criteria of [WB-3700](#) regarding sufficient ductility, all material specified to be used in the construction of the containment and implementing the strain-based acceptance criteria shall meet the requirements of Section III Appendices, Nonmandatory Appendix FF, FF-1122, and FF-1140(a) or FF-1140(b). Assurance of satisfying these requirements shall be documented in the final Design Report. Per Section III Appendices, Nonmandatory Appendix FF, FF-1140(a), when temperature-dependent material test data are not available, the Certified Material Test Report(s) shall include reduction of area values in order to have the necessary data to ensure sufficient material ductility. This requirement is only necessary when strain-based acceptance criteria have been employed in the design of the containment.

**WB-2130 CERTIFICATION OF MATERIAL**

All material used in construction of containments shall be certified as required in NCA-3860. Certified Material Test Reports are required for containment material except as provided by NCA-3860. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

**WB-2140 WELDING MATERIAL**

For the requirements governing the material to be used for welding, see [WB-2400](#).

**WB-2150 MATERIAL IDENTIFICATION**

(17)

The identification of containment material and materials welded thereto shall meet the requirements of NCA-4256. Material for small items shall be controlled during manufacture and installation of a component so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process ([WB-4122](#)).

**WB-2160 DETERIORATION OF MATERIAL IN SERVICE**

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the N3 Certificate Holder to select material suitable for the conditions stated in the Design Specifications ([WA-3351](#)), with specific attention being given to the effects of service conditions upon the properties of the material. Any special requirement shall be specified in the Design Specifications ([WA-3351](#) and [WB-3120](#)). When so specified, the check analysis shall be made in accordance with the base metal specification and in accordance with [WB-2420](#) for the welding material.

**WB-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES**

Carbon steels and low alloy steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

**WB-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL**

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and temperature-calibrated furnaces or shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

**WB-2190 MATERIAL NOT PERFORMING A CONTAINMENT FUNCTION**

Material not performing a containment function welded at or within  $2t$  of the containment shall comply with the requirements of [WB-4430](#).

**WB-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL AND DUCTILE CAST IRON****WB-2210 HEAT TREATMENT REQUIREMENTS****(17) WB-2211 Test Coupon Heat Treatment for Ferritic Material**

Where ferritic steel material is subjected to heat treatment during fabrication of a containment, the material used for the tensile and impact test specimens shall be

heat treated in the same manner as the containment, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens..

**WB-2212 Test Coupon Heat Treatment for Quenched and Tempered Material**

**WB-2212.1 Cooling Rates.** Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing that material shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings ([WB-2223.2](#)). This rule shall apply to coupons taken directly from the material as well as to separate test coupons representing the material, and one of the general procedures described in [WB-2212.2](#) or one of the specific procedures described in [WB-2220](#) shall be used for each product form.

**WB-2212.2 General Procedures.** One of the general procedures stipulated in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with [WB-2220](#). Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material which matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ( $\frac{1}{4}t$ ) and no nearer any heat-treated edge than a distance equal to the nominal thickness  $t$  being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.



(c) When any of the specific procedures described in [WB-2220](#) are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least  $t$  from a quenched edge, where  $t$  equals the material thickness;

(2) attaching a steel pad at least  $t$  wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed. It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

### **WB-2213 Test Coupon Heat Treatment for Ductile Cast Iron**

The tensile and impact coupon shall receive the same heat treatment as the casting.

### **WB-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL AND FOR DUCTILE CAST IRON**

#### **WB-2221 General Requirements**

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by the following paragraphs. References to dimensions signify nominal values.

#### **WB-2222 Plates**

**WB-2222.1 Number of Tension Test Coupons.** The number of tension test coupons required shall be in accordance with the material specification and with SA-20, except that from carbon steel plates weighing 42,000 lb (19 000 kg) and over and alloy steel plates weighing 40,000 lb (18 000 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

(17) **WB-2222.2 Orientation and Location of Coupons.** Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from a rolled surface and with the midlength of the specimen at least  $t$  from any heat-treated edge, where  $t$  is the nominal thickness of the material.

(17) **WB-2222.3 Requirements for Separate Test Coupons.** Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of

the material at least  $\frac{1}{4}t$  deep and  $t$  from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with [WB-2212.2\(b\)](#), the dimensions of the coupon shall be not less than  $3t \times 3t \times t$ , where  $t$  is the nominal material thickness.

### **WB-2223 Forgings**

**WB-2223.1 Location of Coupons.** Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from any surface and with the midlength of the specimens at least  $t$  from any second surface, where  $t$  is the maximum heat-treated thickness. A thermal buffer as described in [WB-2212.2\(c\)](#) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in [WB-2212.2](#). (17)

**WB-2223.2 Very Thick or Complex Forgings.** Test coupons for forgings that are very thick or complex and other forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than  $\frac{3}{4}$  in. (19 mm) to any heat-treated surface and the midlength of the specimens shall be at least  $1\frac{1}{2}$  in. (38 mm) from any second heat-treated surface.

**WB-2223.3 Coupons From Separately Produced Test Forgings.** Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface, and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the

production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with [WB-2223.2](#).

**WB-2223.4 Test Specimens for Forgings.** When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamping on them, and witnessing the testing of these specimens.

#### **WB-2224 Location of Coupons**

(a) *Bars.* Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from the outside or rolled surface and with the midlength of the specimens at least  $t$  from a heat-treated end, where  $t$  is either the bar diameter or thickness.

(b) *Bolting.* For bolting materials, tests shall be made of either full-size bolts or test coupons as required by the base specification. The gage length of the tension specimens and the area under the notch of Charpy specimens shall be at least one diameter or thickness from the heat-treated end.

#### **WB-2225 Tubular Products and Fittings**

**WB-2225.1 Location of Coupons.** Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from the inside or outside surface and with the midlength of the specimens at least  $t$  from a heat-treated end, where  $t$  is the nominal wall thickness of the tubular product.

**WB-2225.2 Separately Produced Coupons Representing Fittings.** Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of [WB-2223.3](#) shall be met.

#### **WB-2226 Tensile Test Specimen Location for Ductile Cast Iron**

Tensile specimens shall be taken from each containment casting or its excess length part that has the same or equivalent solidification property. The location shall be near the center of the thickness and shall be at a distance from the end of the excess length part that is not less than one-half of the maximum casting thickness. The excess length part shall be at least the same thickness as the maximum casting thickness.

### **WB-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL**

#### **WB-2310 MATERIAL TO BE TOUGHNESS TESTED**

#### **WB-2311 Material for Which Toughness Testing Is Required**

(a) Containment material and material welded thereto shall be toughness tested in accordance with the requirements of this subarticle, except that the material listed in (1) through (7) below is not to be toughness tested as a requirement of this Subsection:

(1) material with a nominal section thickness of  $\frac{3}{16}$  in. (5 mm) and less where the thicknesses shall be taken as defined in (-a) through (-c) below:

(-a) for containments, use the nominal thickness of the shell or head, as applicable;

(-b) for items welded to containments, use the lesser of the containment shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(-c) for flat heads or flanges, use the maximum shell thickness associated with the butt welding hub;

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less;

(3) bars with a nominal cross-sectional area of 1 in.<sup>2</sup> (650 mm<sup>2</sup>) and less;

(4) all thicknesses of material for fittings with an NPS 6 (DN 150) diameter and smaller;

(5) material for fittings with all pipe connections of  $\frac{5}{8}$  in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steels, including precipitation hardened austenitic Grade 660 (UNS S66286);

(7) nonferrous material.

(b) Drop weight tests are not required for precipitation hardening steels listed in Section II, Part D, Subpart 1, Table 2A. The other requirements of [WB-2332](#) apply for these steels. For nominal wall thicknesses greater than  $2\frac{1}{2}$  in. (64 mm), the required Charpy V-notch values shall be 40 mils (1.02 mm) lateral expansion.

### **WB-2320 IMPACT TEST PROCEDURES**

#### **WB-2321 Types of Tests**

**WB-2321.1 Drop Weight Tests.** The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-1, P-2, or P-3 may be used. The results, orientation, and location of all tests performed to meet the requirements of [WB-2330](#) shall be reported in the Certified Material Test Report.

**WB-2321.2 Charpy V-Notch Tests.** The Charpy V-notch test ( $C_v$ ), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size 0.394 in. × 0.394 in. (10 mm × 10 mm) specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as

the orientation and location of all tests performed to meet the requirements of [WB-2330](#) shall be reported in the Certified Material Test Report.

- (17) **WB-2321.3 Fracture Toughness Tests.** Fracture toughness tests, when required, shall be performed in accordance with ASTM E399. The tests shall be performed at the lowest service temperature (LST). A test shall consist of two test specimens.
- (17) **WB-2321.4 Dynamic Tear Test.** The dynamic tear tests, when required, shall be performed in accordance with ASTM E604. The tests shall be performed at the LST. A test shall consist of two test specimens.

## WB-2322 Test Specimens

### WB-2322.1 Location of Test Specimens.

(a) Toughness test specimens for quenched and tempered material shall be removed from the locations in each product form specified in [WB-2220](#) for tensile test specimens. For material in other heat-treated conditions, toughness test specimens shall be removed from the locations specified for tensile test specimens in the material specification. For all material, the number of tests shall be in accordance with [WB-2340](#). For bolting, the  $C_v$  toughness test specimen shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat-treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

(b) For fracture toughness requirements, toughness test specimens for ductile cast iron shall be taken from each containment casting or its excess length part. The location shall be the same as that for the tensile specimens.

### WB-2322.2 Orientation of Toughness Test Specimens.

(a) Toughness test specimens shall be oriented as follows:

(1) Specimens for forgings, other than bolting and bars used for containments, shall be oriented in a direction normal to the principal direction in which the material was worked. Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate and castings, shall be oriented in the axial direction.

(3) Specimens from bolting material and bars shall be oriented in the axial direction.

(4) Specimens for all plate material, including that used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) Specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens ([WB-2226](#)).

(6) The plane of the toughness test specimen notch shall be normal to the surface of the material. However, for ductile cast iron, the fracture toughness specimen orientation shall be L-R, as identified in ASTM E399, Fig. 1 (Crack Plane Identifications for Cylindrical Bars and Tubes).

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

## WB-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS<sup>5</sup>

### WB-2331 Material for Containments

**WB-2331.1 Test Requirements for Ferritic Steel Material for Containments.** Ferritic steel material for containments, other than bolting, shall be tested in accordance with (a) and (b), (c), or (d) below. Consideration shall be given to the test temperature requirements of leak testing and hydrostatic testing of the containment ([WB-6212](#)). (17)

(a) For material with a nominal section between  $\frac{3}{16}$  in. (5 mm) and  $\frac{5}{8}$  in. (16 mm) thick, the dynamic tear test shall exhibit at least 80% shear fracture at the LST. For material of  $\frac{5}{8}$  in. (16 mm) and more but not exceeding 12 in. (300 mm) thick, the reference temperature,  $RT_{NDT}$ , shall be established as follows:

(1) Determine a temperature  $T_{NDT}$  that is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than  $T_{NDT} + 60^\circ\text{F}$  ( $T_{NDT} + 33^\circ\text{C}$ ), each specimen of the  $C_v$  test ([WB-2321.2](#)) shall exhibit at least 35 mils (0.89 mm) lateral expansion and not less than 50 ft-lb (68 J) absorbed energy. Retesting in accordance with [WB-2350](#) is permitted. When these requirements are met,  $T_{NDT}$  is the reference temperature  $RT_{NDT}$ .

(3) In the event that the requirements of (2) above are not met, conduct additional  $C_v$  tests in groups of three specimens ([WB-2321.2](#)) to determine the temperature  $T_c$  at which they are met. In this case the reference temperature  $RT_{NDT} = T_c - 60^\circ\text{F}$  ( $RT_{NDT} = T_c - 33^\circ\text{C}$ ). Thus, the reference temperature  $RT_{NDT}$  is the higher of  $T_{NDT}$  and  $(T_c - 60^\circ\text{F})$  ( $T_c - 33^\circ\text{C}$ ).

(4) When a  $C_v$  test has not been performed at  $T_{NDT} + 60^\circ\text{F}$  ( $T_{NDT} + 33^\circ\text{C}$ ), or when the  $C_v$  test at  $T_{NDT} + 60^\circ\text{F}$  ( $T_{NDT} + 33^\circ\text{C}$ ), does not exhibit a minimum of 50 ft-lb (68 J) and 35 mils (0.89 mm) lateral expansion, a temperature representing a minimum of 50 ft-lb (68 J)



and 35 mils (0.89 mm) lateral expansion may be obtained from a full  $C_v$  impact curve developed from the minimum data points of all the  $C_v$  tests performed.

(b) Apply the procedures of (a) above to (1), (2), and (3) below.

(1) the containment base materials,<sup>6</sup>

(2) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with WB-4330;

(3) the weld metal of WB-2431.

(c) For materials where fracture toughness values are determined in accordance with WB-2321.3 the measured fracture toughness shall be reported in the Certified Material Test Report.

(d) Bars having a width or diameter of 2 in. (50 mm) and less which prohibit obtaining drop weight test specimens shall be tested in accordance with WB-2332.

(17) **WB-2331.2 Acceptance Standards for Ferritic Steel Material for Containments.** Except as limited in WB-4330, the reference temperature  $RT_{NDT}$  shall be the highest value of the individual  $RT_{NDT}$  values determined in accordance with WB-2331.1(a) and WB-2331.1(b). If applicable, the containment base materials shall be tested to determine the fracture toughness in accordance with WB-2321.3. The results shall meet the acceptance standards of either (a) or (b) below.

(a) For materials not exceeding 12 in. (305 mm), the reference temperature  $RT_{NDT}$  shall satisfy the value of  $A$  in accordance with Table WB-2331.2-1 where  $A = LST - RT_{NDT}$ .

(b) For materials not exceeding 4 in. (100 mm), the rapid-load fracture toughness of the base material shall satisfy the required value in Table WB-2331.2-2, and

(1) All full penetration fabrication weld joints are ultrasonically examined in accordance with WB-5110 and meet the ultrasonic acceptance standards of WB-5330.

(-a) Rules for fracture toughness requirements based on fracture mechanics methodology are in preparation.

Nominal Wall Thickness, in. (mm)	$A = LST - RT_{NDT}$ , °F (°C)
5/8 (16)	25 (14)
1 (25)	45 (25)
2 (50)	75 (42)
3 (75)	90 (50)
4 (100)	103 (57)
8 (200)	115 (64)
12 (300)	120 (67)

GENERAL NOTE: Linear interpolation is permissible.

Nominal Wall Thickness, in. (mm)	Rapid-Load Fracture Toughness, ksi√in. (MPa√mm) [Note (1)]
5/8 (16)	50 (55)
1 (25)	64 (70)
2 (50)	94 (103)
3 (75)	113 (124)
4 (100)	130 (143)

GENERAL NOTE: Linear interpolation is permissible.

NOTE:  
(1) Measured for test time equal to or less than 10 ms.

**WB-2331.3 Test Requirements for Ductile Cast Iron for Containments.** A rapid-load fracture toughness test shall be performed in accordance with WB-2321.3, except that ASTM E1820 shall be used. A test shall consist of at least four specimens. The test shall be performed at -40°F (-40°C).

**WB-2331.4 Acceptance Standards for Ductile Cast Iron for Containments.** The rapid-load fracture toughness value shall satisfy the following inequality at -40°F (-40°C):

$$(\text{average}) K_{IC,R} - 3\sigma_{SD} \geq 46 \text{ ksi-in.}^{1/2} (50 \text{ MPa-m}^{1/2})$$

where

$K_{IC,R}$  = rapid-load fracture toughness, ksi-in.<sup>1/2</sup> (MPa-m<sup>1/2</sup>)

$\sigma_{SD}$  = standard deviation, ksi-in.<sup>1/2</sup> (MPa-m<sup>1/2</sup>)

The average value and standard deviation shall be established assuming Weibull distribution of the measurements.

**WB-2332 Material for Piping, Excluding Bolting Material (17)**

(a) Containment boundary material, other than bolting, with nominal wall thickness 2 1/2 in. (64 mm) and less for piping (pipe and tubes) and fittings with all pipe connections of nominal wall thickness 2 1/2 in. (64 mm) and less shall be tested as required in (1) and (2) below.

(1) Test three  $C_v$  specimens at a temperature lower than or equal to the LST. All three specimens shall meet the requirements of Table WB-2332(a)-1.

(2) Apply the procedures of (1) above to:

(-a) the base material;<sup>6</sup>

**Table WB-2332(a)-1  
Required  $C_v$  Values for Piping**

Nominal Wall Thickness, in. (mm), [Note (1)]	Lateral Expansion, mils (mm)
$\frac{5}{8}$ (16) or less	No test required
Over $\frac{5}{8}$ to $\frac{3}{4}$ (16 to 19), incl.	20 (0.50)
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	25 (0.64)
Over $1\frac{1}{2}$ to $2\frac{1}{2}$ (38 to 64), incl.	40 (1.0)

NOTE:

(1) For fittings, use the nominal pipe wall thickness of the connecting piping.

(-b) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with [WB-4330](#); and

(-c) the weld metal of [WB-2431](#).

(b) Containment material, other than bolting, with nominal wall thickness over  $2\frac{1}{2}$  in. (64 mm) for piping (pipe and tubes) and fittings with any pipe connections of nominal wall thickness greater than  $2\frac{1}{2}$  in. (64 mm) shall meet the requirements of [WB-2331](#). The LST shall not be lower than  $RT_{NDT} + 100^\circ\text{F}$  ( $RT_{NDT} + 56^\circ\text{C}$ ).

#### (17) **WB-2333 Bolting Material**

For bolting material, including studs, nuts, and bolts, test three  $C_v$  specimens at a temperature no higher than the preload temperature or the LST, whichever is less. All three specimens shall meet the requirements of [Table WB-2333-1](#).

#### **WB-2340 NUMBER OF TOUGHNESS TESTS REQUIRED**

##### **WB-2341 Plates**

One test shall be made from each plate as heat treated. Where plates are furnished in the nonheat-treated condition and qualified by heat-treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

**Table WB-2333-1  
Required  $C_v$  Values for Bolting Material**

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
Over 1 to 4 (25 to 100), incl.	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

#### **WB-2342 Forgings**

(a) Where the weight of an individual forging is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

(c) One test shall be made for each forging of 1,000 lb to 10,000 lb (450 kg to 4 500 kg) in weight.

(d) As an alternative to (c), a separate test forging may be used to represent forgings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot.

#### **WB-2343 Bars**

One test shall be made for each lot of bars with cross-sectional area greater than  $1\text{ in.}^2$  ( $650\text{ mm}^2$ ), where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

#### **WB-2344 Tubular Products and Fittings**

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be tested by more than  $\frac{1}{4}$  in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a  $50^\circ\text{F}$  ( $28^\circ\text{C}$ ) range and equipped with recording pyrometers.

#### **WB-2345 Bolting Material**

One test shall be made for each lot of material, where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

Diameter, in. (mm)	Weight, lb (kg)
$1\frac{3}{4}$ (44) and less	1,500 (680)
Over $1\frac{3}{4}$ to $2\frac{1}{2}$ (44 to 64)	3,000 (1 350)
Over $2\frac{1}{2}$ to 5 (64 to 127)	6,000 (2 700)
Over 5 (127)	10,000 (4 500)

#### **WB-2346 Test Definitions**

Unless otherwise stated in [WB-2341](#) through [WB-2345](#), the term *one test* is defined to include the combination of the drop weight test and the  $C_v$  test when

$RT_{NDT}$  is required [WB-2331.1(a) and WB-2331.1(b)] or only the  $C_v$  test or the fracture toughness test when  $RT_{NDT}$  is not required [WB-2331.1(c) and WB-2331.1(d)].

### WB-2350 RETESTS

(a) For  $C_v$  tests required by WB-2330, one retest at the same temperature may be conducted provided the requirements of (1) through (3) below are met:

(1) the average value of the test results meets the minimum requirements;

(2) not more than one specimen per test is below the minimum requirements;

(3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb (14 J) or 5 mils (0.13 mm) below the specified requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retest, both specimens shall meet the minimum requirements.

### (17) WB-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and test machines used in toughness testing shall be performed at the frequency given in (a) and (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-4258.2 at least once in each 3 month interval.

(b) Test machines shall be calibrated using the frequency and methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology, or any supplier of subcontracted calibration services accredited in accordance with the requirements of WA-3123 and NCA-4255.3(c).

### WB-2400 WELDING MATERIAL

#### WB-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of containments, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this subarticle and to the rules covering identification in WB-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable.

(1) welding process;

(2) SFA Specification and classification;

(3) other identification if no SFA Specification applies;

(4) minimum tensile strength [WB-2431.1(e)] in the as-welded or heat-treated condition or both [WB-2431.1(c)];

(5) drop weight test for material as-welded or heat-treated, or both (WB-2331);

(6) Charpy V-notch test for material as-welded or heat treated, or both (WB-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;

(7) fracture toughness test for material as-welded or heat treated, or both (WB-2331);

(8) the preheat and interpass temperatures to be used during welding of the test coupon [WB-2431.1(c)];

(9) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [WB-2431.1(c)];

(10) elements for which chemical analysis is required per the SFA Specification or Welding Procedure Specification and WB-2432;

(11) minimum delta ferrite (WB-2433).

### WB-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, and PAW processes (Section IX); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux (SAW); for each combination of lot of fabricated electrodes and lot of submerged arc flux; or for each combination of heat of bare electrodes or lot of fabricated electrodes, and dry blend of supplementary powdered filler metal, and lot of submerged arc flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by Article WB-4000 and this subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [see (c) below].

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch or dry blend [(a) and (b) above, respectively], and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry

blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding material is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to ensure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to ensure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) *A heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, and PAW processes, a *heat* may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) *A lot of submerged arc flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) *A dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9 000 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. *A chemically controlled mix of powdered filler metal* is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

## WB-2430 WELD METAL TESTS

### WB-2431 Mechanical Properties Test

Tensile and toughness tests shall be made, in accordance with this paragraph, of welding materials which are used to join P-Nos. 1 and 3 base materials in any combination, with the exceptions listed in (a) through (d) below.

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base material exempted from toughness testing by WB-2311 shall likewise be exempted from the impact testing required by WB-2330 and this paragraph.

**WB-2431.1 General Test Requirements.** The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding. (17)

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be



tested in the applicable postweld heat-treated condition when the production welds are to be postweld heat-treated. The postweld heat treatment holding time shall be at least 80% of the maximum time to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component.

(d) The tensile specimens, and the  $C_v$  test specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1 or the applicable SFA specification. Drop weight and fracture toughness test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For specimen preparation and testing, the applicable parts of WB-2321.1 and WB-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of  $\frac{1}{4}t$  from a surface, where  $t$  is the thickness of the test weld.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Toughness specimens of the weld metal shall be tested where toughness tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of WB-2331.1(a) or WB-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

**WB-2431.2 Standard Test Requirements.** In lieu of the use of the General Test Requirements specified in WB-2431.1, tensile and toughness tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes; the material combinations to require weld material testing, as listed in WB-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the

number of  $C_v$  specimens, drop weight specimens, and fracture toughness test specimens required by WB-2330, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat-treated condition. The PWHT temperatures shall be in accordance with Table WB-4622.1-1 for the applicable P-Number equivalent. The time at PWHT temperature shall be 8 hr. (This qualifies PWHT of 10 hr or less.) When the PWHT of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of WB-2431.1 shall be used.

(d) The tensile and  $C_v$  specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight and fracture toughness test specimens, where required, shall be located and oriented as specified in WB-2431.1(d).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of WB-2431.1(f) shall be applicable to the toughness testing of this option.

**WB-2432 Chemical Analysis Test**

Chemical analysis of filler metal or weld deposits shall be made in accordance with WB-2420 and as required by the following subparagraphs.

**WB-2432.1 Test Method.** The chemical analysis test shall be performed in accordance with this subparagraph and Table WB-2432.1-1, and the results shall conform to WB-2432.2. (17)

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

	<b>GTAW/PAW</b>	<b>GMAW</b>	<b>All Other Processes</b>
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The methods given in the Appendix of SFA-5.9 shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution. The weld for A-No. 8 material to be used with the GMAW process shall be made using the shielding gas composition specified in the WPSs that will be followed when the material is consumed. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by WB-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of WB-2431.1(c) do not apply.

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the WPS that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with Section IX, Table QW-453 for the minimum thickness for which the welding procedure specification is qualified.

**WB-2432.2 Requirements for Chemical Analysis.** The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a) through (c) below.

(a) See (1) and (2) below.

(1) All welding material of ferrous alloys A-No. 8 and A-No. 9 (Section IX, Table QW-442) shall be analyzed for the elements listed in Table WB-2432.2-1 and for any other elements specified in the welding material specification referenced by the WPS or in the WPS.

(2) All other welding material shall be analyzed for the elements specified in either the welding material specification referenced by the WPS or in the WPS.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the welding procedure specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported. Elements listed in Table WB-2432.2-1 but not specified in the welding material specification or WPS shall be reported for information only.

**WB-2433 Delta Ferrite Determination**

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.9 and SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

**WB-2433.1 Method.** Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of WB-2432 in conjunction with Figure WB-2433.1-1.

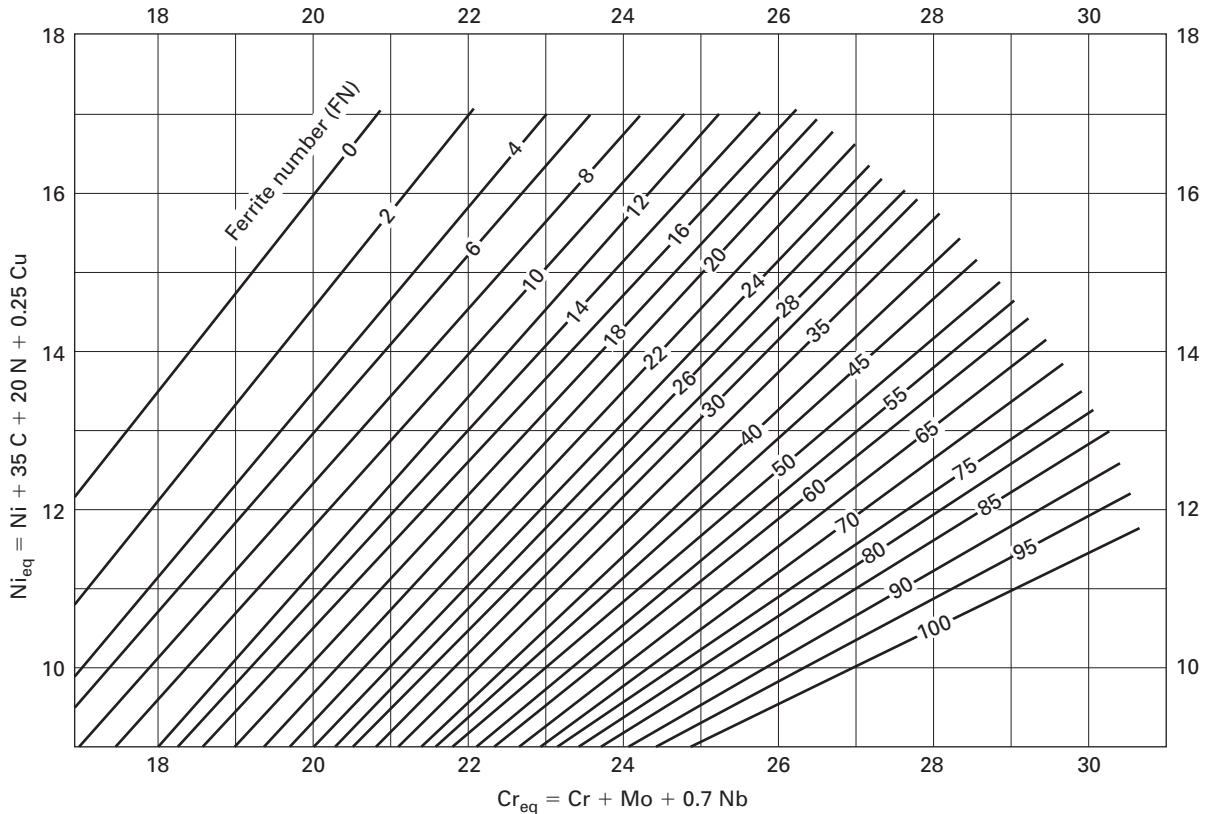
(a) Calibration of magnetic instruments shall conform to AWS-A4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with WB-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

<b>Table WB-2432.2-1 Chemical Analysis for Welding Material</b>	
<b>Materials</b>	<b>Elements</b>
Chromium-Nickel stainless steels	C, Cr, Mo, Ni, Mn, Si, Cb + Ta

**Figure WB-2433.1-1  
Weld Metal Delta Ferrite Content**



**GENERAL NOTES:**

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
  - (1) GMAW welds — 0.08%, except that when self-shielding flux-cored electrodes are used — 0.12%
  - (2) Welds made using other processes — 0.06%
- (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

**WB-2433.2 Acceptance Standards.** The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of [WB-2130](#) or [WB-4120](#).

**WB-2440 STORAGE AND HANDLING OF WELDING MATERIAL**

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

**WB-2500 EXAMINATION AND REPAIR OF CONTAINMENT MATERIAL**

**WB-2510 EXAMINATION OF CONTAINMENT MATERIAL**

(a) Containment material and material welded thereto shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this subarticle. Seamless pipe, tubes, and fittings NPS 1 (DN 25), and less, need not be examined by the rules of this subarticle.

(b) The requirements of this subarticle for repair by welding, including examination of the repair welds, shall be met wherever repair welds are made to containment material and material welded thereto. The exceptions in (a) above do not apply to repair welds.

## WB-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this subarticle for each product form after the quenching and tempering phase of the heat treatment.

## WB-2530 EXAMINATION AND REPAIR OF PLATE

### WB-2531 Required Examination

All plates 2 in. (50 mm) nominal thickness and less shall be examined by the angle beam ultrasonic method in accordance with [WB-2532.2](#). All plates greater than 2 in. (50 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with [WB-2532.1](#).

### WB-2532 Examination Procedures

**WB-2532.1 Straight Beam Examination.** The requirements for straight beam examination shall be in accordance with SA-578, Specification for Straight Beam Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in (a) and (b) below.

(a) *Extent of Examination.* One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

(b) *Acceptance Standards*

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (75 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

**WB-2532.2 Angle Beam Examination.** The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Beam Wave Inspection of Steel Plates, as shown in Section V and supplemented by (a) and (b) below. The calibration notch, extent of examination, and acceptance standards to be applied are given in (a) through (c) below.

(a) *Calibration.* Angle beam examination shall be calibrated from a notch.

(b) *Extent of Examination.* One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than 10% overlap.

(c) *Acceptance Standards.* Material that shows one or more imperfections which produce indications exceeding in amplitude the indication from the calibration notch is unacceptable unless additional exploration by the straight beam method shows the imperfections are laminar in nature and are acceptable in accordance with [WB-2532.1\(b\)](#).

### WB-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) *Ultrasonic examination* shall be performed after rolling to size and after heat treatment, except for postweld heat treatment.

(b) *Radiographic examination* of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) *Magnetic particle or liquid penetrant examination* of repair welds shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No.1 material 2 in. (51 mm) and less nominal thickness.

### WB-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (d) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with [WB-2545](#) or the liquid penetrant method in accordance with [WB-2546](#) to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) When the elimination of the defect reduces the thickness of the section below the minimum required to satisfy [Article WB-3000](#), the product shall be repaired in accordance with [WB-2539](#).

### WB-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of a containment.

**WB-2539.1 Defect Removal.** The defect shall be removed by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair ([WB-4211.1](#)).



**WB-2539.2 Qualification of Welding Procedures and Welders.** The welding procedure and welders or welding operators shall be qualified in accordance with [Article WB-4000](#) and Section IX.

**WB-2539.3 Blending of Repaired Areas.** After repair, the surface shall be blended uniformly into the surrounding surface.

**WB-2539.4 Examination of Repair Welds.** Each repair weld shall be examined by the magnetic particle method ([WB-2545](#)) or by the liquid penetrant method ([WB-2546](#)). In addition, when the depth of the repair cavity exceeds the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed after repair in accordance with [WB-5110](#) and to the acceptance standards of [WB-5320](#). The penetrometer and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness at the repair area.

**WB-2539.5 Heat Treatment After Repairs.** The product shall be heat treated after repair in accordance with the heat treatment requirements of [WB-4620](#).

**WB-2539.6 Material Report Describing Defects and Repairs.** Each defect repair exceeding in depth the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

**WB-2539.7 Repair of Cladding by Welding.** The Material Organization may repair defects in cladding by welding, provided the requirements of (a) through (d) below are met.

(a) *Qualification of Welding Procedures and Welders.* The welding procedure and the welders or welding operators shall be qualified in accordance with [Article WB-4000](#) and with Section IX.

(b) *Defect Removal and Examination of Cavity.* The defect shall be removed, and the cavity prepared for repair shall be examined by the liquid penetrant method ([WB-2546](#)).

(c) *Examination of Repaired Areas.* The repaired area shall be examined by a liquid penetrant method ([WB-2546](#)).

(d) *Report of Repairs.* Each defect repair shall be described in the Certified Material Test Report for each piece, including a chart which shows the location and size of the repair, the welding material identification, welding procedure, heat treatment, and examination results.

## **WB-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS**

### **WB-2541 Required Examinations**

(a) Forgings and bars shall be examined by the ultrasonic method in accordance with [WB-2542](#), except forgings or sections of forgings which have coarse grains, or configurations which do not yield meaningful examination results by ultrasonic methods, shall be examined by radiographic methods in accordance with Section V, Article 2, using the acceptance standards of [WB-5320](#). In addition, all external surfaces and accessible internal surfaces shall be examined by a magnetic particle method ([WB-2545](#)) or a liquid penetrant method ([WB-2546](#)).

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of [WB-2550](#).

(c) Bar material used for bolting shall be examined in accordance with [WB-2580](#).

(d) Forgings and forged or rolled bars which are to be bored to form tubular products or fittings shall be examined in accordance with the requirements of [WB-2550](#) after boring.

### **WB-2542 Ultrasonic Examination**

**WB-2542.1 Examination Procedure.** All forgings in the rough-forged or finished condition, and bars, shall be examined in accordance with Section V, Article 5 and the following supplemental requirements. The techniques of (a) through (d) below are required, as applicable.

(a) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections, provided the acceptance standards are shown to be equivalent to those listed in [WB-2542.2](#).

(b) Cylindrical section bars shall be scanned from the entire external circumference.

(c) Noncylindrical section bars shall be scanned in two perpendicular directions to the maximum extent possible (through each pair of parallel sides).

(d) Bar products do not require recording and reporting of indications smaller than the acceptance standard, except when so specified for specialized applications.

#### **WB-2542.2 Acceptance Standards.**

(a) *Straight Beam General Rule.* A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors which produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) *Straight Beam Special Rule for Containment Shell Sections*

(1) A ring forging made to fine grain melting practice and used for containment shell sections shall be unacceptable if the results of the straight beam radial examination show one or more reflectors producing a continuous

complete loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed with a circle whose diameter is 3 in. (75 mm) or one-half of the wall thickness, whichever is greater.

(2) In addition, two or more reflectors smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger reflector or unless they may be collectively encompassed by the circle described in (1) above.

(c) *Angle Beam Rule.* A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors which produce indications exceeding in amplitude the indication from the appropriate calibration notches.

### WB-2545 Magnetic Particle Examination

**WB-2545.1 Examination Procedure.** The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

#### WB-2545.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the WB-2545.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

#### WB-2545.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for material less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for material from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater;

(3) four or more indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

### WB-2546 Liquid Penetrant Examination

**WB-2546.1 Examination Procedure.** The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

#### WB-2546.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are not relevant.

(b) Any indication in excess of the WB-2546.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation, which would mask defects, are unacceptable.

(c) *Relevant indications* are indications which result from imperfections. *Linear indications* are indications in which the length is more than three times the width. *Rounded indications* are indications which are circular or elliptical with the length equal to or less than three times the width.

#### WB-2546.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for material less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for material from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater;

(3) four or more indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

### WB-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in (a) through (d) below.

(a) Ultrasonic examination may be performed at any time after forging [WB-2541(d)], and the maximum practical volume, including weld repairs, if required, shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination shall be performed in the finished condition, except repair welds of P-No. 1 material, 2 in. (50 mm) nominal thickness and less, may be examined prior to postweld heat treatment.

(d) Forgings and rolled bars which are to be bored or turned to form tubular parts or fittings shall be examined after boring or turning, except for threading.

### **WB-2548 Elimination of Surface Defects**

Elimination of surface defects shall be made in accordance with WB-2538.

### **WB-2549 Repair by Welding**

Repair by welding shall be in accordance with WB-2539, except that:

(a) the depth of repair that is permitted is not limited; and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic method in accordance with the requirements of WB-2542 in lieu of radiography.

### **WB-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED TUBULAR PRODUCTS AND FITTINGS**

#### **(17) WB-2551 Required Examination**

In addition to the requirements of the material specification and of this Article, seamless and welded tubular products (including pipe flanges and fittings machined from forgings and bars) shall comply with the following.

(a) Wrought seamless and welded pipe and tubing shall be examined over the entire volume of the material in accordance with (1), (2), or (3), as follows. The volumetric examinations required by this paragraph need only be conducted from one surface. Tubular products may require both outside and inside surface conditioning prior to examination.

#### *(1) Pipe and Tubing*

(-a) Pipe and tubing smaller than 2½ in. (64 mm) O.D. shall be examined by the ultrasonic method in accordance with WB-2552.1(a) in two opposite circumferential directions<sup>7</sup> and by the eddy current method in accordance with WB-2554, provided the product is limited to sizes, materials, and thicknesses for which meaningful results can be obtained by eddy current examination as evidenced by detection of required standards. Each method shall be calibrated to the appropriate standard: that is, the ultrasonic method shall be calibrated to the axial

notches or grooves of WB-2552.1(b), and the eddy current method shall be calibrated to the circumferential notches and grooves as well as the radial hole of WB-2554.2.

(-b) As an alternative to the eddy current examination or when the eddy current examination does not yield meaningful results, an axial scan ultrasonic examination in two opposite axial directions,<sup>7</sup> in accordance with WB-2552.1(b), shall be made.

(2) Pipe and tubing 2½ in. (64 mm) O.D. and larger shall be examined by the ultrasonic method in accordance with WB-2552.1(a) in two opposite circumferential directions, and in accordance with WB-2552.1(b) in two opposite axial directions. Alternatively, for welded without filler metal pipe larger than 6¾ in. (170 mm) O.D., the plate shall be examined by the ultrasonic method in accordance with WB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with WB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming and may be performed prior to any required postweld heat treatment.

(3) Copper-nickel alloy and nickel alloy seamless pipe and tubing shall be examined as follows.

(-a) Each pipe and tube, all sizes shall be ultrasonically examined in accordance with WB-2552.1(a) in two opposite circumferential directions.

(-b) Pipe and tubing smaller than 2½ in. (64 mm) O.D. shall be examined by the eddy current method in accordance with WB-2554 if meaningful indications can be obtained from the reference specimen notches. If meaningful indications cannot be obtained from the reference specimen, an axial scan ultrasonic examination in two opposite axial directions, in accordance with WB-2552.1(b), shall be made.

(-c) Pipe and tubing 2½ in. (64 mm) O.D. and larger shall be examined by an axial scan ultrasonic examination in two opposite axial directions in accordance with WB-2552.1(b).

(b) Wrought seamless and welded without filler metal fittings (including pipe flanges and fittings machined from forgings and bars) shall be examined in accordance with the material specification, and in addition by the magnetic particle method in accordance with WB-2555, or the liquid penetrant method in accordance with WB-2556 on all external surfaces and all accessible internal surfaces (excluding bolt holes and threads). Additionally, for fittings over NPS 6 (DN 150), the entire volume shall be examined by the ultrasonic method, if feasible, in accordance with WB-2552, or the radiographic method in accordance with WB-2553. Alternatively, the plate shall be examined by the ultrasonic method in accordance with WB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with WB-2553. Radiographic examination of welds, including

repair welds, shall be performed after final rolling and forming, and may be performed prior to any required postweld heat treatment.

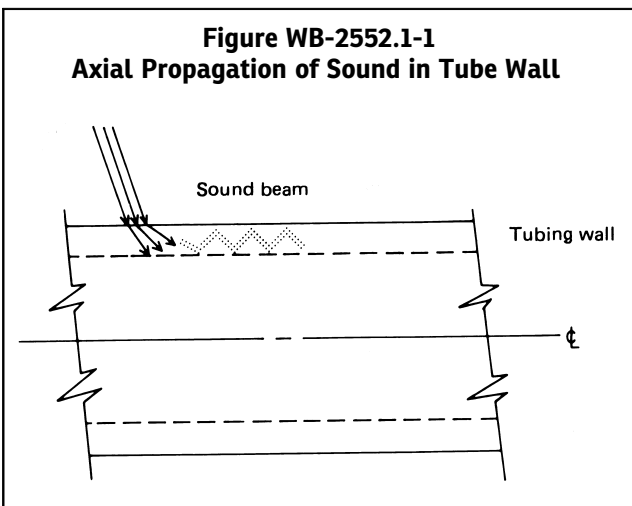
## WB-2552 Ultrasonic Examination<sup>7</sup>

**WB-2552.1 Examination Procedure for Pipe and Tubing.** Independent channels or instruments shall be employed for circumferential and axial scans.

(a) *Circumferential Direction.* The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213 except as required in WB-2551(a)(1), WB-2551(a)(2), and WB-2551(a)(3)(-a), and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to, or greater than, the indications produced by the standard defects included in the reference specimens specified in WB-2552.3.

(b) *Axial Direction.* When required by WB-2551, the ultrasonic examination of pipe and tubing shall include angle beam scanning in the axial direction. The procedure for the axial scans shall be in accordance with SE-213, except that the propagation of sound in the tube or pipe wall shall be in the axial direction instead of the circumferential direction and as required in WB-2551(a)(1)(-b), WB-2551(a)(2), WB-2551(a)(3)(-b), and WB-2551(a)(3)(-c). Figure WB-2552.1-1 illustrates the characteristic oblique entry of sound into the pipe or tube wall and the axial direction of ultrasonic energy propagation to detect transverse notches or similar surface discontinuities.

(c) *Acceptance Standards.* Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with WB-2558 or WB-2559.



## WB-2552.2 Examination Procedure for Fittings.

(a) *Procedure.* The procedure for ultrasonic examination of fittings shall be in accordance with the requirements of SA-388 for straight beam examination and, where feasible, angle-beam examination in two circumferential directions.

(b) *Acceptance Standards.* Fittings shall be unacceptable if straight beam examination shows one or more reflectors that produce indications accompanied by complete loss of back reflection not associated with or attributable to the geometric configuration, or if angle beam examination results show one or more reflectors that produce indications exceeding in amplitude the indications from the calibrated notch. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

## WB-2552.3 Reference Specimens.

(a) The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition as the product which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen, and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed  $\frac{1}{16}$  in. (1.5 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. For axial scanning in accordance with SE-213, a transverse (circumferential) notch shall be introduced on the inner and outer surfaces of the standard. Dimensions of the transverse notch shall not exceed those of the longitudinal notch. The reference specimen may be the product being examined.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

## WB-2552.4 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum

- (a) at the beginning of each production run of a given size and thickness of a given material;
- (b) after each 4 hr or less during the production run;
- (c) at the end of the production run;
- (d) at any time that malfunctioning is suspected. If, during any check, it is determined that the test equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.



**WB-2553 Radiographic Examination**

(a) *General.* When radiographic examination is performed as an alternative for ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) *Examination Procedure.* The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by [WB-5111](#).

(c) *Acceptance Standard.* Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication which has a length greater than:

(a)  $\frac{1}{4}$  in. for  $t$  up to  $\frac{3}{4}$  in. (6 mm to 19 mm), inclusive

(b)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. to  $2\frac{1}{4}$  in., inclusive (19 mm to 57 mm)

(c)  $\frac{3}{4}$  in. for  $t$  over  $2\frac{1}{4}$  in. (19 mm to 57 mm) where  $t$  is the thickness of the thinner portion of the weld;

(3) any group of aligned indications having an aggregate length greater than  $t$  in a length of  $12t$ , unless the minimum distance between successive indications exceeds  $6L$ , in which case the aggregate length is unlimited,  $L$  being the length of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

**WB-2554 Eddy Current Examination**

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

**WB-2554.1 Examination Procedure.** The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in [WB-2554.2](#). Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with [WB-2558](#) or [WB-2559](#) as applicable.

**WB-2554.2 Reference Specimens.** The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a  $\frac{1}{16}$  in. (1.5 mm) diameter hole drilled through the wall. For copper-nickel alloy and nickel alloy materials, the standard shall have one notch extending circumferentially on the outside surface and one notch extending circumferentially on the inside

surface plus a  $\frac{1}{16}$  in. (1.5 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed  $\frac{1}{16}$  in. (1.5 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in [WB-2552.3](#).

**WB-2554.3 Checking and Calibration of Equipment.**

The checking and calibration of examination equipment shall be the same as in [WB-2552.4](#).

**WB-2555 Magnetic Particle Examination**

Magnetic particle examination shall be performed in accordance with the requirements of [WB-2545](#).

**WB-2556 Liquid Penetrant Examination**

Liquid penetrant examination shall be performed in accordance with the requirements of [WB-2546](#).

**WB-2557 Time of Examination**

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows:

(1) Ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment.

(2) Radiographic examination, when required, may be performed prior to any required postweld heat treatment.

(3) Magnetic particle or liquid penetrant examination, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (50 mm) and less nominal thickness.

(4) Forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

**WB-2558 Elimination of Surface Defects**

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of [Article WB-3000](#), the product shall be repaired in accordance with [WB-2559](#).

### WB-2559 Repair by Welding

Repair of defects shall be in accordance with [WB-2539](#), except repair by welding is not permitted on copper-nickel alloy and nickel alloy materials.

### WB-2570 EXAMINATION AND REPAIR OF CAST PRODUCTS

#### WB-2571 Required Examination

For examination of the containment casting, the following shall apply:

(a) All cast products shall be examined by the ultrasonic method as specified in [WB-2574](#).

(b) All external and accessible internal surfaces, except threaded surfaces, shall be examined using either the liquid penetrant method ([WB-2576](#)) or the magnetic particle method ([WB-2577](#)).

#### WB-2572 Time of Nondestructive Examination

All examinations shall be performed after final machining except that ultrasonic testing shall be performed at the time when the configuration is best suited for scanning and the most meaningful results can be obtained.

#### WB-2573 Provisions for Repair of Base Material by Welding

Castings shall not be repaired by plugging, welding, brazing, impregnation, or any other means.

#### WB-2574 Ultrasonic Examination of Castings

Ultrasonic examination shall be performed in accordance with Section V, Article 5, T-571.4. Each manufacturer shall certify that the procedure is in accordance with the following requirements and shall make the procedure available for approval upon request.

The following acceptance standards shall be applied:

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thickness indicated.

(1) Quality Level 1 for thicknesses up to 2 in. (50 mm)

(2) Quality Level 3 for thicknesses 2 in. to 4 in. (50 mm to 100 mm)

(3) Quality Level 4 for thicknesses greater than 4 in. (100 mm)

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation shall be unacceptable:

UT Quality Level	Longest Dimension of Area, in. (mm)
	[Notes (1), (2), and (3)]
1	1.5 (38)
2	2.0 (50)
3	2.5 (64)
4	3.0 (75)

NOTES:

(1) The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which continuous indication, exceeding the transfer-corrected distance amplitude curve, is maintained.

(2) Areas shall be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

(3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread shall be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm), whichever is less, shall be unacceptable.

(4) Two or more indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications shall be unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (1).

(5) Two or more indications greater than permitted for Quality Level 1 for castings less than 2 in. (50 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. through 4 in. (50 mm through 100 mm), and greater than permitted for Quality Level 3 for thicknesses greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications, shall be unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (1).

#### WB-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks,

scale, or dents may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be regarded as a defect until it is reexamined to verify whether actual defects are present. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those that result from mechanical discontinuities. Linear indications are those whose length is more than 3 times the width. Rounded indications are those that are circular or elliptical with the length less than 3 times the width. Indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) are considered relevant.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for materials less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for materials from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge-to-edge

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated

### **WB-2577 Magnetic Particle Examination (for Ductile Cast Iron)**

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards that is believed to be nonrelevant shall be regarded as a defect until it is reexamined to verify whether actual defects are present. Nonrelevant indications that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those that result from unacceptable mechanical discontinuities and have a major dimension greater than  $\frac{1}{16}$  in. (1.5 mm). Linear indications are those whose length is more than 3 times the width. Rounded indications are those that are circular or elliptical with the length less than 3 times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for materials less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for materials from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) long for materials from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge-to-edge

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated

### **WB-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS**

#### **WB-2581 Required Examination (17)**

All bolting material shall be visually examined in accordance with [WB-2582](#). In addition, nominal sizes greater than 1 in. (25 mm) shall be examined by either the magnetic particle method in accordance with [WB-2583](#) or the liquid penetrant method in accordance with [WB-2584](#). In addition, nominal sizes greater than 2 in. (50 mm) but not over 4 in. (100 mm) shall be examined by the ultrasonic method in accordance with [WB-2585](#) and nominal sizes greater than 4 in. (100 mm) shall be examined by the ultrasonic method in accordance with both [WB-2585](#) and [WB-2586](#).

#### **WB-2582 Visual Examination (17)**

The final surfaces of threads, shanks, and heads shall be visually examined for workmanship, finish, and appearance in accordance with the requirements of ASTM F788 for bolting material and ASTM F812 for nuts. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to [WB-5100](#) or by personnel qualified in accordance with [WB-5500](#).

### **WB-2583 Magnetic Particle Examination (for Ferritic Steel Bolting Material Only)**

**WB-2583.1 Examination Procedure.** All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by the magnetic particle method in accordance with ASTM A275. If desired, the supplier may perform liquid penetrant examination in accordance with [WB-2584](#) instead of magnetic particle examination. Such examination shall be performed on the finished

component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved). This examination shall be performed on all accessible surfaces.

**WB-2583.2 Evaluation of Indications.**

(a) All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than 3 times the width. Rounded indications are those which are circular or elliptical with the length equal to or less than 3 times the width.

(b) All indications are not necessarily relevant: leakage of magnetic fields and permeability variations may produce indications that are not relevant to the detection of unacceptable discontinuities. Indications with major dimensions of  $\frac{1}{16}$  in. (1.5 mm) or less are not relevant.

(c) Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning.

(d) Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

(e) As an alternative to magnetic particle reexamination, other nondestructive examination means (such as liquid penetrant examination for surface discontinuities) may be used to determine relevancy.

**WB-2583.3 Acceptance Standard.** Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.

**WB-2584 Liquid Penetrant Examination**

**WB-2584.1 Examination Procedure.** All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by a liquid penetrant method in accordance with the methods of Section V, Article 6. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved).

**WB-2584.2 Evaluation of Indications.** All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those which are circular to elliptical with the length equal to or less than three times the width. All penetrant indications are not necessarily relevant. Surface imperfections such as machining marks and scratches may produce indications that are nonrelevant to the detection of unacceptable discontinuities. Broad areas of pigmentation, which could mask indications of defects, are unacceptable. Indications with major dimensions of  $\frac{1}{16}$  in. (1.5 mm) or less are not relevant. Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning. Any area of

pigmentation also shall be reexamined after recleaning or light surface conditioning, as appropriate. Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

**WB-2584.3 Acceptance Standard.** Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) long are unacceptable.

**WB-2585 Ultrasonic Examination for Sizes Greater Than 2 in. (50 mm)**

All bolts, studs, and nuts greater than 2 in. (50 mm) nominal bolt size shall be ultrasonically examined over the entire cylindrical surface prior to threading in accordance with the following requirements.

**WB-2585.1 Ultrasonic Method.** Examination shall be carried out by the straight beam, radial-scan method in accordance with Section V, Article 23, SA-388.

**WB-2585.2 Examination Procedure.** Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit not to exceed 1 in.<sup>2</sup> (650 mm<sup>2</sup>).

**WB-2585.3 Calibration of Equipment.** Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full-screen height.

**WB-2585.4 Acceptance Standard.** Any discontinuity that causes an indication in excess of 20% of the height of the first back reflection or any discontinuity that prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

**WB-2586 Ultrasonic Examination for Sizes Over 4 in. (100 mm)**

In addition to the requirements of [WB-2585](#), all bolts, studs, and nuts over 4 in. (100 mm) nominal bolt size shall be ultrasonically examined over the entire surface of each end before or after threading in accordance with the following requirements.

**WB-2586.1 Ultrasonic Method.** Examination shall be carried out by the straight beam, longitudinal-scan method.

**WB-2586.2 Examination Procedure.** Examination shall be performed at a nominal frequency of 2.25 MHz with a search unit having a circular cross section with a diameter not less than  $\frac{1}{2}$  in. (13 mm) nor more than  $1\frac{1}{8}$  in. (29 mm).

**WB-2586.3 Calibration of Equipment.** Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A  $\frac{3}{8}$  in. (10 mm) diameter by 3 in. (75 mm) deep flat-bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance–amplitude curve shall be established by scanning from both ends of the test bar.



**WB-2586.4 Acceptance Standard.** Any discontinuity that causes an indication in excess of that produced by the calibration hole in the reference specimen as corrected by the distance–amplitude curve is not acceptable.

**WB-2587 Time of Examination**

Acceptance examinations shall be performed after the final heat treatment required by the basic material specification.

**WB-2588 Elimination of Surface Defects**

Unacceptable surface defects on finished bolts, studs, and nuts are not permitted, and are cause for rejection.

**WB-2589 Repair by Welding**

Weld repairs of bolts, studs, and nuts are not permitted.

**WB-2600 MATERIAL ORGANIZATION'S QUALITY SYSTEM PROGRAMS**

(17) **WB-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS**

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of [WA-3800](#).

(b) The requirements of NCA-3860 and NCA-4256 shall be met as required by [WB-2130](#) and [WB-2150](#), respectively. The other requirements of [WA-3800](#) need not be used by Material Organizations for small products, as defined in (c) below, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program ([Article WA-4000](#)) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (4) below:

(1) pipe, tube, pipe fittings, and flanges NPS 2 (DN 50) and less;

(2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 in.<sup>2</sup> (650 mm<sup>2</sup>) and less; and

(4) material for valves with inlet pipe connections of NPS 2 (DN 50) and less.

**WB-2700 DIMENSIONAL STANDARDS**

Dimensions of standard items shall comply with the standards and specifications listed in [Article WA-7000](#).

# ARTICLE WB-3000 DESIGN

## WB-3100 GENERAL DESIGN

### WB-3110 LOADING CRITERIA

#### WB-3111 Loading Conditions

The loadings considered in designing a containment as identified in the Design Specification shall include, but are not limited to those in (a) through (g) below:

- (a) internal and external pressures
- (b) impact loads caused by either internal or external conditions, including drop and puncture
- (c) weight of the containment and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids
- (d) superimposed loads such as other components, operating equipment, impact limiting devices, shielding, insulation, and linings
- (e) shock loads, vibration loads, transportation loads, and handling loads
- (f) reaction loads from attachments and supports
- (g) temperature effects caused by contents, the external environment, and other components

#### WB-3112 Design Loadings

The Design Loadings shall be established in accordance with [WA-2123.1](#) and the following subparagraphs.

**WB-3112.1 Design Pressure.** The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with [WA-2123.1\(a\)](#).

**WB-3112.2 Design Temperature.** The specified Design Temperature shall be established in accordance with [WA-2123.1\(b\)](#). It shall be used in computations involving the Design Pressure and the coincidental Design Mechanical Loads. If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature of the metal exceed the maximum temperature listed in the applicability column of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, nor exceed the maximum temperature limitations specified elsewhere in this Subsection.

**WB-3112.3 Design Mechanical Loads.** The specified Design Mechanical Loads shall be established in accordance with [WA-2123.1\(c\)](#). They shall be used in conjunction with the Design Pressure.

#### WB-3112.4 Design Stress Intensity Values.

(a) Design stress intensity values for Section III, Class TC materials listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 shall be used. The materials shall not be used at temperatures that exceed the temperature limit established in the stress tables. The stress intensity values in the tables may be interpolated for intermediate temperatures. As an additional control on permitted transportation containment materials listed in Section II, Part D, Subpart 1, Tables 2A and 2B, only the following materials shall be used:

- (1) materials whose P-numbers are listed in [Table WB-4622.1-1](#), or
- (2) ductile cast iron castings per specifications SA-874 or SA/JIS G5504 of Section II, Part D, Subpart 1, Table 2A

(b) The design of a containment shall be determined so that the primary membrane and primary membrane plus bending stress intensities due to any combination of Design Loading does not exceed the maximum design stress intensity value permitted at the Design Temperature. These design stress intensity values may be interpolated for an intermediate Design Temperature.

#### WB-3113 Operating and Test Conditions

(17)

(a) Transportation containments ([WA-1110](#)) are subject to operating and test conditions that are required to be considered in the design of the containment in order to satisfy applicable safety criteria.

(b) The selection of operating and test conditions is beyond the scope of this Division. The Design Specification shall specify these conditions using appropriate guidance from safety criteria documents for transportation containments and the requirements of regulatory and enforcement authorities having jurisdiction.

(c) Each operating and test condition to which the containment may be subjected shall be classified in accordance with [WA-2120](#), and Service Limits [[WA-2123.4\(b\)](#)] shall be designated in the Design Specification in such detail as will provide a complete basis for design in accordance with this Subsection.

(d) When any loading for which Level A or D Service Limits are specified in the Design Specification, they shall be evaluated in accordance with [WA-2120](#) and in compliance with the applicable design and stress intensity limits of this Subsection.

**WB-3114 Stress Limits**

Stress limits associated with operating and test conditions are specified in [WB-3220](#) and [WB-3230](#).

**WB-3120 SPECIAL CONSIDERATIONS****WB-3121 Material Degradation**

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made in the Design Specification for these effects by indicating the increase in the thickness of the base metal over that determined by the design analysis ([WB-3200](#)). Other suitable methods of protection may be used. Material added or included for these purposes need not be of the same thickness for all areas of the containment if different rates of attack are expected for the various areas.

**WB-3122 Cladding**

The rules of this paragraph apply to the design of clad containments constructed of materials permitted in Section II, Part D, Subpart 1, Tables 2A and 2B. Only materials whose P-numbers are listed in [Table WB-4622.1-1](#) shall be used.

**WB-3122.1 Primary Stresses.** No structural strength shall be attributed to the cladding.

**WB-3122.2 Design Dimensions.** The dimensions given in (a) and (b) below shall be used in the design of the containment.

(a) For containments subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For containments subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

**WB-3122.3 Secondary and Peak Stresses.** In satisfying [WB-3222.6](#) and [WB-3222.9](#), the presence of the cladding shall be considered with respect to both the thermal analysis and the stress analysis. The stresses in both materials shall be limited to the values specified in [WB-3222.6](#) and [WB-3222.9](#). However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the containment, the presence of the cladding may be neglected.

**WB-3122.4 Bearing Stresses.** In satisfying [WB-3227.1](#), the presence of cladding shall be included.

**WB-3123 Welding**

**WB-3123.1 Dissimilar Metals.** In satisfying the requirements of this subarticle, caution shall be exercised in design and construction involving dissimilar metals having different chemical compositions, mechanical properties, and coefficients of thermal expansion to avoid difficulties in service.

**WB-3123.2 Fillet Welded Attachments.** Fillet welds conforming to [Figure WB-4427-1](#) may be used for attachments to containments except as limited by [WB-4433](#). Limits for primary and secondary stress intensities in the weld shall be one-half of the allowable primary and secondary stress intensities for the weaker of the materials being joined. Evaluation for cyclic loading shall be made in accordance with [WB-3222.9](#), using a fatigue strength reduction factor of 4, and shall include consideration of temperature differences between the containment and the attachment, and of expansion or contraction of the containment produced by internal or external pressure.

**WB-3130 GENERAL DESIGN RULES****WB-3131 Design Reports**

The Certificate Holder shall provide a Design Report conforming to the requirements of [WA-3352](#) and [WB-3211](#).

**WB-3132 Dimensional Standards for Standard Products**

Dimensions of standard products shall comply with the standards and specifications listed in [Table WA-7100-1](#) when the standard or specification is referenced in the specific design subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis.

**WB-3133 External Pressure, Axial Compression, Buckling, and Instability**

Rules are given in this paragraph for the consideration of statically applied external pressure and axial compression loads for Design Loadings and normal loadings. Compressive loads as a result of accident loadings shall use the rules from [WB-3224.1\(e\)](#).

**WB-3133.1 General.** Rules are given in this paragraph for determining the thickness of spherical shells, cylindrical shells with or without stiffening rings, and formed heads under external pressure loading.

**WB-3133.2 Nomenclature.** The symbols used in this paragraph are defined as follows:

$A$  = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having  $D_o/T$  values less than 10, see [WB-3133.3\(b\)](#). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.

$A_s$  = cross-sectional area of a stiffening ring

- $B$  = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi (MPa)
- $D_o$  = outside diameter of the cylindrical shell
- $E$  = modulus of elasticity of material at Design Temperature, psi (MPa). For external pressure and axial compression design in accordance with this Subsection, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Section II, Part D, Subpart 2, Tables TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design
- $I$  = available moment of inertia of the combined ring-shell section about its neutral axis, parallel to the axis of the shell. The width of the shell which is taken as contributing to the combined moment of inertia shall be not greater than  $1.10 \sqrt{D_o T_n}$  and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.
- $I_s$  = required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell
- $L$  = the design length of a containment taken as the largest of the following:
- (a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings
  - (b) the greatest center-to-center distance between any two adjacent stiffening rings
  - (c) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the containment
- $L_s$  = one-half the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is one of the following:
- (a) a stiffening ring that meets the requirements of this paragraph
  - (b) a circumferential line on a head at one-third the depth of the head from the head tangent line
  - (c) circumferential connection to a jacket for a jacketed section of a cylindrical shell
- $P$  = external Design Pressure, psi (MPa) (gage or absolute, as required)

- $P_a$  = allowable external pressure, psi (MPa) (gage or absolute as required)
- $R$  = inside radius of spherical shell
- $S$  = the lesser of 1.5 times the stress intensity at design metal temperature from Section II, Part D, Subpart 1, Tables 2A and 2B or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1, psi (MPa)
- $T$  = minimum required thickness of cylindrical shell or spherical shell
- $T_n$  = nominal thickness used, less corrosion allowance, of a cylindrical shell

**WB-3133.3 Cylindrical Shells.** The thickness of cylinders under external pressure shall be determined by the procedure given in (a) or (b) below.

(a) Cylinders having  $D_o/T$  values  $\geq 10$ :

*Step 1.* Assume a value for  $T$  and determine the ratios  $L/D_o$  and  $D_o/T$ .

*Step 2.* Enter Section II, Part D, Subpart 3, Figure G at the value at  $L/D_o$  determined in [Step 1](#). For values of  $L/D_o$  greater than 50, enter the chart at a value of  $L/D_o$  of 50. For values of  $L/D_o$  less than 0.05, enter the chart at a value of  $L/D_o$  of 0.05.

*Step 3.* Move horizontally to the line for the value of  $D_o/T$  determined in [Step 1](#). Interpolation may be made for intermediate values of  $D_o/T$ . From this point of intersection move vertically downward to determine the value of factor  $A$ .

*Step 4.* Using the value of  $A$  calculated in [Step 3](#), enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material/temperature line, see [Step 7](#).

*Step 5.* From the intersection obtained in [Step 4](#), move horizontally to the right and read the value of  $B$ .

*Step 6.* Using this value of  $B$ , calculate the value of the maximum allowable external pressure  $P_a$  using the following equation:

$$P_a = \frac{4B}{3(D_o/T)}$$

*Step 7.* For values of  $A$  falling to the left of the applicable material/temperature line, the value of  $P_a$  can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8. Compare  $P_a$  with  $P$ . If  $P_a$  is smaller than  $P$ , select a larger value for  $T$  and repeat the design procedure until a value of  $P_a$  is obtained that is equal to or greater than  $P$ .

(b) Cylinders having  $D_o/T$  values <10:

Step 1. Using the same procedure as given in (a) above, obtain the value of  $B$ . For values of  $D_o/T$  less than 4, the value of factor  $A$  can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of  $A$  greater than 0.10, use a value of 0.10.

Step 2. Using the value of  $B$  obtained in Step 1, calculate a value  $P_{a1}$  using the following equation:

$$P_{a1} = \left[ \frac{2.167}{(D_o/T)} - 0.0833 \right] B$$

Step 3. Calculate a value  $P_{a2}$  using the following equation:

$$P_{a2} = \frac{2S}{(D_o/T)} \left[ 1 - \frac{1}{(D_o/T)} \right]$$

Step 4. The smaller of the values of  $P_{a1}$  calculated in Step 2, or  $P_{a2}$  calculated in Step 3 shall be used for the maximum allowable external pressure  $P_a$ . Compare  $P_a$  with  $P$ . If  $P_a$  is smaller than  $P$ , select a larger value for  $T$  and repeat the design procedure until a value for  $P_a$  is obtained that is equal to or greater than  $P$ .

**WB-3133.4 Spherical Shells and Formed Heads.**

(a) *Spherical Shells.* The minimum required thickness of a spherical shell under external pressure shall be determined by the procedure given in Steps 1 through 6 below.

Step 1. Assume a value for  $T$  and calculate the value of factor  $A$  using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of  $A$  calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor  $B$ .

Step 4. Using the value of  $B$  obtained in Step 3, calculate the value of the maximum allowable external pressure  $P_a$  using the following equation:

$$P_a = \frac{B}{(R/T)}$$

Step 5. For values of  $A$  falling to the left of the applicable material/temperature line for the Design Temperature, the value of  $P_a$  can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6. Compare  $P_a$  obtained in Steps 4 or 5 with  $P$ . If  $P_a$  is smaller than  $P$ , select a larger value for  $T$  and repeat the design procedure until a value for  $P_a$  is obtained that is equal to or greater than  $P$ .

(b) *Nomenclature for Formed Heads.* The nomenclature defined below is used in the equations of (c) through (e) below.

$D$  = inside length of the major axis of an ellipsoidal head  
 $D_o$  = outside diameter of the head skirt at the point under consideration

$h$  = one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line, head bend line

$K_1$  = a factor depending on the ellipsoidal head proportions, given in Table WB-3133.4-1

$R$  = for hemispherical heads, the inside radius in the corroded condition  
 = for ellipsoidal heads, the equivalent inside spherical radius taken as  $K_1 D_o$  in the corroded condition  
 = for torispherical heads, the inside radius of the crown portion of the head in the corroded condition

$T$  = minimum required thickness of head after forming, exclusive of corrosion allowance

(c) *Hemispherical Heads.* The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in (a) above for determining the thickness for a spherical shell.

<b>Table WB-3133.4-1 Values of Spherical Radius Factor, <math>K_1</math></b>											
$D/2h$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
$K_1$	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Equivalent spherical radius =  $K_1 D$ ;  $D/2h$  = axis ratio; interpolation permitted for intermediate values.

(17)



(d) *Ellipsoidal Heads.* The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

*Step 1.* Assume a value for  $T$  and calculate the value of factor  $A$  using the following equation:

$$A = \frac{0.125}{(R/T)}$$

*Step 2.* Using the value of  $A$  calculated in [Step 1](#), follow the same procedure as that given for spherical shells in [\(a\) Step 2](#) through [\(a\) Step 6](#) above.

(e) *Torispherical Heads.* The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in [\(d\)](#) above, using the appropriate value for  $R$ .

#### WB-3133.5 Stiffening Rings for Cylindrical Shells.

(a) The required moment of inertia of the combined ring-shell section is given by the equation:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

The available moment of inertia  $I$  for a stiffening ring shall be determined by the procedure given in [Steps 1](#) through [6](#) below.

*Step 1.* Assuming that the shell has been designed and  $D_o$ ,  $L_s$ , and  $T_n$  are known, select a member to be used for the stiffening ring and determine its area  $A_s$  and the value of  $I$  defined in [WB-3133.2](#). Then calculate  $B$  by the equation:

$$B = \frac{3}{4} \left( \frac{PD_o}{T_n + A_s / L_s} \right)$$

*Step 2.* Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of  $B$  determined in [Step 1](#). If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor  $A$  in [Step 4](#) or [Step 5](#) below.

*Step 3.* Move horizontally to the left to the material/temperature line for the design metal temperature. For values of  $B$  falling below the left end of the material/temperature line, see [Step 5](#).

*Step 4.* Move vertically to the bottom of the chart and read the value of  $A$ .

*Step 5.* For values of  $B$  falling below the left end of the material/temperature line for the Design Temperature, the value of  $A$  can be calculated using the following equation:

$$A = 2B/E$$

*Step 6.* If the required  $I_s$  is greater than the computed moment of inertia  $I$  for the combined ring-shell section selected in [Step 1](#), a new section with a larger moment of inertia must be selected and a new  $I_s$  determined. If the required  $I_s$  is smaller than the computed  $I$  for the section selected in [Step 1](#), that section should be satisfactory.

(b) Stiffening rings may be attached to either the outside or the inside of the containment by continuous welding.

**WB-3133.6 Cylinders Under Axial Compression.** The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in [\(a\)](#) or [\(b\)](#) below:

(a) the  $S_m$  value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 2A and 2B

(b) the value of the factor  $B$  determined from the applicable chart in Section II, Part D, Subpart 3 using the following definitions for the symbols on the charts:

$R$  = inside radius of the cylindrical shell

$T$  = selected thickness of the shell, exclusive of the corrosion allowance

The value of  $B$  shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in [Steps 1](#) through [5](#) below.

*Step 1.* Using the selected values of  $T$  and  $R$ , calculate the value of factor  $A$  using the following equation:

$$A = \frac{0.125}{(R/T)}$$

*Step 2.* Using the value of  $A$  calculated in [Step 1](#), enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material/temperature line, see [Step 4](#).

*Step 3.* From the intersection obtained in [Step 2](#), move horizontally to the right and read the value of factor  $B$ . This is the maximum allowable compressive stress for the values of  $T$  and  $R$  used in [Step 1](#).

*Step 4.* For values of  $A$  falling to the left of the applicable material/temperature line, the value of  $B$  shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

*Step 5.* Compare the value of  $B$  determined in [Step 3](#) or [Step 4](#) with the computed longitudinal compressive stress in the cylindrical shell, using the selected values of  $T$  and

R. If the value of  $B$  is smaller than the computed compressive stress, a greater value of  $T$  must be selected and the design procedure repeated until a value of  $B$  is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell.

#### **WB-3134 Leak Tightness**

The leak tightness requirements for each containment shall be set forth in the Design Specification.

#### **WB-3135 Attachments**

(a) Except as permitted in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the containment as defined in WB-1130 shall meet the stress limits of the containment.

(b) The design of the containment shall include consideration of the interaction effects and loads transmitted through the attachment to and from the containment. Thermal stresses, stress concentrations, and restraint of the containment shall be considered.

(c) Beyond  $2t$  from the outside surface of the containment shell, where  $t$  is the nominal thickness of the containment shell, the appropriate design rules as identified in the Design Specification may be used.

(d) Nonstructural attachments shall meet the requirements of WB-4435.

### **WB-3200 DESIGN OF CONTAINMENTS**

#### **WB-3210 DESIGN CRITERIA**

##### **WB-3211 Requirements for Acceptability**

The requirements for the acceptability of a design by analysis are given in (a) through (d) below.

(a) The design shall be such that stress intensities will not exceed the limits described in this subarticle and tabulated in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The material shall not be used at metal or Design Temperature that exceeds the temperature limit in the applicability column for which stress intensity values are listed. The values in the tables may be interpolated for intermediate temperatures.

(b) The design details shall conform to the rules given in this Article.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, the critical buckling stress shall be taken into account as specified in WB-3133.

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in WB-2300.

##### **WB-3212 Basis for Determining Stresses**

The theory of failure, used in the rules of this Subsection for combining stresses, is the maximum shear stress theory. The maximum shear stress at a point is equal to

one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

#### **WB-3213 Terms Relating to Stress Analysis**

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs.

**WB-3213.1 Stress Intensity.**<sup>8</sup> Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

**WB-3213.2 Gross Structural Discontinuity.** Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness of the containment. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, reinforcement of openings in containment shells and heads, and junctions between shells of different diameters or thicknesses.

**WB-3213.3 Local Structural Discontinuity.** Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii and small attachments.

**WB-3213.4 Normal Stress.** Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components, one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

**WB-3213.5 Shear Stress.** Shear stress is the component of stress tangent to the plane of reference.

**WB-3213.6 Membrane Stress.** Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

**WB-3213.7 Bending Stress.** Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

**WB-3213.8 Primary Stress.** Primary stress is any normal stress or shear stress developed by an imposed loading, that is necessary to satisfy the laws of

equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are:

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads;

(b) bending stress in the central portion of a flat head due to pressure;

(c) longitudinal stress due to cylinder bending in the central portion of a horizontal cylindrical shell being decelerated by forces applied at its extreme ends.

Refer to [Table WB-3217-1](#) for examples of primary stress.

**WB-3213.9 Secondary Stress.** Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are:

(a) general thermal stress [[WB-3213.13\(a\)](#)];

(b) bending stress at a gross structural discontinuity.

Refer to [Table WB-3217-1](#) for examples of secondary stress.

**WB-3213.10 Local Primary Membrane Stress.** Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress.

A stressed region may be considered local if the distance over which the membrane stress intensity exceeds  $1.1S_m$  does not extend in the meridional direction more than  $1.0\sqrt{Rt}$ , where  $R$  is the minimum midsurface radius of curvature and  $t$  is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions that exceed  $1.1S_m$  shall not be closer in the meridional direction than  $2.5\sqrt{R_L t_L}$ , where  $R_L$  is defined as  $(R_1 + R_2)/2$  and  $t_L$  is defined as  $(t_1 + t_2)/2$  (where  $t_1$  and  $t_2$  are the minimum thicknesses at each of the regions considered, and  $R_1$  and  $R_2$  are the minimum midsurface radii of curvature at these regions where the membrane stress

intensity exceeds  $1.1S_m$ ). Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets, where the membrane stress intensity exceeds  $1.1S_m$ , shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds  $1.1S_m$ .

**WB-3213.11 Peak Stress.** Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [[WB-3213.13\(b\)](#)], or localized application of dynamic load including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stress are:

(a) the thermal stress in the austenitic steel cladding of a carbon steel part;

(b) certain thermal stresses that may cause fatigue but not distortion;

(c) the stress at a local structural discontinuity;

(d) surface stresses produced by thermal shock.

**WB-3213.12 Load-Controlled Stress.** Load-controlled stress is the stress resulting from application of a loading, such as internal pressure, inertial loads, or gravity, whose magnitude is not reduced as a result of displacement.

**WB-3213.13 Thermal Stress.** Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in [Table WB-3217-1](#). Examples of general thermal stress are:

(1) stress produced by an axial temperature distribution in a cylindrical shell;

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;

(3) the equivalent linear stress<sup>9</sup> produced by the radial temperature distribution in a cylindrical shell.



(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Table WB-3217-1. Examples of local thermal stress are:

(1) the stress in a small hot spot in a containment wall;

(2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;

(3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal.

**WB-3213.14 Total Stress.** Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

**WB-3213.15 Operational Cycle.** Operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of operating conditions that may occur are further defined in WB-3113.

**WB-3213.16 Stress Cycle.** Stress cycle is a condition in which the alternating stress difference [WB-3222.9(e)] goes from an initial value through an algebraic maximum value to an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

**WB-3213.17 Fatigue Strength Reduction Factor.** Fatigue strength reduction factor is a stress intensification factor that accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. In the absence of experimental data, the theoretical stress concentration factor may be used.

**WB-3213.20 Deformation.** Deformation of a component part is an alteration of its shape or size.

**WB-3213.21 Ratcheting.** Ratcheting is a progressive incremental inelastic deformation or strain that can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both.

**WB-3213.22 Shakedown.** Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

## WB-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of WB-3220 and WB-3230 is satisfied when the component is subjected to the loadings of WB-3110.

## WB-3215 Derivation of Stress Intensities

(17)

One requirement for the acceptability of a design (WB-3210) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the component that is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts  $t$ ,  $l$ , and  $r$ . The stress components in these directions are then designated  $\sigma_t$ ,  $\sigma_l$ , and  $\sigma_r$  for direct stresses and  $\tau_{lt}$ ,  $\tau_{lr}$ , and  $\tau_{rt}$  for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected, and assign each set of stress values to one or a group of the following categories:

(1) general primary membrane stress  $P_m$  (WB-3213.8);

(2) local primary membrane stress  $P_L$  (WB-3213.10);

(3) primary bending stress  $P_b$  (WB-3213.7 and WB-3213.8);

(4) secondary stress  $Q$  (WB-3213.9);

(5) peak stress  $F$  (WB-3213.11).

WB-3217 provides guidance for this step.

(c) For each category, calculate the algebraic sum of the  $\sigma_t$  values that result from the different types of loadings and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the  $t$ ,  $l$ , and  $r$  directions into principal stresses  $\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$ . In many pressure component calculations, the  $t$ ,  $l$ , and  $r$  directions may be so chosen that the shear stress components are zero and  $\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$  are identical to  $\sigma_t$ ,  $\sigma_l$ , and  $\sigma_r$ .

(e) Calculate the stress differences  $S_{12}$ ,  $S_{23}$ , and  $S_{31}$  from the relations:

$$\begin{aligned} S_{12} &= \sigma_1 - \sigma_2 \\ S_{23} &= \sigma_2 - \sigma_3 \\ S_{31} &= \sigma_3 - \sigma_1 \end{aligned}$$

The stress intensity  $S$  is the largest absolute value of  $S_{12}$ ,  $S_{23}$ , and  $S_{31}$ .

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c).

### WB-3216 Derivation of Stress Differences

If the specified operation of the component does not meet the conditions of WB-3222.9(d), the ability of the component to withstand the specified cyclic operation without fatigue failure shall be determined as provided in WB-3222.9(e). The determination shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic operating loadings, as specified in the Design Specification, need to be considered.

**WB-3216.1 Constant Principal Stress Direction.** For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a) through (c) below shall be taken to determine the alternating stress intensity.

(a) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects, which vary during the cycle. These are designated as  $\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$  for later identification.

(b) *Stress Differences.* Determine the stress differences  $S_{12} = \sigma_1 - \sigma_2$ ,  $S_{23} = \sigma_2 - \sigma_3$ , and  $S_{31} = \sigma_3 - \sigma_1$  versus time for the complete cycle. In what follows, the symbol  $S_{ij}$  is used to represent any one of these three stress differences.

(c) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference  $S_{ij}$  fluctuates and find the absolute magnitude of this range for each  $S_{ij}$ . Call this magnitude  $S_{rij}$  and let  $S_{alt\ ij} = 0.5S_{rij}$ . The alternating stress intensity  $S_{alt}$  is the largest  $S_{alt\ ij}$  value.

**WB-3216.2 Varying Principal Stress Direction.** For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e) below.

(a) Consider the values of the six stress components  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$ , and  $\tau_{rt}$  versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects that vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript  $i$ . In most cases, it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases, it may be necessary to try different points in time to find the one that results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components  $\sigma_{ti}$ ,  $\sigma_{li}$ , etc., from the corresponding stress components  $\sigma_t$ ,  $\sigma_l$ , etc., at each point in time during the cycle and call the resulting components  $\sigma'_{t}$ ,  $\sigma'_{l}$ , etc.

(d) At each point in time during the cycle, calculate the principal stresses  $\sigma'_1$ ,  $\sigma'_2$ , and  $\sigma'_3$  derived from the six stress components  $\sigma'_{t}$ ,  $\sigma'_{l}$ , etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences  $S'_{12} = \sigma'_1 - \sigma'_2$ ,  $S'_{23} = \sigma'_2 - \sigma'_3$ , and  $S'_{31} = \sigma'_3 - \sigma'_1$  versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity  $S_{alt}$  is one-half of this magnitude.

### WB-3217 Classification of Stresses

Table WB-3217-1 provides assistance in the determination of the category to which a stress should be assigned.

### WB-3220 STRESS LIMITS FOR OTHER THAN BOLTS

#### WB-3221 Design Limits

The stress intensity limits that must be satisfied for Design Loadings (WB-3112) stated in the Design Specification are the limits of the following subparagraphs and the Special Stress Limits of WB-3227. The design stress intensity values  $S_m$  are given by WB-3229. The limits are summarized in Figure WB-3221-1.

**WB-3221.1 General Primary Membrane Stress Intensity.** (Derived from  $P_m$  in Figure WB-3221-1) This stress intensity is derived from the average value across the thickness of a section of the general primary stresses (WB-3213.8) produced by Design Loadings, which include internal pressure and other specified mechanical loads, but excluding secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of this stress intensity is  $S_m$  at the Design Temperature.

**WB-3221.2 Local Primary Membrane Stress Intensity.** (Derived from  $P_L$  in Figure WB-3221-1) This stress intensity is derived from the average value across the thickness of a section of the local primary stresses (WB-3213.10) produced by Design Pressure and specified Design Mechanical Loads, but excluding all thermal and peak stresses. Averaging is to be applied to the stress components prior to the determination of the stress intensity values. The allowable value of the stress intensity is  $1.5S_m$ .

**WB-3221.4 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity.** [Derived from  $(P_m$  or  $P_L) + P_b$  in Figure WB-3221-1] This stress intensity is derived from the highest value across the thickness of a section of the general or local primary membrane

**Table WB-3217-1  
Classification of Stress Intensity in Containments for Some Typical Cases**

Containment Part	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane	$P_m$
			Gradient through plate thickness	$Q$
		Axial thermal gradient	Membrane	$Q$
			Bending	$Q$
	Junction with head or flange	Internal pressure	Membrane	$P_L$
			Bending	$Q$ [Note (1)]
Any shell or head	Any section across entire containment	External load or moment, or internal pressure	General membrane averaged across full section	$P_m$
		External load or moment	Bending across full section	$P_m$
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane	$P_L$
			Bending	$Q$
			Peak (fillet or corner)	$F$
	Any location	Temperature difference between shell and head	Membrane	$Q$ [Note (2)]
			Bending	$Q$ [Note (3)]
	Any location away from impact area	Impact on unyielding surface	General membrane	$P_m$
			Bending across full section	$P_m$
	At impact area	Impact on puncture bar	Local membrane	$P_L$ [Note (4)]
			Local bending	$Q$
	Dished head or conical head	Crown	Internal pressure	Membrane
Bending				$P_b$
Knuckle or junction to shell		Internal pressure	Membrane	$P_L$ [Note (5)]
			Bending	$Q$
Flat head	Center region	Internal pressure	Membrane	$P_m$
			Bending	$P_b$
	Junction to shell	Internal pressure	Membrane	$P_L$
			Bending	$Q$ [Note (1)]
Square or rectangular containment of flat plates	Center region	Uniform pressure	Membrane	$P_m$
			Bending	$P_b$
	Junction between flat plates	Uniform pressure	Membrane	$P_L$
			Bending	$P_b$
	Any section across entire containment	Lateral internal loading	Bending across full cross section	$P_m$
	Cladding	Any	Differential expansion	Membrane
Bending				$F$
Any	Any	Radial temperature distribution [Note (6)]	Equivalent linear stress [Note (7)]	$Q$
			Nonlinear portion of stress distribution	$F$
Any	Any	Any	Stress concentration (notch effect)	$F$

GENERAL NOTE:  $Q$  and  $F$  classification of stresses refers to other than design condition (Figure WB-3222-1).

NOTES:

(1) If the bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge bending is classified as  $P_b$ . Otherwise, it is classified as  $Q$ .

**Table WB-3217-1**  
**Classification of Stress Intensity in Containments for Some Typical Cases (Cont'd)**

## NOTES (CONT'D):

- (2) Components such as concentric shells attached to each other at the ends or in close radial contact may develop stresses due to temperature differences or differential expansion between dissimilar materials. Members subjected to compressive load shall be evaluated against buckling, treating the membrane stresses as  $P_m$ .
- (3) If an end connection of two concentric shells is relatively weak, the differential thermal expansion of the shells may lead to the formation of a plastic hinge in the connection and could cause excessive deformation or failure. The end connection shall be evaluated for such a condition treating the bending stresses as  $P_b$ .
- (4) The special stress limits of [WB-3227](#) shall also be met.
- (5) Consideration shall also be given to the possibility of wrinkling and excessive deformation in containments with a large diameter-thickness ratio.
- (6) Consider possibility of thermal stress ratchet.
- (7) Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.

stresses plus primary bending stresses produced by Design Pressure and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. For solid rectangular sections, the allowable value of this stress intensity is  $1.5S_m$ . For other than solid rectangular sections, a value of  $\alpha$  times the limit established in [WB-3221.1](#) may be used, where the factor  $\alpha$  is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified design load set. The value of  $\alpha$  shall not exceed the value calculated for bending only ( $P_m = 0$ ). In no case shall the value of  $\alpha$  exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated.

### WB-3222 Level A Services Limits

The stress intensity limits that must be satisfied for normal loadings ([WB-3113](#)) stated in the Design Specification are the Level A Service Limits [[WA-2123.4\(b\)\(1\)](#)] of the following subparagraphs and the Special Stress Limits of [WB-3227](#). The design stress intensity values  $S_m$  are given by [WB-3229](#). The limits are summarized in [Figure WB-3222-1](#).

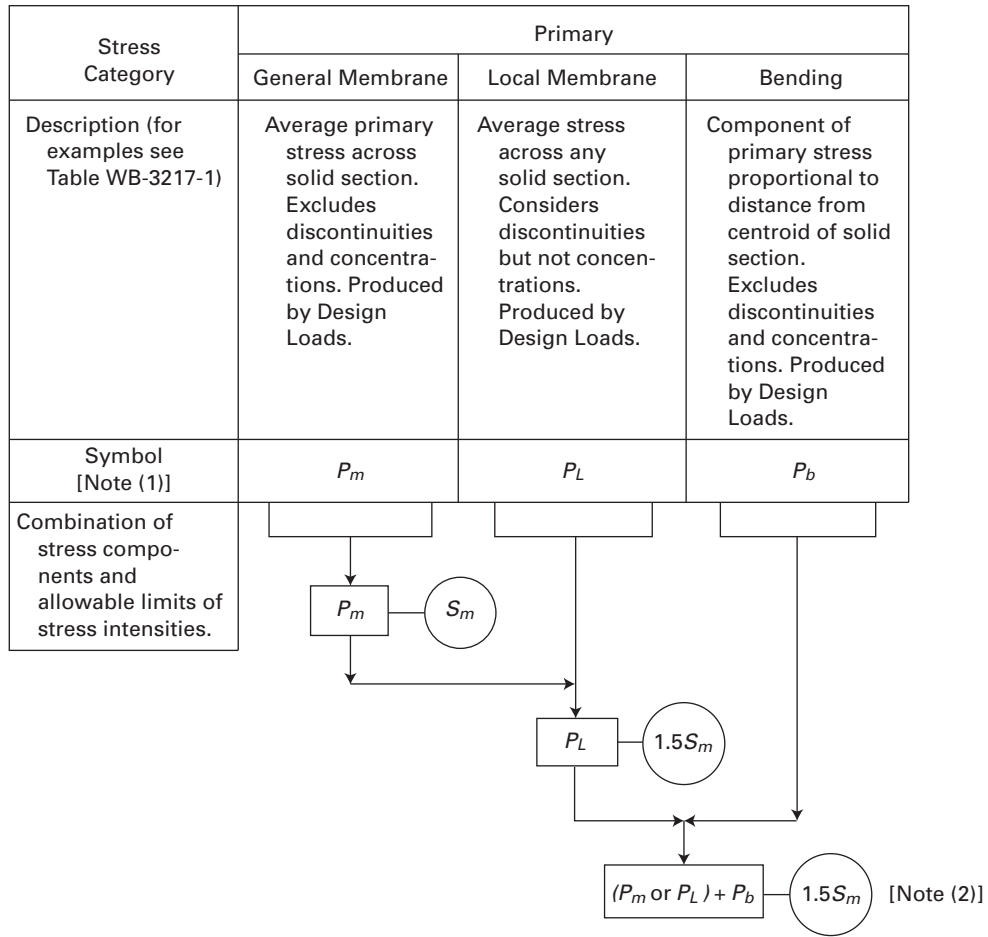
**WB-3222.1 General Primary Membrane Stress Intensity.** (Derived from  $P_m$  in [Figure WB-3222-1](#)) This stress intensity is derived from the average value across the thickness of a section of the general primary stresses ([WB-3213.8](#)) produced by normal loads, which include internal pressure and other specified mechanical loads, but excluding secondary and peak stresses. Averaging is to be applied to the stress components prior to

determination of the stress intensity values. The allowable value of this stress intensity is  $S_m$  at the normal operating temperature.

**WB-3222.2 Local Primary Membrane Stress Intensity.** (Derived from  $P_L$  in [Figure WB-3222-1](#)) This stress intensity is derived from the average value across the thickness of a section of the local primary stresses ([WB-3213.10](#)) produced by normal loads, but excluding all thermal and peak stresses. Averaging is to be applied to the stress components prior to the determination of the stress intensity values. The allowable value of this stress intensity is  $1.5S_m$ .

**WB-3222.4 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity.** (17) [Derived from  $(P_m \text{ or } P_L) + P_b$  in [Figure WB-3222-1](#)] This stress intensity is derived from the highest value across the thickness of a section of the general or local primary membrane stresses plus primary bending stresses produced by normal loads, but excluding all secondary and peak stresses. For solid rectangular sections, the allowable value of this stress intensity is  $1.5S_m$ . For other than solid rectangular sections, a value of  $\alpha$  times the limit established in [WB-3222.1](#) may be used, where the factor  $\alpha$  is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified design load set. The value of  $\alpha$  shall not exceed the value calculated for bending only ( $P_m = 0$ ). In no case shall the value of  $\alpha$  exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated.

**Figure WB-3221-1  
Stress Categories and Limits of Stress Intensity for Design Loadings**



Legend:

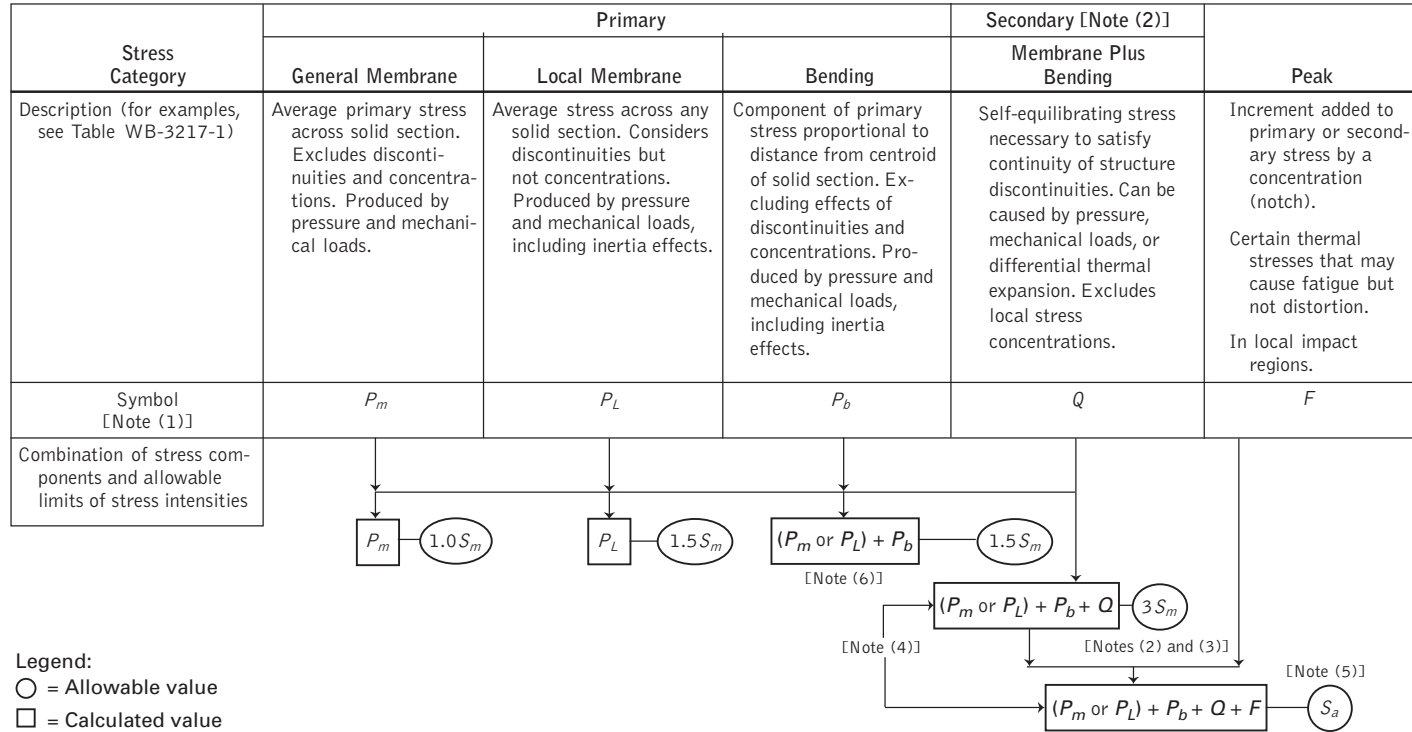
○ = Allowable value

□ = Calculated value

NOTES:

- (1) The symbols  $P_m$ ,  $P_L$ , and  $P_b$  do not represent single quantities, but rather sets of six quantities representing the six stress components  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$ , and  $\tau_{rt}$ .
- (2) Allowable values shown are for a solid rectangular section. See [WB-3221.4](#) for other than a solid rectangular section.

**Figure WB-3222-1**  
**Stress Categories and Limits of Stress Intensity for Normal Loadings**



**NOTES:**

- (1) The symbols  $P_m$ ,  $P_L$ ,  $P_b$ ,  $Q$ , and  $F$  do not represent single quantities, but sets of six quantities representing the six stress components:  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$ ,  $\tau_{rt}$ .
- (2) When the secondary stress is due to a temperature transient at the point at which the stresses are being analyzed, the value of  $S_m$  shall be taken as the average of the tabulated  $S_m$  values for the highest and the lowest temperatures of the metal during the transient. When part or all of the secondary stress is due to the mechanical load, the value of  $S_m$  shall not exceed the value for the highest temperature during the transient.
- (3) The  $3S_m$  limit is applicable to the range of stresses.
- (4) The stresses in Category  $Q$  are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and they do not include primary stresses that may also exist at the same point. However, it should be noted that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, the calculated value represents the total of  $P_m + P_b + Q$ , and not  $Q$  alone. Similarly, if the stress in Category  $F$  is produced by a stress concentration, the quantity  $F$  is the additional stress produced by the notch over and above the nominal stress. For example, if a point has a nominal stress intensity  $P_m + P_m(K - 1) = KP_m$ . However,  $P_L$  is the total membrane stress that results from mechanical loads, including discontinuity effects rather than a stress increment. Therefore, the  $P_L$  value always includes the  $P_m$  contribution.
- (5)  $S_a$  is obtained from the fatigue curves, Section III Appendices, Mandatory Appendix I. The allowable stress intensity for the full range of fluctuation is  $2S_a$ .
- (6) Allowable values shown are for a solid rectangular section. See WB-3222.4 for other than a solid rectangular section.



- (17) **WB-3222.6 Primary Plus Secondary Stress Intensity.** [Derived from  $(P_m \text{ or } P_L) + P_b + Q$  in [Figure WB-3222-1](#)]. This stress intensity is derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses, plus primary bending stresses plus secondary stresses, produced by normal loads. The allowable value of the maximum range of this stress intensity is  $3S_m$ .

NOTE: The concept of stress differences discussed in [WB-3216](#) is essential to determination of the maximum range, since algebraic signs must be retained in the computation. This limitation on range is applicable to the entire history of normal loadings, not just to the stresses resulting from each individual transient.

- (17) **WB-3222.9 Analysis for Cyclic Operation.**

(a) *Suitability for Cyclic Operation.* The suitability of a component for specified normal loadings and Test Loadings [if required by [WB-3225\(d\)](#)] involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength bolts shall be determined by the methods of [WB-3232.4\(b\)](#), and the possibility of thermal stress ratchet shall be investigated in accordance with [WB-3222.11](#). If the specified normal loads of the component meet all of the conditions of (d) below, no analysis for cyclic operation is required, and it may be assumed that the limits on peak stress intensities, as governed by fatigue, have been satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection. If the normal loads do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with Section III Appendices, Mandatory Appendix II, II-1500.

(b) *Peak Stress Intensity.* This stress intensity is derived from the highest value at any point across the thickness of a section of the combination of all primary, secondary, and peak stresses produced by specified normal loads.

(c) *Conditions and Procedures.* The conditions and procedures of [WB-3222.9](#) are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I. These curves show the allowable amplitude  $S_a$  of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is

the condition where the stress fluctuates about a mean value that is different from zero. As a consequence of this procedure, it is essential that the requirements of [WB-3222.6](#) be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(5) below.

(d) *Components Not Requiring Analysis for Cyclic Operation.* An analysis for cyclic operation is not required, and it may be assumed that the limits on peak stress intensities, as governed by fatigue, have been satisfied for a component by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection, provided the specified normal loads of the component, or portion thereof, meet all the conditions stipulated in (1) through (5) below.

(1) *Atmospheric to Normal Pressure Cycle.* The specified number of times that the pressure will be cycled from atmospheric pressure to normal pressure and back to atmospheric pressure during normal conditions does not exceed the number of cycles on the applicable fatigue curve of Section III Appendices, Mandatory Appendix I, corresponding to an  $S_a$  value of three times the  $S_m$  value for the material at the maximum normal temperature.

(2) *Normal Pressure Fluctuation.* The specified full range of pressure fluctuations during normal conditions does not exceed the quantity  $\frac{1}{3} \times \text{Design Pressure} \times (S_a/S_m)$ , where  $S_a$  is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuations and  $S_m$  is the allowable stress intensity for the material at the maximum normal temperature. If the total specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the  $S_a$  value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the total excursion exceeds one-third of the Design Pressure multiplied by  $(S_a/S_m)$  where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) *Temperature Difference — Normal Condition.* The total algebraic range of temperature difference, °F (°C), between any two adjacent points<sup>10</sup> does not change during normal conditions by more than the quantity  $S_a/2E\alpha$ , where  $S_a$  is the value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I, for the total specified number of significant temperature difference fluctuations,  $\alpha$  is the value of the instantaneous coefficient of thermal expansion, and

$E$  at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Tables TE and TM. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity  $S/2E\alpha$ , where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(4) *Temperature Difference — Dissimilar Materials.* For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation, °F (°C), experienced by the component during normal conditions does not exceed the magnitude  $S_a/2(E_1\alpha_1 - E_2\alpha_2)$ , where  $S_a$  is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations,  $E_1$  and  $E_2$  are the moduli of elasticity (Section II, Part D, Subpart 2, Tables TM), and  $\alpha_1$  and  $\alpha_2$  are the values of the instantaneous coefficients of thermal expansion (Section II, Part D, Subpart 2, Tables TE) at the mean temperature value involved for the two materials of construction. A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity  $S/2(E_1\alpha_1 - E_2\alpha_2)$ , where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of  $S_a$  shall be used in applying the rules of this paragraph.

(5) *Mechanical Loads.* The specified full range of mechanical loads, excluding pressure but including support reactions, handling and transportation loads, and assembly/disassembly loads, does not result in load stresses whose range exceeds the  $S_a$  value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I, for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the  $S_a$  value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the quantity  $S$ , where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) *Procedure for Analysis for Cyclic Loading.* If the specified normal loads for the component do not meet the conditions of (d), the ability of the component to withstand the specified cyclic operation without fatigue failure shall be determined as provided in this subsubparagraph. The determination shall be made on the basis of the stresses at a point, and the allowable stress cycles shall be adequate for the specified normal loads at every point. Only the stress differences due to operation cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the component is suitable from the standpoint of possible fatigue failure; complete suitability for the specified normal loads is also dependent on meeting the general stress limits of WB-3222 and any applicable special stress limits of WB-3227.

(1) *Stress Differences.* For each normal load, determine the stress differences and the alternating stress intensity  $S_a$  in accordance with WB-3216.

(2) *Local Structural Discontinuities.* These effects shall be evaluated for all conditions using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or numerical stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the procedures of Section III Appendices, Mandatory Appendix II, II-1600, except for high strength alloy steel bolting for which the requirements of WB-3232.4(c) shall apply when using the design fatigue curve of Section III Appendices, Mandatory Appendix I, Figure I-9.4. No fatigue strength reduction factor greater than five need be used.

(3) *Design Fatigue Curves.* Section III Appendices, Mandatory Appendix I, contains the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each is identified. Where curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.

(4) *Effect of Elastic Modulus.* Multiply  $S_{alt}$  (as determined in WB-3216.1 or WB-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the operating cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.



(5) *Cumulative Damage*. If there are two or more types of stress cycle that produce significant stresses, their cumulative effect shall be evaluated as stipulated in [Steps 1](#) through [6](#) below.

*Step 1*. Designate the specified number of times each type of stress cycle of types 1, 2, 3, ...,  $n$ , will be repeated during the life of the component as  $n_1, n_2, n_3, \dots, n_n$ , respectively.

NOTE: In determining  $n_1, n_2, n_3, \dots, n_n$ , consideration shall be given to the superposition of cycles of various origins that produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of a stress difference variation from zero to +60,000 psi (+414 MPa) and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to -50,000 psi (-345 MPa), the two types of cycle to be considered are defined by the following parameters:

(a) for type 1 cycle,  $n_1 = 1,000$  and  $S_{alt\ 1} = (60,000 + 50,000)/2 = 55,000$  psi;

(b) for type 2 cycle,  $n_2 = 9,000$  and  $S_{alt\ 2} = (50,000 + 0)/2 = 25,000$  psi.

*Step 2*. For each type of stress cycle, determine the alternating stress intensity  $S_{alt}$  by the procedures of [WB-3216.1](#) or [WB-3216.2](#) above. Call these quantities  $S_{alt\ 1}, S_{alt\ 2}, S_{alt\ 3}, \dots, S_{alt\ n}$ .

*Step 3*. For each value  $S_{alt\ 1}, S_{alt\ 2}, S_{alt\ 3}, \dots, S_{alt\ n}$ , use the applicable design fatigue curve to determine the maximum number of repetitions that would be allowable if this type of cycle were the only one acting. Call these values  $N_1, N_2, N_3, \dots, N_n$ .

*Step 4*. For each type of stress cycle, calculate the usage factors  $U_1, U_2, U_3, \dots, U_n$ , from  $U_1 = n_1/N_1, U_2 = n_2/N_2, U_3 = n_3/N_3, \dots, U_n = n_n/N_n$ .

*Step 5*. Calculate the cumulative usage factor  $U$  from  $U = U_1 + U_2 + U_3 + \dots + U_n$ .

*Step 6*. The cumulative usage factor  $U$  shall not exceed 1.0.

**WB-3222.10 Deformation Limits.** Any deformation limits prescribed by the Design Specifications, such as those intended to limit leakage, shall be satisfied.

(17) **WB-3222.11 Thermal Stress Ratchet.** It should be noted that under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in [WB-3227.3](#).

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady state internal pressure in order to prevent cyclic growth in diameter is as follows. Let

$x$  = maximum general membrane stress due to pressure divided by the yield strength,  $S_y$   
 $y'$  = maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength,  $S_y$

NOTE: For both  $x$  and  $y'$ , it is permissible to use  $1.5S_m$  whenever it is greater than  $S_y$ .

*Case 1* : Linear variation of temperature through the wall: for  $0 < x < 0.5$ ,  $y' = 1/x$  and, for  $0.5 < x < 1.0$ ,  $y' = 4(1 - x)$

*Case 2* : Parabolic constantly increasing or constantly decreasing variation of temperature through the wall: for  $0.615 < x < 1.0$ ,  $y' = 5.2(1 - x)$  and, approximately for  $x < 0.615$ ,  $y' = 4.65, 3.55$ , and  $2.70$  for  $x = 0.3, 0.4$ , and  $0.5$ , respectively

(b) Use of yield strength,  $S_y$ , in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to  $S_y$ . If the yield strength of the material is higher than 2 times the  $S_a$  value for the maximum number of cycles on the applicable fatigue curve of Section III Appendices, Mandatory Appendix I for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

## WB-3224 Level D Service Limits

(a) Level D Service Limits [[WA-2123.4\(b\)\(3\)](#)] are those limits that must be satisfied for accident loadings ([WB-3113](#)) stated in the Design Specification.

(b) Any deformation limits prescribed by the Design Specification for accident loadings, such as those to limit leakage, shall be satisfied.

**WB-3224.1 Elastic Analysis.** The stress intensity limits that must be satisfied for accident loadings stated in the Design Specification are the Level D Service Limits of this paragraph and in [Figure WB-3224.1-1](#) for elastic analysis. The design stress intensity values  $S_m$  are given by [WB-3229](#). (17)

(a) The general primary membrane stress intensity  $P_m$  shall not exceed the lesser of  $2.4S_m$  and  $0.7S_u$  for austenitic steel, high-nickel alloy, and copper-nickel alloy materials included in Section II, Part D, Subpart 1, Tables 2A and 2B, or  $0.7S_u$  for ferritic steel materials included in Section II, Part D, Subpart 1, Table 2A.

(b) The local primary membrane stress intensity  $P_L$  shall not exceed 150% of the limit for general primary membrane stress intensity  $P_m$  but not greater than  $1.0S_u$ .

(c) The primary membrane (general or local) plus primary bending stress intensity,  $(P_m$  or  $P_L) + P_b$  shall not exceed 150% of the limit for general primary membrane stress intensity  $P_m$ , but not greater than  $1.0S_u$ . For other than solid rectangular sections, consideration of the factor  $\alpha$  as discussed in [WB-3221.4](#) shall be incorporated into the stress evaluation. The  $\alpha$  factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Section III Appendices, Mandatory Appendix XXVII.

(d) The average primary shear across a section loaded in pure shear shall not exceed  $0.42S_u$ .

**Figure WB-3224.1-1**  
**Stress Categories and Limits of Stress Intensity for Accident Loadings for Elastic Analysis**

Stress Category	Primary [Note (2)]			Secondary	Peak
	General Membrane	Local Membrane	Bending	Membrane Plus Bending	
Description (for examples, see Table WB-3217-1)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced by pressure and mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced by pressure and mechanical loads, including inertia effects.	Component of primary stress proportional to distance from centroid of solid section. Excluding discontinuities and concentrations. Produced by pressure and mechanical loads, including inertia effects.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical loads or by differential thermal expansion. Excludes local stress concentration.	Increment added to primary or secondary stress by a concentration (notch).  Certain thermal stresses that may cause fatigue but not distortion of vessel shape.
Symbol [Note (1)]	$P_m$ WB-3213.6 and WB-3213.8	$P_L$ WB-3213.10	$P_b$ WB-3213.7 and WB-3213.8	$Q$ WB-3213.9	$F$ WB-3213.11
Combination of stress components and allowable limits of stress intensities	$P_m$ — $\left( \begin{array}{c} 2.4 S_m \\ 0.7 S_y \end{array} \right)$ [Note (3)]	$P_L$ — $\left( \begin{array}{c} 3.6 S_m \\ 1.0 S_y \end{array} \right)$ [Note (3)]	$(P_m \text{ or } P_L) + P_b$ — $\left( \begin{array}{c} 3.6 S_m \\ 1.0 S_y \end{array} \right)$ [Note (4)] [Note (3)]	$(P_m \text{ or } P_L) + P_b + Q + F$ — $2S_y @ 10 \text{ cycles}$	

**Legend:**

○ = Allowable value

□ = Calculated value

**NOTES:**

- (1) The symbols  $P_m$  or  $P_L$ ,  $P_b$ ,  $Q$ , and  $F$  do not represent single quantities, but sets of six quantities representing the six stress components:  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$ ,  $\tau_{rt}$ .
- (2) For configurations where compressive stresses occur, the stress limits shall be revised to take into account critical buckling stresses [WB-3211(c)].
- (3) Use the lesser of the values specified.
- (4) Allowable values shown are for a solid rectangular section. See WB-3224.1(c) for other than a solid rectangular section.

(e) For compressive loads, Section III Appendices, Mandatory Appendix XXVII shall be used.

- (17) **WB-3224.2 Plastic Analysis.** The plastic analysis rules contained in Section III Appendices, Mandatory Appendix XXVII may be used to evaluate primary stresses resulting from accident loadings, provided the requirements of **WB-3224(b)** are satisfied.

**WB-3224.3 Alternative Strain-Based Acceptance Criteria.** In lieu of the requirements provided in **WB-3224.1** or **WB-3224.2**, the requirements of **WB-3700** may be used to evaluate inelastic containment responses to energy-limited dynamic events.

### WB-3225 Testing Limits

The evaluation of pressure test loadings [**WB-3113**] shall be in accordance with (a) through (d) below.

(a) The containments shall be subjected to an internal pressure test. The general primary membrane stress intensity  $P_m$  produced in the containment during the test shall not exceed 90% of the tabulated yield strength  $S_y$  at test temperature.

(b) For pressure tested containments, the primary membrane plus bending stress intensity  $P_m + P_b$  shall not exceed the applicable limits given in (1) or (2) below:

$$(1) \text{ For } P_m \leq 0.67S_y$$

$$P_m + P_b \leq 1.35S_y$$

$$(2) \text{ For } 0.67S_y < P_m \leq 0.90S_y$$

$$P_m + P_b \leq (2.15S_y - 1.2P_m)$$

where

$S_y$  = the tabulated yield strength at test temperature

(c) Additional tests may be specified in the Design Specification. Stresses produced in the containment by such tests shall not exceed the limits specified for normal loadings (**Figure WB-3222-1**).

(d) Tests, with the exception of either the first 10 hydrostatic tests in accordance with **WB-6220**, the first 10 pneumatic tests in accordance with **WB-6320**, or any combination of 10 such tests, shall be considered in the fatigue evaluation of the component. In this fatigue evaluation, the limits on the primary plus secondary stress intensity range (**WB-3222.6**) may be taken as the larger of  $3S_m$  or  $2S_y$  when at least one extreme of the stress intensity range is determined by the test loadings.

### WB-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Design and Operating Loadings or configurations. Some of these deviations are more restrictive, and some are less restrictive, than the basic stress limits. In cases of conflict between these

requirements and the basic stress limits, the rules of **WB-3227** take precedence for the particular situations to which they apply.

#### WB-3227.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings, Test Loadings, or Operating Loadings, except those for which Level D Service Limits are designated, shall be limited to  $S_y$  at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of  $1.5S_y$  at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only (**WB-3213.12**), the average shear stress shall be limited to  $0.6S_m$ . In the case of load stress plus secondary stress (**WB-3213.9**), the average shear stress shall not exceed (1) or (2) below:

(1) for material to which Section II, Part D, Subpart 1, Table 2A, Note G7 or Table 2B, Note G1, applies, the lower of  $0.5S_y$  at 100°F (38°C) and  $0.675S_y$  at temperature;

(2) for all other materials,  $0.5S_y$  at temperature.

For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(c) When considering bearing stresses in pins and similar members, the  $S_y$  at temperature value is applicable, except that a value of  $1.5S_y$  may be used if no credit is given to bearing area within one pin diameter from a plate edge.

#### WB-3227.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings, Test Loadings, or Operating Loadings except those for which Level D Service Limits are designated (for example, keys, shear rings, screw threads), shall be limited to  $0.6S_m$ .

(b) The maximum primary shear that is experienced as a result of Design Loadings, Test Loadings, or Operating Loadings (except those for which Level D Service Limits are designated), exclusive of stress concentration, at the periphery of a solid circular section in torsion shall be limited to  $0.8S_m$ . Primary plus secondary and peak shear

stresses shall be converted to stress intensities (equal to two times the pure shear stress) and as such shall not exceed the basic stress limits of [WB-3222.6](#) and [WB-3222.9](#).

**WB-3227.3 Progressive Distortion of Nonintegral Connections.** Screwed on caps, screwed in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections that are subject to failure by bell mousing or other types of progressive deformation. If any combination of applied loads (including Test Loads) produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities ([WB-3222.6](#)), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value  $S_y$  (Section II, Part D, Subpart 2, Table Y-1).

**WB-3227.4 Triaxial Stresses.** The algebraic sum of the three primary principal stresses ( $\sigma_1 + \sigma_2 + \sigma_3$ ) shall not exceed four times the tabulated value of  $S_m$ , except for accident loadings.

**WB-3227.5 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.** Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of  $3S_m$  ([WB-3222.6](#)) has been placed at a level that ensures shakedown to elastic action after a few repetitions of the stress cycle, except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore:

(a) In evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis.

(b) In evaluating stresses for comparison with fatigue allowables, all stresses except those that result from local thermal stresses [[WB-3213.13\(b\)](#)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = 0.5 - 0.2 \left( S_y / S_a \right), \text{ but not less than } 0.3$$

where

$S_a$  = alternating stress intensity determined in [WB-3222.9\(e\)](#) prior to the elastic modulus adjustment in [WB-3222.9\(e\)\(4\)](#)

$S_y$  = yield strength of the material at the mean value of the temperature of the cycle

### WB-3229 Design Stress Values

The design stress intensity values  $S_m$  are given in Section II, Part D, Subpart 1, Tables 2A and 2B for component materials. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 2, Table Y-1. Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Tables TE, and values of the modulus of elasticity are in Section II, Part D, Subpart 2, Tables TM. The basis for establishing stress values is given in Section III Appendices, Mandatory Appendix III. The design fatigue curves used in conjunction with [WB-3222.9](#) are those of Section III Appendices, Mandatory Appendix I.

### WB-3230 STRESS LIMITS FOR BOLTS

The evaluation of bolting requires a number of analysis considerations, including (a) through (f) below and the criteria specified in this subsubarticle for the loads imposed.

(a) When gaskets are used for preservice testing only, the design is satisfactory if [WB-3231](#) requirements are satisfied for  $m = y = 0$ , and the requirements of [WB-3232](#) are satisfied when the appropriate  $m$  and  $y$  factors are used for the test gasket.

(b) The membrane and bending stresses in the bolt produced by thermal expansion due to differences in the temperature or thermal expansion coefficients, shall be treated as primary stresses in bolting analysis.

(c) The bolting analysis shall consider the effects of loading eccentricities due to puncture loads and eccentric impact loads.

(d) The bolting analysis shall consider prying effects, which cause amplification of the bolt loads due to rotation of the closure surfaces.

(e) Bolting analysis shall consider bolt preload application methodology and resulting bolt forces.

(f) Gasket characteristics and leak tightness requirements shall be considered in the bolting analysis.

### WB-3231 Design Limits

The number and cross-sectional area of bolts required to resist the Design Pressure shall be determined in accordance with the procedures of Section III Appendices, Nonmandatory Appendix E, using the larger of the bolt loads, given by the equations of Section III Appendices, Nonmandatory Appendix E, as a Design Mechanical Load. The stress limits shall utilize the values given in Section II, Part D, Subpart 1, Table 4 for bolting material.

**WB-3232 Level A Service Limits**

Actual stresses in bolts, such as those produced by the combination of preload, pressure, and differential thermal expansion, may be higher than the values given in Section II, Part D, Subpart 1, Table 4.

**WB-3232.1 Average Stress.** The maximum value of stress, averaged across the bolt cross section and neglecting stress concentrations, shall not exceed two-thirds of the yield strength values,  $S_y$ , of Section II, Part D, Subpart 1, Table Y-1.

**WB-3232.2 Shear Stress.** The average bolt shear stress expressed in terms of available shear stress area shall not exceed 40% of the yield strength values,  $S_y$ , (at temperature) of Section II, Part D, Subpart 1, Table Y-1.

**WB-3232.3 Maximum Stress.** The maximum value of stress, except as restricted by [WB-3232.4\(b\)](#), at the periphery of the bolt cross section resulting from direct tension plus bending and neglecting stress concentrations shall not exceed the yield strength values,  $S_y$ , of Section II, Part D, Subpart 1, Table Y-1. Stress intensity, rather than maximum stress, shall be limited to this value when the bolts are tightened by methods other than heaters, stretchers, or other means which minimize residual torsion.

**WB-3232.4 Fatigue Analysis of Bolts.** Unless the components on which they are installed meet all the conditions of [WB-3222.9\(d\)](#) and thus require no fatigue analysis, the suitability of bolts for cyclic service shall be determined in accordance with the procedures of [\(a\)](#) through [\(e\)](#) below. Thermal stress ratchet shall be evaluated in accordance with [WB-3222.11](#).

*(a) Bolting Having Less Than 100.0 ksi (689 MPa) Tensile Strength.* Bolts made of material which has specified minimum tensile strength of less than 100.0 ksi (689 MPa) shall be evaluated for cyclic service by the methods of [WB-3222.9\(e\)](#), using the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I and an appropriate fatigue strength reduction factor [see [\(c\)](#)].

*(b) High Strength Alloy Steel Bolting.* High strength alloy steel bolts and studs may be evaluated for cyclic service by the methods of [WB-3222.9\(e\)](#) using the design fatigue curve of Section III Appendices, Mandatory Appendix I, provided:

*(1)* the maximum value of the stress ([WB-3232.3](#)) at the periphery of the bolt cross section, resulting from direct tension plus bending and neglecting stress concentration, shall not exceed  $0.9S_y$  if the higher of the two fatigue design curves given in Section III Appendices, Mandatory Appendix I, Figure I-9.4 is used. The  $\frac{2}{3}S_y$  limit for direct tension is unchanged.

*(2)* threads shall be of a Vee-type having a minimum thread root radius no smaller than 0.003 in. (0.08 mm).

*(3)* fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

*(c) Fatigue Strength Reduction Factor ([WB-3213.17](#)).* Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall be not less than 4.0. However, when applying the rules of [\(b\)](#) for high strength alloy steel bolts, the value used shall be not less than 4.0

*(d) Effect of Elastic Modulus.* Multiply  $S_{alt}$  (as determined in [WB-3216.1](#) or [WB-3216.2](#)) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the cyclic operation being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

*(e) Cumulative Damage.* The bolts shall be acceptable for the specified cyclic application of loads and thermal stresses provided the cumulative usage factor  $U$ , as determined in [WB-3222.9\(e\)\(5\)](#), does not exceed 1.0.

**WB-3234 Level D Service Limits**

(17)

*(a)* The rules contained in Section III Appendices, Mandatory Appendix XXVII may be used in evaluating loadings for which Level D Service Limits are specified, independently of all other loadings.

*(b)* If leak tightness of the closure is required by the Design Specification, the analysis of the bolting shall demonstrate that no yielding occurs in the bolt or sealing surface materials. This requirement may be satisfied by using the rules of [WB-3232](#).

**WB-3235 Testing Limits**

Bolts shall not yield for test conditions.

**WB-3236 Design Stress Intensity Values**

The design stress intensity values  $S_m$  are given in Section II, Part D, Subpart 1, Table 4 for bolting. Values for intermediate temperatures may be found by interpolation.

**WB-3240 NOZZLES OR OPENINGS**

*(a)* The rules for nozzles or openings are given in [\(1\)](#) through [\(5\)](#) below, where  $R$  is the mean radius and  $t$  is the nominal thickness of the containment shell or head at the location of the nozzle or opening; and *locally stressed area* means any area in the containment where the primary local membrane stress exceeds  $1.1S_m$ .

*(1)* A single nozzle or opening shall not have a diameter exceeding  $0.2\sqrt{Rt}$  or NPS 2 (DN 50), whichever is smaller. Nozzles shall be self-reinforcing.



(2) If there are two or more nozzles or openings within any circle of diameter  $2.5\sqrt{Rt}$ , the sum of the diameters of such nozzles or openings shall not exceed  $0.25\sqrt{Rt}$ .

(3) No two nozzles or openings shall have their centers closer to each other, measured on the inside of the containment wall, than 1.5 times the sum of their diameters.

(4) No nozzle or opening shall have its center closer than  $2.5\sqrt{Rt}$  to the edge of a locally stressed area in the shell.

(5) Nozzles or openings shall be such that there are substantially no significant external load or reactions on the nozzle(s).

(b) Any nozzle or opening not meeting the requirements in (a) above shall meet the requirements of WB-3220.

**WB-3250 DESIGN OF WELDED CONSTRUCTION**

**WB-3251 Welded Joint Category**

The term *Category* defines the location of a joint in a containment, but not the type of joint. The categories established are for use in specifying special requirements regarding joint type and degree of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure WB-3251-1 illustrates typical joint locations included in each category.

- (17) **WB-3251.1 Category A.** Category A comprises longitudinal welded joints within the main containment shell, transitions in diameter, any welded joint within a sphere, within a formed or flat head, or within the side plates of a

flat sided containment; and circumferential welded joints connecting hemispherical heads to main containment shells, or transitions in diameters.

**WB-3251.2 Category B.** Category B comprises circumferential welded joints within the main containment shell or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting formed heads other than hemispherical to main shells.

**WB-3251.3 Category C.** Category C comprises welded joints connecting flanges or flat heads to main containment shell, to formed heads, or to transitions in diameter, any welded joint connecting one side plate to another side plate of a flat sided containment.

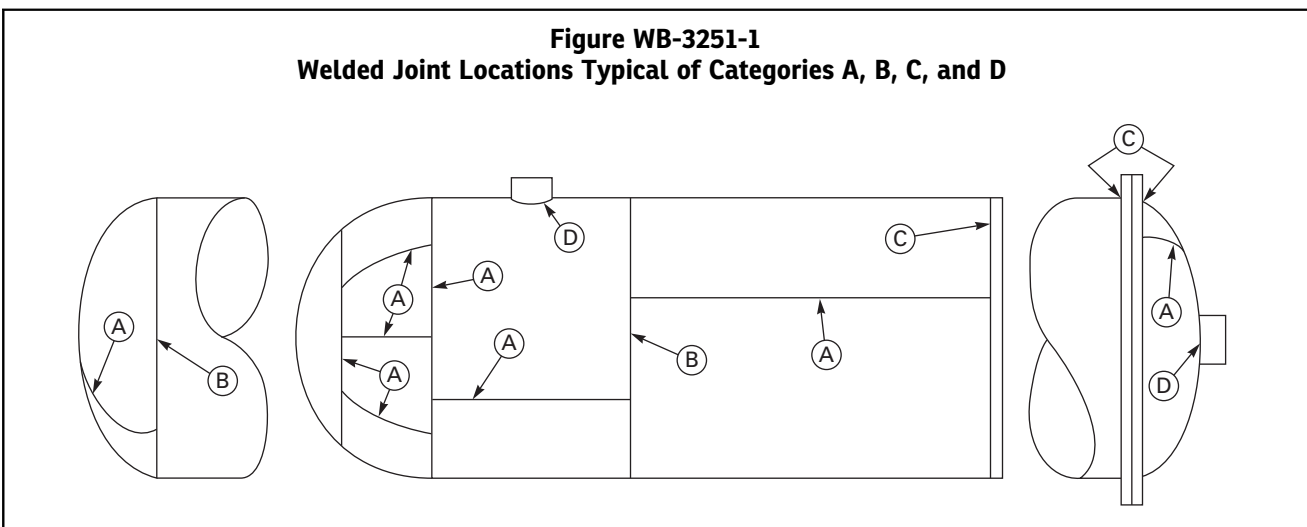
**WB-3251.4 Category D.** Category D comprises welded joints connecting integral attachments or protrusions to main containment shells, to spheres, to transitions in diameter, to heads, or to flat sided containments.

**WB-3252 Permissible Types of Welded Joints**

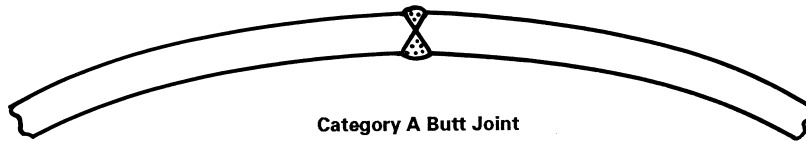
The design of the containment shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Figure WB-3252-1 shows typical butt welds for each category joint.

**WB-3252.1 Joints of Category A.** All welded joints of Category A as defined in WB-3251 shall meet the fabrication requirements of WB-4241 and shall be capable of being examined in accordance with WB-5210.

**WB-3252.2 Joints of Category B.** All welded joints of Category B as defined in WB-3251 shall meet the fabrication requirements of WB-4242 and shall be capable of being examined in accordance with WB-5220. When joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used,



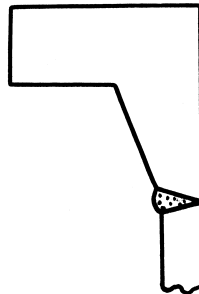
**Figure WB-3252-1  
Typical Butt Joints**



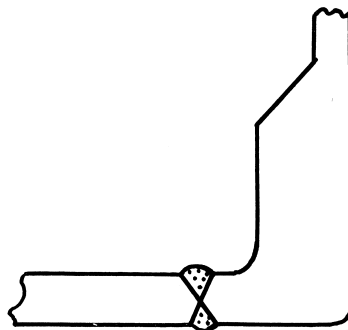
**Category A Butt Joint**



**Category B Butt Joint**



**Category C Butt Joint**



**Category D Butt Joint**



the suitability for cyclic operation shall be analyzed by the method of [WB-3222.9](#) using a fatigue strength reduction factor of not less than 2.

**WB-3252.3 Joints of Category C.** All welded joints of Category C, as defined in [WB-3251](#), shall meet the fabrication requirements of [WB-4243](#) and shall be capable of being examined in accordance with [WB-5230](#). Minimum dimensions of the welds and throat thickness shall be as shown in [Figure WB-4243-1](#) or [Figure WB-4243-2](#) where:

(a) for forged flat heads and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

$t, t_n$  = nominal thicknesses of welded parts  
 $t_c = 0.7t_n$  or  $1/4$  in. (6 mm), whichever is less  
 $t_w = t_n/2$  or  $t/4$ , whichever is less

(b) for all other material forms and for forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

$t, t_n$  = nominal thicknesses of welded parts  
 $t_c = 0.7t_n$  or  $1/4$  in. (6 mm), whichever is less  
 $t_w = t_n$  or  $t/2$ , whichever is less

(c) Hubs for butt welding to the adjacent shell, head, or other containment part, as in [Figure WB-4243-2](#), shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical. In [Figure WB-4243-2](#), the minimum dimensions are as follows:

- (1) sketch (a),  $r$  not less than  $1.5t_n$
- (2) sketch (b),  $r$  not less than  $1.5t_n$ , and  $e$  not less than  $t_n$
- (3) sketch (c),  $r$  not less than  $1.5t_n$
- (4) sketch (d),  $t_f$  not less than  $2t_n$  and  $r$  not less than  $3t_f$
- (5) sketch (e),  $t_f$  not less than  $2t_n$ ,  $r$  not less than  $3t_f$ , and  $e$  not less than  $t_f$

**WB-3252.4 Joints of Category D.** All welded joints of Category D, as defined in [WB-3251](#), shall be in accordance with the requirements of one of (a) through (f) below.

(a) *Full Penetration Welds.* Full penetration welds, as shown in [Figures WB-4244\(a\)-1](#), [WB-4244\(b\)-1](#), and [WB-4244\(c\)-1](#) may be used [except as otherwise provided in (b)] for the purposes of achieving continuity of metal and facilitating the required radiographic examination. When all or part of the required reinforcement is attributable to the connecting item, the connecting items shall be attached by full penetration welds through either the containment shell or head, the thickness of the connecting item, or both.

(b) *Partial Penetration Welds*

(1) Partial penetration welds, as shown in [Figure WB-4244\(d\)-1](#), are allowed only for connecting items on which there are substantially no reaction loads, such as openings for instrumentation. For such connecting items, all reinforcement shall be integral with the portion of the containment boundary penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the connecting items. Connecting items attached by partial penetration welds shall have an interference fit or a maximum diametric clearance between the item and the containment boundary penetration of

- (-a) 0.010 in. (0.25 mm) for  $d \leq 1$  in. (25 mm)
- (-b) 0.020 in. (0.50 mm) for  $1$  in. (25 mm)  $< d \leq 4$  in. (100 mm)
- (-c) 0.030 in. (0.76 mm) for  $d > 4$  in. (100 mm)

where  $d$  is the outside diameter of the item, except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limits on maximum clearance, and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for deflection of the connecting item.

(2) In satisfying the limit of [WB-3222.6](#), the stress intensities resulting from pressure-induced strains (dilation of hole) may be treated as secondary in the penetrating part of partial penetration welded construction, provided the requirements of (f) and [Figure WB-4244\(d\)-1](#) are fulfilled.

(c) *Butt-Welded Connections.* Connections shall meet the fabrication requirements of [WB-4244\(a\)](#) and shall be capable of being examined in accordance with [WB-5242](#). The minimum dimensions and geometrical requirements of [Figure WB-4244\(a\)-1](#) shall be met, where

$r_1 = 1/4t$  or  $3/4$  in. (19 mm), whichever is less  
 $r_2 = 1/4$  in. (6 mm) minimum  
 $t$  = nominal thickness of part penetrated  
 $t_n$  = nominal thickness of penetrating part

(d) *Full Penetration Corner-Welded Connections.* Connections shall meet the fabrication requirements of [WB-4244\(b\)](#) and shall be capable of being examined as required in [WB-5243](#). The minimum dimensions of [Figure WB-4244\(b\)-1](#) shall be met, where

$r_1 = 1/4t$  or  $3/4$  in. (19 mm), whichever is less  
 $r_2 = 1/4$  in. (6 mm) minimum  
 $t$  = nominal thickness of part penetrated  
 $t_c = 0.7t_n$  or  $1/4$  in. (6 mm), whichever is less  
 $t_n$  = nominal thickness of penetrating part

*(e) Use of Deposited Weld Metal for Openings and Connections*

(1) Connections shall meet the fabrication requirements of [WB-4244\(c\)](#) and shall be capable of being examined in accordance with [WB-5244](#).

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the connection shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of [Figure WB-4244\(c\)-1](#) shall be met, where

$$r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less}$$

$t$  = nominal thickness of part penetrated

$$t_c = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less}$$

$t_n$  = nominal thickness of penetrating part

(4) The corners of the end of each connection extending less than  $\sqrt{dt_n}$  beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness  $t_n$  of the connection or  $\frac{3}{4}$  in. (19 mm), whichever is smaller.

*(f) Attachment of Connections Using Partial Penetration Welds*

(1) Partial penetration welds used for connections as permitted in [\(b\)](#) shall meet the fabrication requirements of [WB-4244\(d\)](#) and shall be capable of being examined in accordance with the requirements of [WB-5245](#).

(2) The minimum dimensions of [Figure WB-4244\(d\)-1](#) shall be met where

$d$  = outside diameter of the connecting item

$$r_1 = \frac{1}{4}t_n \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less}$$

$t$  = nominal thickness of part penetrated

$$t_c = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less}$$

$t_n$  = nominal thickness of penetrating part

(3) The corners of the end of each connecting item, extending less than  $\sqrt{dt_n}$  beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half of the thickness  $t_n$  of the penetrating part or  $\frac{3}{4}$  in. (19 mm), whichever is smaller.

(4) Weld groove design for partial penetration joints attaching connecting item may require special consideration to achieve the  $1.25t_n$  minimum depth of weld and adequate access for welding examination. The welds shown in the sketches of [Figure WB-4244\(d\)-1](#) may be on either the inside or the outside of the containment shell. Weld preparation may be J-groove, as shown in the figures, or straight bevel.

(5) A fatigue strength reduction factor of not less than four shall be used when fatigue analysis is required.

**WB-3254 Structural Attachment Welds**

Welds for structural attachments shall meet the requirements of [WB-4430](#).

**WB-3255 Welding Grooves**

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in [WB-3252.4](#).

**WB-3256 Thermal Treatment**

All containments and containment parts shall be given the appropriate postweld heat treatment prescribed in [WB-4620](#).

**WB-3260 SPECIAL CONTAINMENT REQUIREMENTS****WB-3261 Category A or Category B Joints Between Sections of Unequal Thickness**

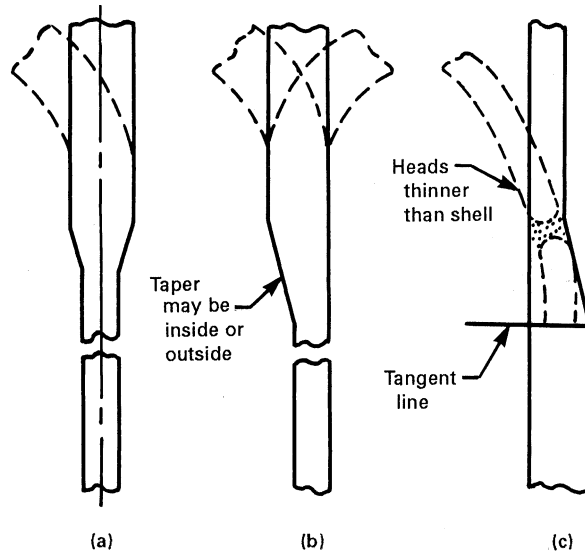
In general, a tapered transition section as shown in [Figure WB-3261-1](#), which is a type of gross structural discontinuity ([WB-3213.2](#)), shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head that has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter. A uniform taper is not required for flanged hubs. The adequacy of the transition shall be evaluated by stress analysis. Stress intensity limitations are given in [WB-3220](#). The requirements of this paragraph do not apply to flange hubs.

**WB-3700 STRAIN-BASED ACCEPTANCE CRITERIA**

The strain-based acceptance criteria are applicable only to the metallic containments of transportation packagings subject to energy-limited dynamic events. It is not the intent of this subarticle to permit significant regions or major portions of the containment to experience strains at or near the limits of these strain-based acceptance criteria without consideration of the overall component deformation. These strain-based acceptance criteria are established to address the regions of the containment that experience high strains due to the effects of direct impacts. Deformation limits, if any, provided in the Design Specification shall be satisfied.

Section III Appendices, Nonmandatory Appendix FF provides the strain-based acceptance criteria.

**Figure WB-3261-1**  
**Categories A and B Joints Between Sections of Unequal Thickness**



GENERAL NOTE: Length of taper may include the width of the weld.

# ARTICLE WB-4000 FABRICATION

## WB-4100 GENERAL REQUIREMENTS

### WB-4110 INTRODUCTION

Containments shall be fabricated and installed in accordance with the requirements of this Article and shall be manufactured from materials that meet the requirements of [Article WB-2000](#).

### WB-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY CERTIFICATE HOLDER

#### WB-4121 Means of Certification

The Certificate Holder for a containment shall certify, by application of the Certification Mark and completion of the appropriate Data Report in accordance with [Article WA-8000](#), that the materials used comply with the requirements of [Article WB-2000](#) and that the fabrication complies with the requirements of this Article.

- (17) **WB-4121.1 Certification of Treatments, Tests, and Examinations.** If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by this Division, the NPT or N3 Certificate Holder shall certify that this requirement has been fulfilled ([WA-3800](#) or [WA-8410](#)). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

**WB-4121.2 Repetition of Tensile or Impact Tests.** If during the fabrication of the containment the material is subjected to heat treatment that has not been covered by treatment of the test coupons ([WB-2200](#)) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of [Article WB-2000](#).

**WB-4121.3 Repetition of Surface Examination After Machining.** If, during the fabrication of a containment, materials are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with [WB-2500](#) when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with [WB-2500](#); and

(b) the amount of material removed from the surface exceeds the lesser of  $\frac{1}{8}$  in. (3 mm) or 10% of the minimum required thickness of the item.

### WB-4122 Material Identification

(a) Material performing a containment function shall carry identification markings which will remain distinguishable until the containment is assembled. If the original identification markings are cut off or the material is divided, the marks shall either be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, and nuts it is permissible to identify the Certified Material Test Reports for material in each component or item in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding material, shall be identified and controlled so that they can be traced to the containment, or else a control procedure shall be employed which ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be re-marked upon establishing positive identification.

**WB-4122.1 Marking Material.** Material shall be marked in accordance with [WB-2150](#).

### WB-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of [Article WB-4000](#), may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to [WB-5500](#) and [WB-5100](#), respectively, unless so specified.

## **WB-4124 Additional Requirements When Strain-Based Acceptance Criteria Have Been Implemented**

In order to satisfy the strain-based acceptance criteria of [WB-3700](#) regarding the locations of unique material heats used in containment fabrication, traceability of all unique material heats and their specific location(s) of use shall be established and documented in the final Design Report and the as-built Design Drawings. This requirement is only necessary when strain-based acceptance criteria have been employed in the design of the containment.

## **WB-4125 Testing of Welding Material**

All welding material shall meet the requirements of [WB-2400](#).

## **WB-4130 REPAIR OF MATERIAL**

### **WB-4131 Elimination and Repair of Defects**

Material originally accepted on delivery in which defects exceeding the limits of [WB-2500](#) are known or discovered during the process of fabrication is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of [WB-2500](#) for the applicable product form, except

(a) the limitation on the depth of the weld repair does not apply

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with [WB-5130](#)

### **WB-4132 Documentation of Repair Welds of Base Material**

The Certificate Holder who makes a repair weld exceeding in depth the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness, shall prepare a report which shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds.

## **WB-4200 FORMING, FITTING, AND ALIGNING**

### **WB-4210 CUTTING, FORMING, AND BENDING**

#### **WB-4211 Cutting**

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

#### **WB-4211.1 Preheating Before Thermal Cutting.**

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to

preheating the material, using preheat schedules such as suggested in Section III Appendices, Nonmandatory Appendix D.

### **WB-4212 Forming and Bending Processes**

Any process may be used to hot or cold form or bend containment material, including weld metal, provided the required dimensions are attained (see [WB-4214](#) and [WB-4220](#)), and provided the impact properties of the material, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (38°C) below the lower transformation temperature of the material.

### **WB-4213 Qualification of Forming Processes for Impact Property Requirements**

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the containment. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the containment. Applicable tests shall be conducted to determine that the required impact properties of [WB-2300](#) are met after straining.

**WB-4213.1 Exemptions.** Procedure qualification tests are not required for materials listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed material represented by test coupons required in either [WB-2211](#) or [WB-4121.2](#), which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) material that does not require impact tests in accordance with [WB-2300](#);

(d) material that has a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing is required by [WB-2300](#) is performed on each heat and lot, as applicable, after forming.

**WB-4213.2 Procedure Qualification Test.** The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of [Article WB-2000](#) and shall be taken from the tension side of the strained material.



(c) The percent strain shall be established by the following equations:

(1) For cylinders

$$\% \text{ strain} = \frac{50t}{R_f} \left( 1 - \frac{R_f}{R_o} \right)$$

(2) For spherical or dished surfaces

$$\% \text{ strain} = \frac{75t}{R_f} \left( 1 - \frac{R_f}{R_o} \right)$$

(3) For pipe

$$\% \text{ strain} = \frac{100r}{R}$$

where

$R$  = nominal bending radius to the center line of the pipe, in. (mm)

$R_f$  = final radius to center line of shell, in. (mm)

$R_o$  = original radius (equal to infinity for a flat part), in. (mm)

$r$  = nominal radius of the pipe, in. (mm)

$t$  = nominal thickness, in. (mm)

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient  $C_v$  test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (WB-2300). In addition, drop weight tests shall be made when required by WB-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(-a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(-b) the maximum change of temperature at the lateral expansion and energy levels under consideration; or

(2) when lateral expansion is the acceptance criterion (WB-2300), either the maximum change in temperature or the maximum change in lateral expansion.

**WB-4213.3 Acceptance Criteria for Formed Material.** To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming processes used.

**WB-4213.4 Requalification.** A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering WB-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

### WB-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article WB-3000, the material may be repaired in accordance with WB-4130.

### WB-4220 FORMING TOLERANCES

#### WB-4221 Tolerance for Containment Shells

Cylindrical or spherical shells of a completed containment vessel, except formed heads covered by WB-4222, shall meet the requirements of the following subparagraphs at all cross sections, where not further limited by design.

**WB-4221.1 Maximum Difference in Cross-Sectional Diameters.** (17) The difference in inches (millimeters) between the maximum and minimum diameters at any cross section shall not exceed the smaller of

(U.S. Customary Units)

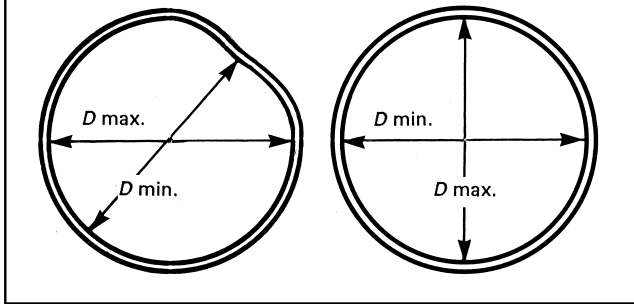
$$\frac{D + 50}{200} \quad \text{and} \quad \frac{D}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \quad \text{and} \quad \frac{D}{100}$$

where  $D$  is the nominal inside diameter, in. (mm), at the cross section under consideration. The diameters may be measured on the inside or outside of the containment cylindrical shell. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Figure WB-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening.

**Figure WB-4221.1-1**  
**Maximum Difference in Cross-Sectional**  
**Diameters**



**WB-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.** Containments designed for external pressure shall meet the tolerances given in (a) through (e) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Figure WB-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Figure WB-4221.2(a)-2. For Figure WB-4221.2(a)-1, the maximum permissible deviation  $e$  need not be less than  $0.3t$ . For Figure WB-4221.2(a)-2, the arc length need not be greater than  $0.30D_o$ . Measurements shall not be taken on welds or other raised parts.

(b) The value of  $t$ , in., at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of  $L$  in Figures WB-4221.2(a)-1 and WB-4221.2(a)-2 is determined by (1) and (2) below.

(1) For cylinders,  $L$  is the total length, in., of the design length of a containment section, taken as the largest of the following:

(-a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings;

(-b) the greatest center-to-center distance between any two adjacent stiffening rings; or

(-c) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the containment, in.

(2) For spheres,  $L$  is one-half of the outside diameter  $D_o$ , in.

(d) The dimensions of a completed containment may be brought within the requirements by any process which will not impair the strength of the material.

(e) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

**WB-4221.3 Deviations From Tolerances.** Deviations from the tolerance requirements stipulated in WB-4221.1 and WB-4221.2 are permitted, provided the drawings are modified and deviations are reconciled with the calculations and the licensing documents. Deviations are permitted, provided Design Documents (WA-3350) and corrective actions are certified by a Certifying Engineer in an addendum to the Design Report. (17)

**WB-4221.4 Tolerance Deviations for Containment Parts Fabricated From Pipe.** Containments subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

## WB-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

**WB-4222.1 Maximum Difference in Cross-Sectional Diameters.** The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches (millimeters) between the maximum and minimum diameters does not exceed the lesser of (17)

(U.S. Customary Units)

$$\frac{D + 50}{200} \quad \text{and} \quad \frac{D + 12}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \quad \text{and} \quad \frac{D + 300}{100}$$

where  $D$  is the nominal inside diameter, in. (mm), and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in WB-4232.

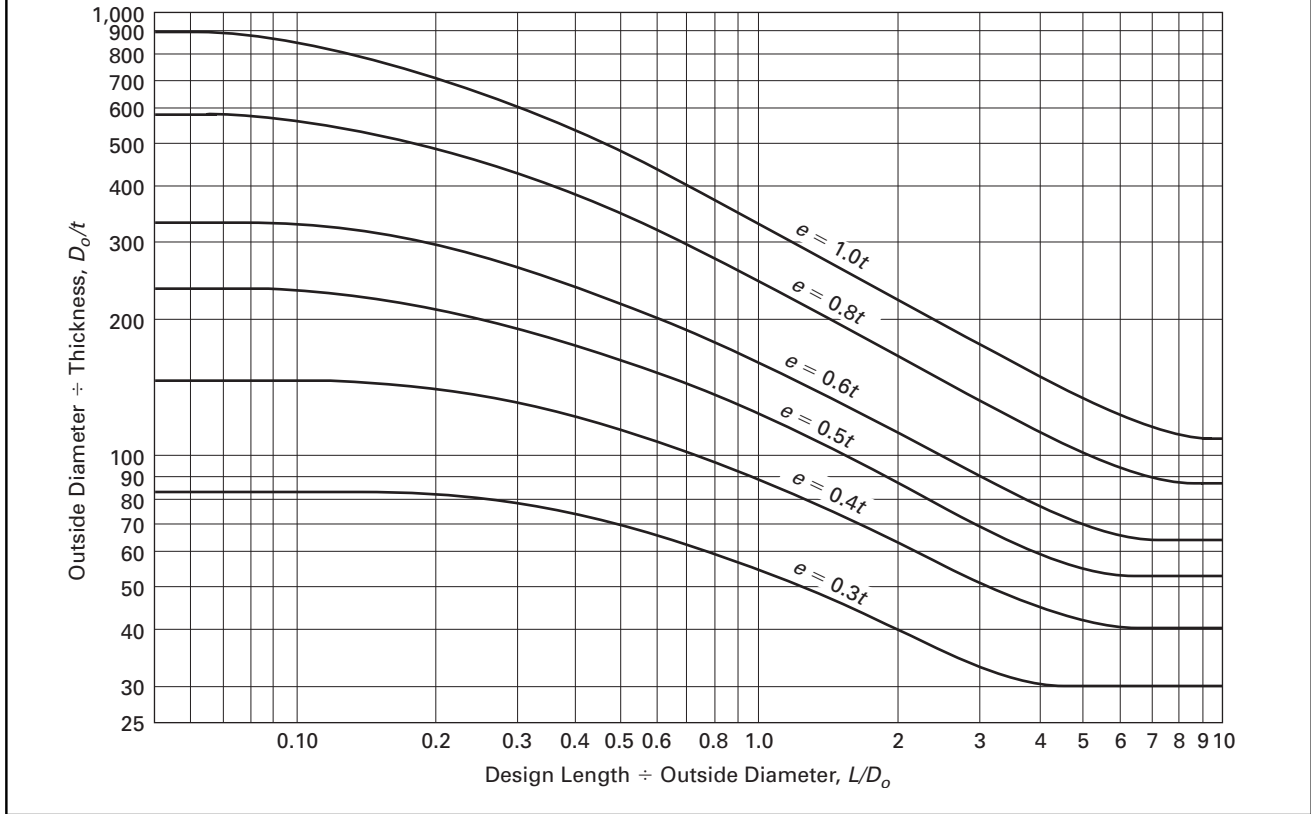
### WB-4222.2 Deviation From Specified Shape.

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than  $1\frac{1}{4}\%$  of  $D$ , inside the specified shape by more than  $\frac{5}{8}\%$  of  $D$ , where  $D$  is the nominal inside diameter of the containment. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the containment.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in WB-4221.2, using  $L$  as the outside spherical radius, in. (mm), and  $D_o$  as two times  $L$ .



**Figure WB-4221.2(a)-1  
Maximum Permissible Deviation  $e$  From a True Circular Form**



(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

**WB-4230 FITTING AND ALIGNING**

**WB-4231 Fitting and Aligning Methods**

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

**WB-4231.1 Tack Welds.** Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds shall be removed.

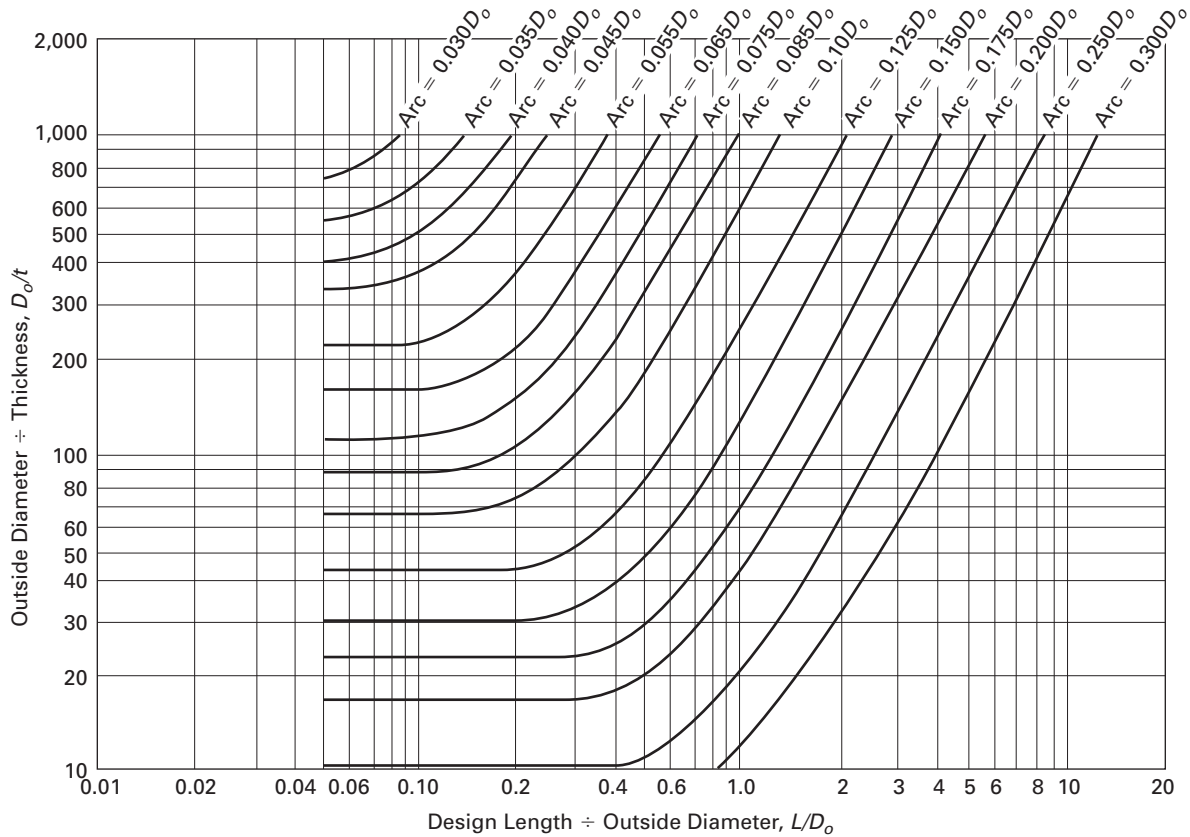
**WB-4232 Alignment Requirements When Containments Are Welded From Two Sides**

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in [Table WB-4232-1](#), where  $t$  is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical containments or within heads, and joints between cylindrical shells and hemispherical heads shall meet the requirements in [Table WB-4232-1](#) for longitudinal joints.

**WB-4232.1 Fairing of Offsets.** Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in [Table WB-4232-1](#) are acceptable provided the requirements of [WB-3200](#) are met.

**Figure WB-4221.2(a)-2  
Maximum ARC Length for Determining Plus or Minus Deviation**



**WB-4233 Alignment Requirements When Inside Surfaces Are Inaccessible**

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with WB-4232, alignment of sections shall meet the requirements of (1) and (2) below:

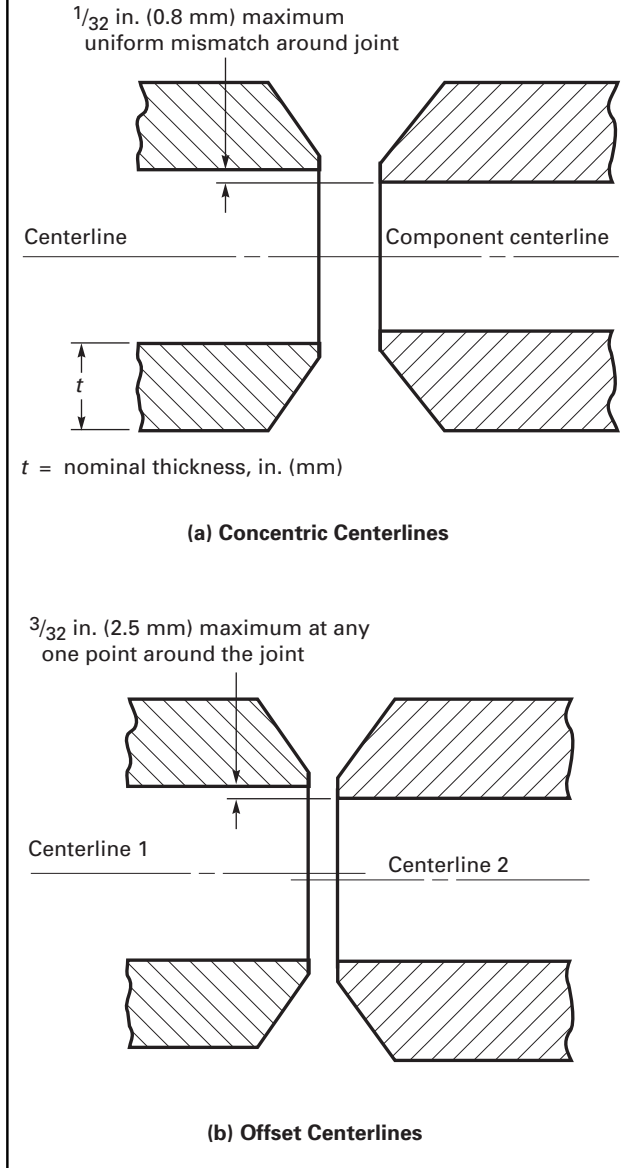
(1) See (-a) and (-b) below.

(-a) For circumferential joints the inside diameters shall match each other within  $\frac{1}{16}$  in. (1.5 mm). When the items are aligned concentrically, a uniform mismatch of  $\frac{1}{32}$  in. (0.8 mm) all around the joint can result as shown in Figure WB-4233(a)-1 sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed  $\frac{3}{32}$  in. (2.5 mm) as shown in Figure WB-4233(a)-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations which do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided a gradual change in thickness from the item to adjoining items is maintained. Any welding transition is acceptable, provided the wall thickness in the transition region is not less than the minimum wall thickness of the containment or item and sharp reentrant angles and abrupt changes in slope in the transition region are avoided.

**Table WB-4232-1  
Maximum Allowable Offset in Final Welded Joints**

Section Thickness, in. (mm)	Direction of Joints	
	Longitudinal in. (mm)	Circumferential in. (mm)
Up to $\frac{1}{2}$ (13), incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$ (13 to 19), incl.	$\frac{1}{8}$ (3)	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	$\frac{1}{8}$ (3)	$\frac{3}{16}$ (5)
Over $1\frac{1}{2}$ to 2 (38 to 50), incl.	$\frac{1}{8}$ (3)	$\frac{1}{8}t$
Over 2 (50)	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ (10)	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ (19)

**Figure WB-4233(a)-1**  
**Butt Weld Alignment and Mismatch Tolerances**  
**for Unequal I.D. and O.D. When Items Are**  
**Welded From One Side and Fairing Is Not**  
**Performed**



(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed  $\frac{3}{32}$  in. (2.5 mm) and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single-welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of WB-4232.

## WB-4240 REQUIREMENTS FOR WELD JOINTS IN CONTAINMENTS

### WB-4241 Category A Weld Joints in Containments

Category A weld joints in containments shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of WB-4424.

### WB-4242 Category B Weld Joints in Containments

Category B weld joints in containments shall be full penetration butt joints. When used, backing strips shall be continuous in cross section. Joints prepared with opposing lips to form an integral backing strip and joints with backing strips which are not later removed are acceptable provided the requirements of WB-3252.2 are met.

### WB-4243 Category C Weld Joints in Containments

(17)

Category C weld joints shall be described in subparas. (a) through (c) below.

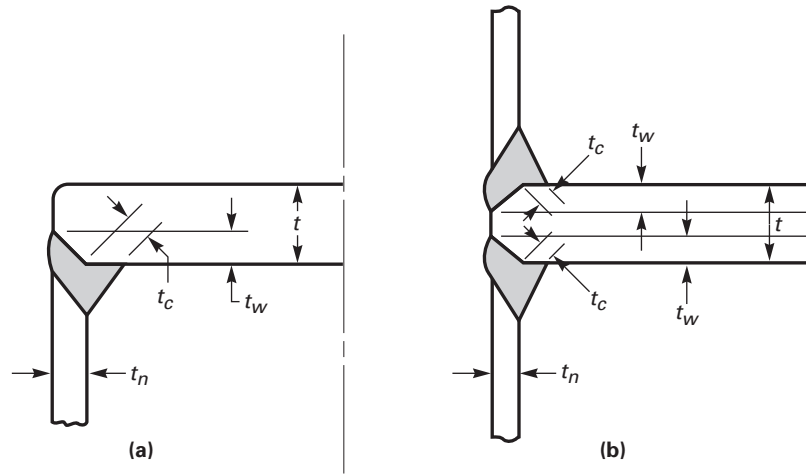
(a) *Full Penetration Butt Joints.* Category C welds shall be full penetration joints. Joints that have been welded from one side with backing where backing has been subsequently removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of WB-4424. Butt-welded joints are shown in Figure WB-4243-1.

(b) *Full Penetration Corner Joints.* Full penetration corner joints shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Typical details for type No. 1 and No. 2 full penetration corner joints are shown in Figure WB-4243-1.

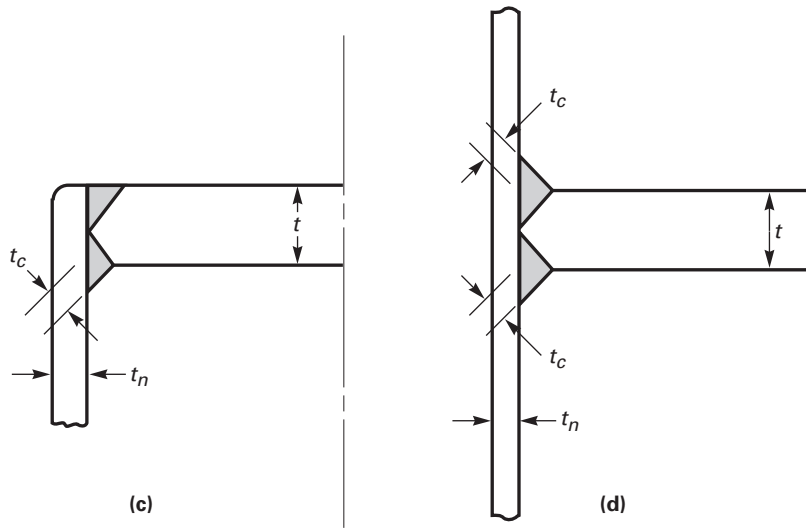
#### (c) Flat Heads With Hubs

(1) Hubs for butt welding to the adjacent shell, head, or other containment parts, as shown in Figure WB-4243-2, for flat heads, shall not be machined from flat plate. The hubs shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material in the direction parallel to the axis of the containment vessel. Proof of this shall be furnished by a tension test specimen (subsize, if necessary) taken in this direction and as close to the hubs as is practical. One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat material and the same heat treatment lot, and forged in the same manner. The minimum height of the hub shall be the lesser of  $1\frac{1}{2}$  times

**Figure WB-4243-1**  
**Acceptable Full Penetration Weld Details for Category C Joints**



**Type 1 Corner Welds**



**Type 2 Corner Welds**

GENERAL NOTE: For definitions of nomenclature, see [WB-3252.3](#).

the thickness of the containment part to which it is welded or  $\frac{3}{4}$  in. (19 mm), but need not be greater than 2 in. (50 mm).

(2) Hubbed flanges shall not be machined from flat plate.

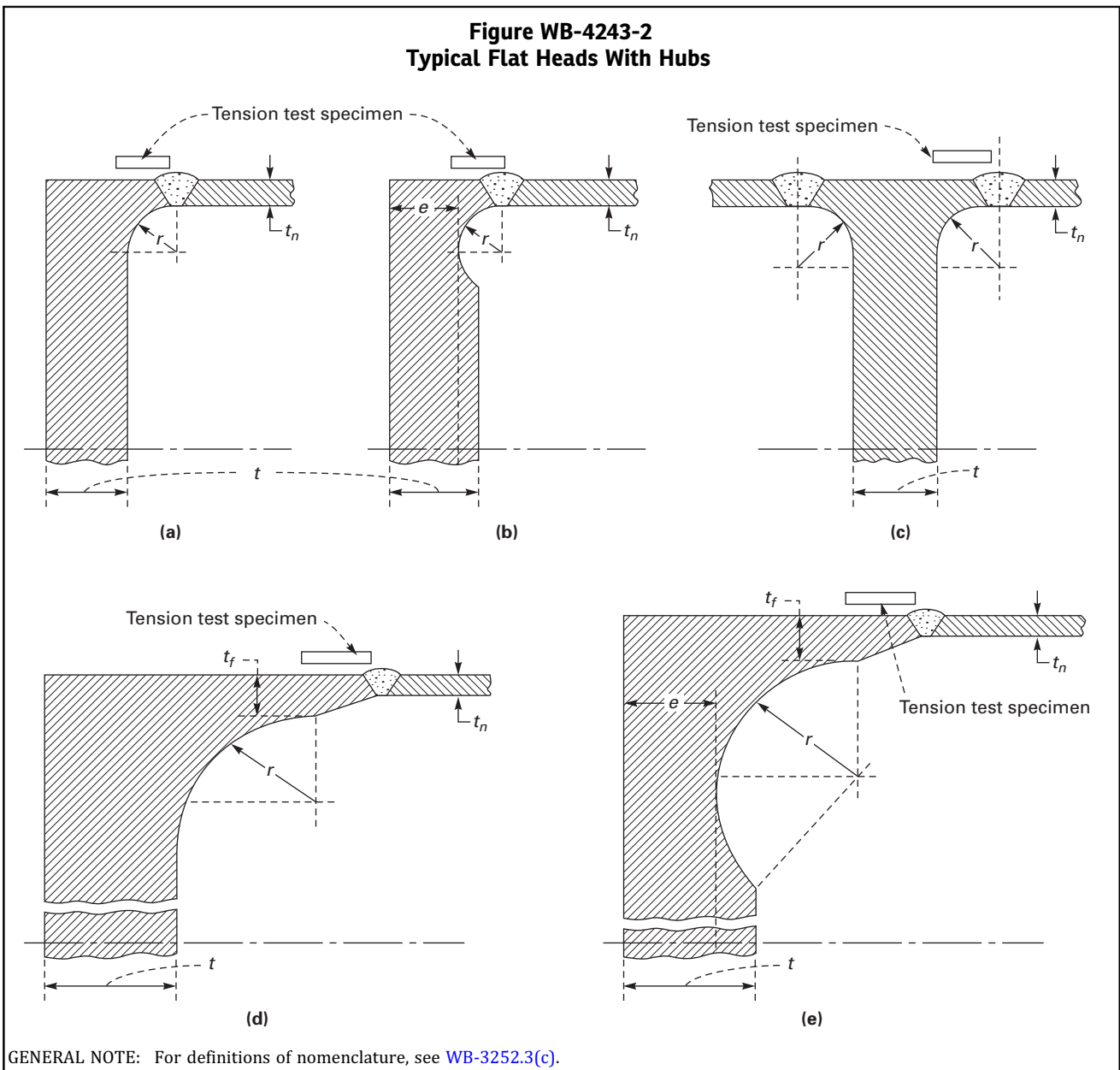
**WB-4244 Category D Weld Joints in Containments**

Category D weld joints in containments and similar weld joints in other components shall be full or partial penetration weld joints using one of the details of (a) through (d) below.

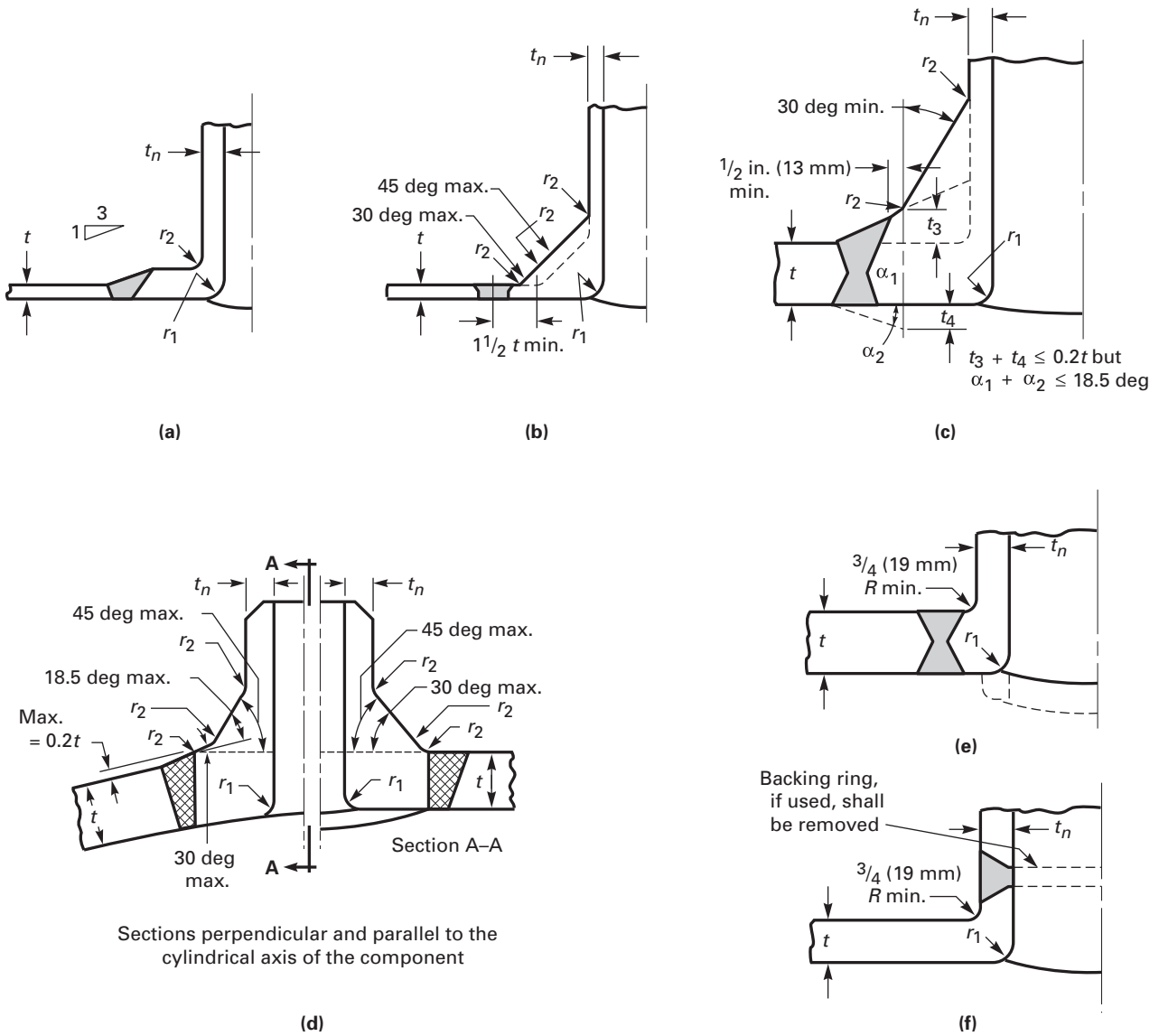
(a) *Butt-Welded Nozzles.* Nozzles shall be attached by full penetration butt welds through the wall of the containment as shown in Figure WB-4244(a)-1. Backing strips, if used, shall be removed.

(b) *Corner-Welded Nozzles.* Nozzles shall be joined to the containment by full penetration welds through the wall of the containment similar to those shown in Figure WB-4244(b)-1. Backing strips, if used, shall be removed.

(c) *Deposited Weld Metal of Openings for Nozzles.* Nozzles shall be joined to the containment by full penetration weld to built-up weld deposits applied to the containment as shown in Figure WB-4244(c)-1. Backing strips, if used, shall be removed. Fillet welds shall be used only to provide a transition between the parts joined or to provide

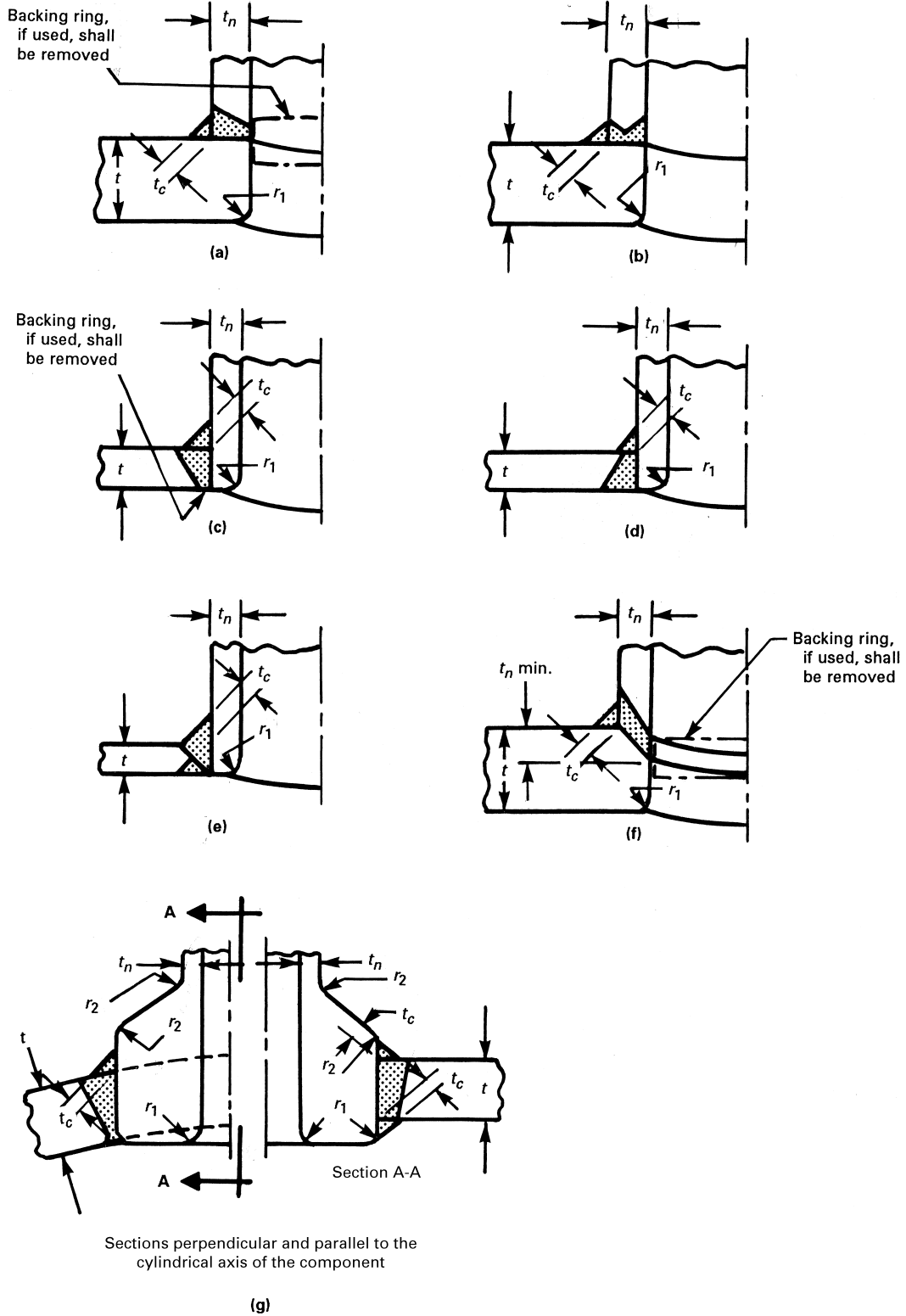


**Figure WB-4244(a)-1**  
**Nozzles Attached by Full Penetration Butt Welds**



GENERAL NOTE: For definition of nomenclature, see [WB-3252.4](#).

**Figure WB-4244(b)-1**  
**Nozzles Attached by Full Penetration Corner Welds**



GENERAL NOTE: For definition of nomenclature, see [WB-3252.4](#).



a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

(d) *Partial Penetration Welded Nozzles.* Partial penetration welds in containments shall meet the weld design requirements of [WB-3252.4\(f\)](#). Nozzles shall be attached as shown in [Figures WB-4244\(d\)-1](#).

## **WB-4300 WELDING QUALIFICATIONS**

### **WB-4310 GENERAL REQUIREMENTS**

#### **WB-4311 Types of Processes Permitted**

(a) Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding containment material or attachments thereto. Any process used shall be such that the records required by [WB-4320](#) can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

(b) This Subsection does not permit the use of inertia and continuous drive friction welding, specially designed seal welds, electroslag, or electrogas welding.

**WB-4311.1 Stud Welding Restrictions.** Stud welding is acceptable only for nonstructural and temporary attachments ([WB-4435](#)). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and  $\frac{3}{4}$  in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with [WB-4600](#), except that time at temperature need not exceed  $\frac{1}{2}$  hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

**WB-4311.2 Capacitor Discharge Welding.** Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

(a) temporary attachments are removed in accordance with the provisions of [WB-4435\(b\)](#); and

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec, and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

## **WB-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS**

### **WB-4321 Required Qualifications**

(a) Each Certificate Holder is responsible for the welding done by his organization, and each Certificate Holder shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to containments and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

(d) [WA-3131](#) provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Authorization.

### **WB-4322 Maintenance and Certification of Records**

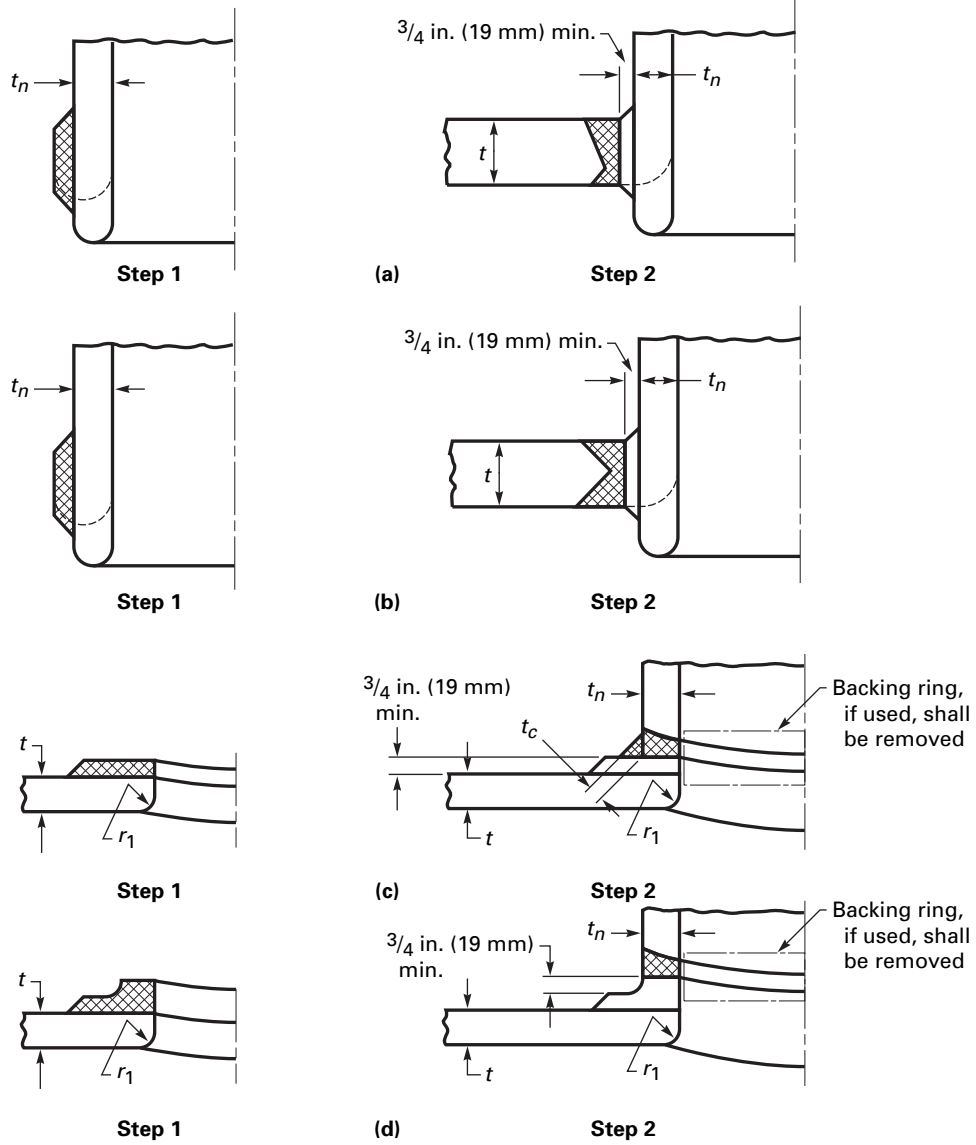
The Certificate Holder shall maintain a record of the qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program and shall be available to the Authorized Nuclear Inspector.

#### **WB-4322.1 Identification of Joints by Welder or Welding Operator.**

(a) Each welder or welding operator shall apply the identification mark assigned by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

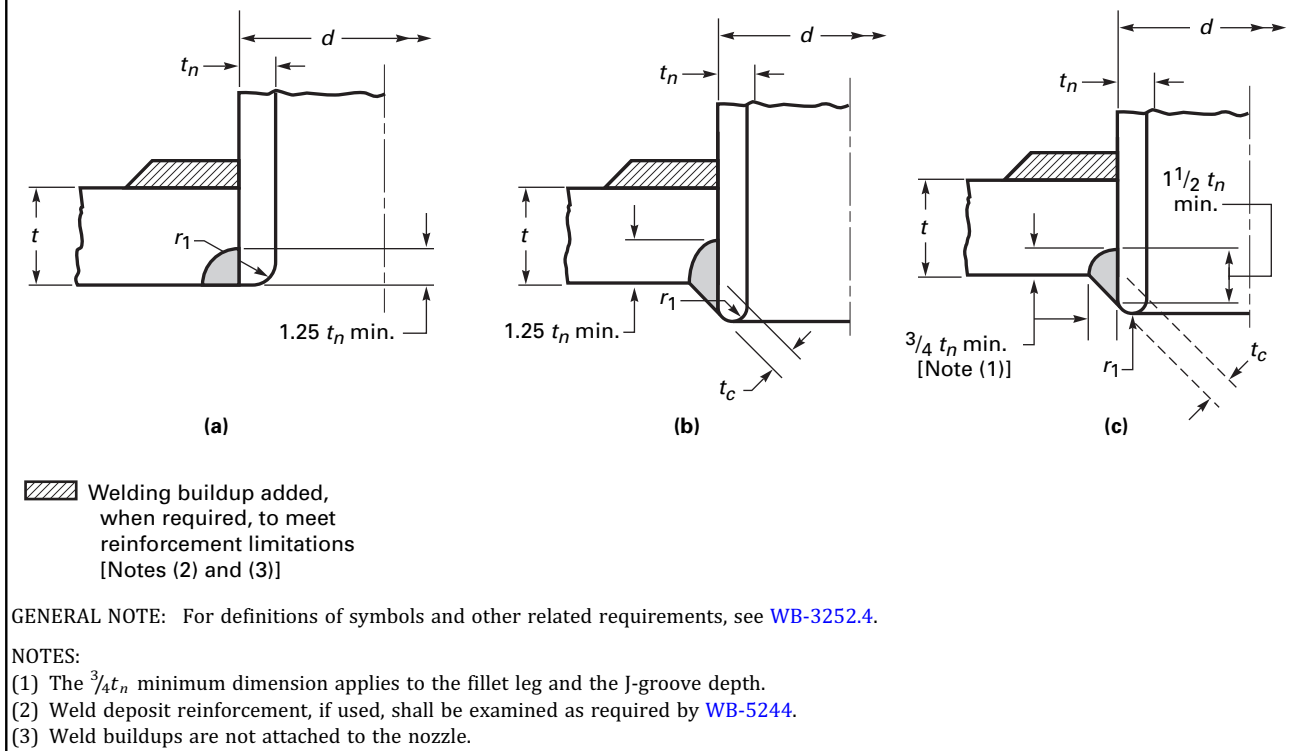
(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, weld metal cladding, and hard surfacing are

**Figure WB-4244(c)-1**  
**Deposited Weld Metal Used as Reinforcement of Openings for Nozzles**



GENERAL NOTE: For definition of nomenclature, see [WB-3252.4](#).

**Figure WB-4244(d)-1**  
**Nozzles Attached by Partial Penetration Welds**



made on the containment, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided the following applies:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on the containment so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

### WB-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with [WB-4320](#) and Section IX shall be used.

### WB-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX.

### WB-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

#### WB-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

#### WB-4333 Heat Treatment of Qualification Welds for Ferritic Materials

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of [WB-4600](#) and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

#### WB-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the  $\frac{1}{4}t$  location required by this Subsection, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

**WB-4334.1 Coupons Representing the Weld Deposit.** Impact test specimens and testing methods shall conform to [WB-2321](#). The impact specimen shall be located so that the longitudinal axis of the specimen is at least  $0.25t$  and, where the thickness of the test assembly permits, not less than  $\frac{3}{8}$  in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in [WB-4620](#) and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of  $t$  from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

**WB-4334.2 Coupons Representing the Heat-Affected Zone.** Where impact tests of the heat-affected zone are required by [WB-4335.2](#), specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of [WB-2321.2](#). The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line.

(c) For the comparison of heat-affected zone values with base material values [[WB-4335.2\(b\)](#)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat-affected zone

specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by [WB-4335.2\(b\)](#), drop-weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of [WB-2321.1](#).

## WB-4335 Impact Test Requirements

When materials are required to be impact tested per [WB-2300](#), impact tests of the weld metal and heat-affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of [WB-2330](#) and [WB-4334](#). Retests in accordance with the provisions of [WB-2350](#) are permitted.

### WB-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding  $\frac{5}{8}$  in. (16 mm) in thickness when the weld will be made on the surface or penetrate base material that requires impact testing in accordance with [WB-2310](#). In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with [WB-2310](#), regardless of the depth of the repair. Exemption from impact testing under [WB-2311\(a\)](#) does not apply to weld metal of welding procedure qualification tests for either production weld joints or base metal repairs unless the specific weld metal used is A-No. 8.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in [WB-2330](#) for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal except where this is otherwise specified in the Design Specification.

(c) Impact tests are not required for austenitic and nonferrous weld metal.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Division 1, Subsection NB or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

### WB-4335.2 Impact Tests of Heat-Affected Zone.

(a) Charpy V-notch tests of the heat-affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds  $\frac{5}{8}$  in. (16 mm) and either of the base materials require

impact testing in accordance with the rules of [WB-2310](#). The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated.

(2) the qualification for weld deposit cladding.

(3) that portion of the heat-affected zone associated with GTAW root deposits with a maximum of two layers or  $\frac{3}{16}$  in. (5 mm) thickness, whichever is less.

(b) The required testing shall be in accordance with (c) below for base material tested under [WB-2331](#) or [WB-2332\(b\)](#) and in accordance with (d) below for base material tested under [WB-2332\(a\)](#).

(c) For heat-affected zones associated with base material tested under [WB-2331](#) or [WB-2332\(b\)](#), the required testing shall be in accordance with (1) through (7).

(1) Determine the  $T_{NDT}$  of the unaffected base material to be used in the welding procedure qualification test assembly.

(2) Charpy V-notch test specimens representing both the heat-affected zone and the unaffected base material shall be tested. The unaffected base material specimens shall be tested at the  $(T_{NDT} + 60^{\circ}\text{F})$  ( $T_{NDT} + 33^{\circ}\text{C}$ ) temperature.

(3) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of [WB-2330](#) or additional testing shall be performed at higher temperatures until the requirements of [WB-2330](#) are met.

(4) The heat-affected zone specimens shall be tested at the test temperature determined in (3). The average lateral expansion value of the specimens shall equal or exceed the average lateral expansion value of the unaffected base material. For this case, the qualification test is acceptable for the essential and supplemental essential variables recorded on the welding procedure qualification record. If the heat-affected zone average lateral expansion value is less than the unaffected base material lateral expansion value, the adjustment given in (5) through (7) shall be determined and applied as provided in (e). Alternatively, another test coupon may be welded and tested.

(5) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than 35 mils (0.89 mm). The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature between  $T_{HAZ}$  and  $T_{UBM}$ , where the heat-affected zone and the unaffected base material average lateral expansion values are the same and not less than 35 mils (0.89 mm), shall be used to determine the adjustment temperature  $T_{ADJ}$ , where:

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If  $T_{ADJ} \leq 0$ , then  $T_{ADJ} = 0$

(6) As an alternative to (5), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm) and the average of the heat-affected zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material specimens,  $T_{ADJ}$  may be taken as  $15^{\circ}\text{F}$  ( $8^{\circ}\text{C}$ ).

(7) As a second alternative to (5), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3) below.

(d) For heat-affected zones associated with base materials tested under [WB-2332\(a\)](#), the required testing shall be in accordance with (1) through (5).

(1) Three Charpy V-notch specimens shall be removed from both the unaffected base material and the heat-affected zone. The unaffected base material specimens shall be tested at a test temperature established in the Design Specification, or additional testing shall be performed at higher temperatures until the applicable requirements of [Table WB-2332\(a\)-1](#) are met for the thickness of material to be welded in production.

(2) The heat-affected zone specimens shall be tested at the test temperature determined in (1). The average lateral expansion value of the specimens shall equal or exceed the average lateral expansion value of the unaffected base material. For this case, the qualification test is acceptable for the essential and supplemental essential variables recorded on the weld procedure qualification record. If the heat-affected zone average lateral expansion value is less than the unaffected base material lateral expansion value, the adjustment given in (3) through (5) shall be determined and applied as provided in (e). Alternatively, another test coupon may be welded and tested.

(3) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than the values shown in [Table WB-2332\(a\)-1](#) for the thickness of base material to be welded in production. The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature between  $T_{HAZ}$  and  $T_{UBM}$ , where the heat-affected zone and the unaffected base material average lateral expansion values are the same and not less than that specified in (2) above, shall be used to determine the adjustment temperature  $T_{ADJ}$ , where:

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If  $T_{ADJ} \leq 0$ , then  $T_{ADJ} = 0$

(4) As an alternative to (3), if the average lateral expansion value of the heat-affected zone is no less than 35 mils (0.89 mm) and the average of the heat-affected



zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material,  $T_{ADJ}$  may be taken as 15°F (8°C).

(5) As a second alternative to (3), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3) below.

(e) At least one of the following methods shall be used to compensate for the heat-affected zone toughness decrease due to the welding procedure effects:

(17) (1) The  $RT_{NDT}$  temperature established in WB-2331 or WB-2332(b) or the LST specified in the Design Specification [WB-2332(a)] for all of the material to be welded in production Welding Procedure Specifications supported by this Procedure Qualification Record shall be increased by the adjustment temperature  $T_{ADJ}$ .

(2) The specified testing temperature for the production material may be reduced by  $T_{ADJ}$ .

(3) The materials to be welded may be welded using the WPS, provided they exhibit Charpy V-notch values which are no less than the minimum required lateral expansion value required by WB-2300 plus the difference in average lateral expansion values established in (c)(7) or (d)(5) above.

(f) The Charpy V-notch testing results shall be recorded on the welding procedure qualification record and any offsetting  $T_{ADJ}$  or increased toughness requirements shall be noted on the welding procedure qualification record and on the welding procedure specification. More than one compensation method may be used on a par basis.

(g) A Welding Procedure Specification qualified to the impact testing requirements of Division 1, Subsection NB or Subsection NE may be accepted as an alternative to the Welding Procedure impact testing requirements of this Subsection.

#### **WB-4336 Qualification Requirements for Built-Up Weld Deposits**

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of WB-4331 through WB-4335.

#### **WB-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS**

##### **WB-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING**

##### **WB-4411 Identification, Storage, and Handling of Welding Material**

Each Certificate Holder is responsible for control of the welding electrodes and other material which is used in the fabrication of containments (WB-4120). Suitable

identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

#### **WB-4412 Cleanliness and Protection of Welding Surfaces**

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

#### **WB-4420 RULES FOR MAKING WELDED JOINTS**

##### **WB-4421 Backing Rings**

Backing rings shall conform to the requirements of WB-4240. The material for backing rings, when used, shall be compatible with the base metal. Permanent backing rings, when permitted by WB-3252, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

##### **WB-4422 Peening**

Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer, root of the weld metal, or on the final layer unless the weld is postweld heat treated.

##### **WB-4423 Miscellaneous Welding Requirements**

(a) Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods, such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

(b) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(c) Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

##### **WB-4424 Surfaces of Welds**

As-welded surfaces are permitted. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, and abrupt ridges and valleys to meet (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examinations of the

weld. In those cases where there is a question regarding the surface condition of the weld on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with [WB-4426.1](#).

(c) Undercuts shall not exceed  $\frac{1}{32}$  in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of [Article WB-3000](#).

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

## WB-4426 Reinforcement of Welds

**WB-4426.1 Thickness of Weld Reinforcement for Containments.** The surface of the reinforcement of all butt-welded joints in containments may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thickness in the following tabulation:

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Up to 1 (25), incl.	$\frac{3}{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$\frac{1}{8}$ (3.0)
Over 2 to 3 (50 to 75), incl.	$\frac{5}{32}$ (4.0)
Over 3 to 4 (75 to 100), incl.	$\frac{7}{32}$ (5.5)
Over 4 to 5 (100 to 125), incl.	$\frac{1}{4}$ (6)
Over 5 (125)	$\frac{5}{16}$ (8)

## WB-4427 Shape and Size of Fillet Welds

Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of [Figure WB-4427-1](#). A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than  $\frac{1}{16}$  in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. In making socket welds, a gap as shown in [Figure WB-4427-1](#) shall be provided prior to welding. The gap need not be present nor be verified after welding.

## WB-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

## WB-4429 Welding of Clad Parts<sup>11</sup>

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition.

## WB-4430 WELDING OF ATTACHMENTS

### WB-4431 Materials for Attachments

Attachments ([WB-1132](#)) welded to the containment shall be of materials which meet the requirements of [WB-2121](#). Materials for the containment attachments shall meet the requirements of [WB-2120](#).

### WB-4432 Welding of Structural Attachments

The rules of [WB-4321](#) governing welding qualifications shall apply to the welding of structural attachments to containments.

### WB-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous welds. When fillet and partial penetration welds are used on containments, the requirements of [WB-3123.2](#) shall be met. Attachments to the internal surfaces of containments shall be made only with full penetration welds. [Figure WB-4433-1](#) illustrates some of the typical details for attaching structural attachments to a containment using full penetration welds.

### WB-4434 Welding of Internal Structural Supports to Clad Containments

Internal structural supports on clad containments shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

### WB-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

(a) Nonstructural attachments welded to the containment need not comply with [Article WB-2000](#) and may be welded with continuous fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

(1) The welding procedure and the welders have been qualified in accordance with [WB-4321](#).

(2) The material is identified and is compatible with the material to which it is attached.

(3) The welding material is identified and compatible with the materials joined.

(4) The welds are postweld heat treated when required by [WB-4620](#).

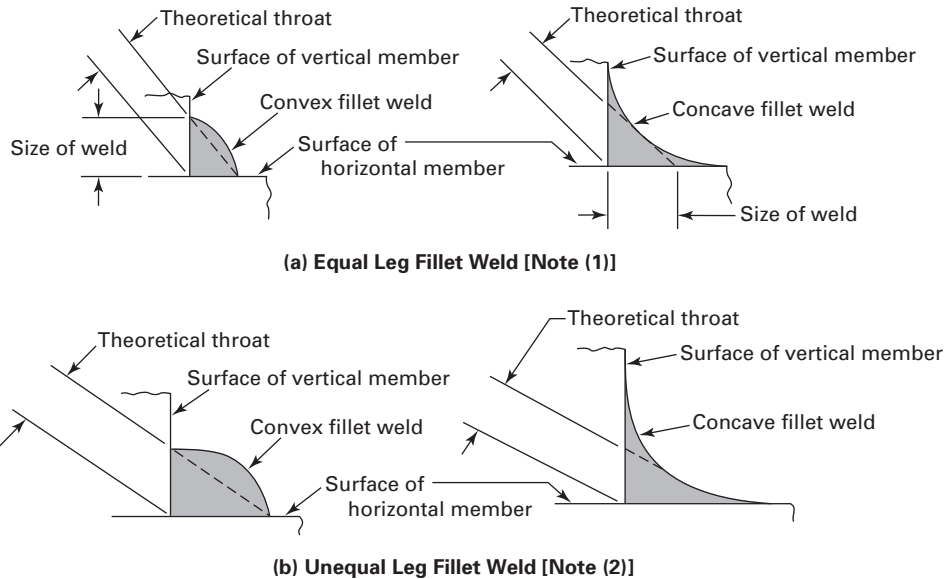
(b) Removal of nonstructural attachments, when temporary, shall be accomplished as follows.

(1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.

(2) The temporary attachment is completely removed in accordance with the procedures of [WB-4211](#).



**Figure WB-4427-1  
Fillet Weld Details**



**NOTES:**

- (1) The size of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle. Theoretical throat =  $0.7 \times$  size of weld.  
 (2) The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross section.

(3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of [WB-5110](#), and meets the acceptance standards of [WB-5340](#) or [WB-5350](#), whichever is applicable.

(4) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with [WB-5110](#) after blending and meets the acceptance standards of [WB-5300](#) to ensure that the defect has been removed or reduced to an imperfection of acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

**WB-4450 REPAIR OF WELD METAL DEFECTS**

**WB-4451 General Requirements**

Defects in weld metal detected by the examinations required by [Article WB-5000](#), or by the tests of [Article WB-6000](#), shall be eliminated and repaired when necessary.

**WB-4452 Elimination of Surface Defects**

Weld metal surface defects may be removed by grinding or machining, and need not be repaired by welding, provided that the requirements of (a) through (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by [Article WB-3000](#).

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

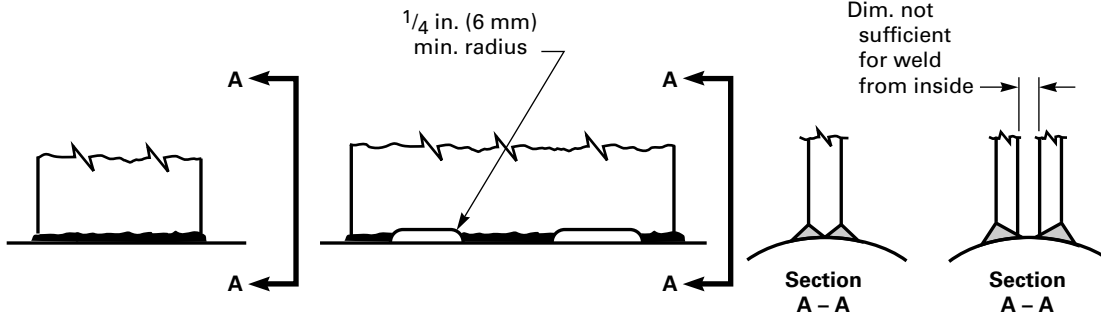
**WB-4453 Requirements for Making Repairs of Welds**

Excavations in weld metal, when repaired by welding, shall meet the following requirements.

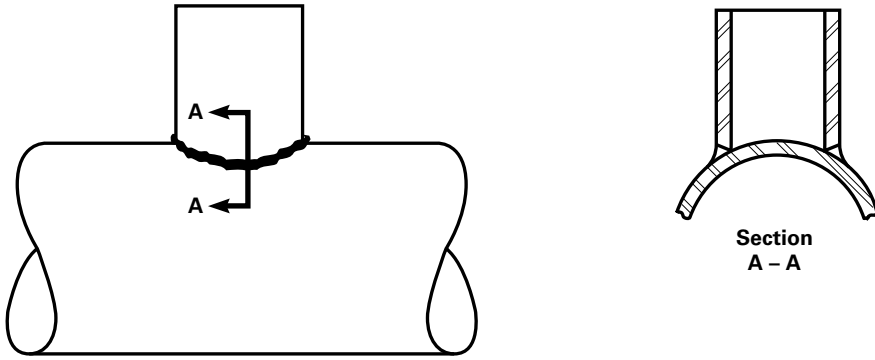
**WB-4453.1 Defect Removal.** Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with [WB-5110](#), and meet the acceptance standards of [WB-5340](#) or [WB-5350](#). This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

**WB-4453.2 Requirements for Welding Material, Procedures, and Welders.** The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with [WB-4125](#) and [WB-4300](#).

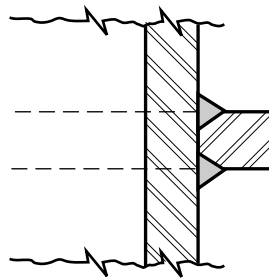
**Figure WB-4433-1**  
**Types of Attachment Welds**



**(a) Attachment of Lugs, Shoes, and Brackets**



**(b) Attachment of Trunnions**



**(c) Attachment of Rings**

**WB-4453.3 Blending of Repaired Areas.** After repair, the surface shall be blended uniformly into the surrounding surface.

**WB-4453.4 Examination of Repair Welds.**

(a) The examination of a weld repair shall be repeated as required for the original weld, except that when the defect was originally detected by the liquid penetrant or magnetic particle method, and when the repair cavity does not exceed the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the thickness, it need only be reexamined by the liquid penetrant or magnetic particle method.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a) above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted provided:

(1) the weld had been previously radiographed and met the applicable acceptance standards;

(2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article 4, to the acceptance standards of [WB-5330](#);

(3) the substitution is limited to Category A and B welds in containments, and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

**WB-4453.5 Heat Treatment of Repaired Areas.** The area shall be heat treated in accordance with [WB-4620](#).

## **WB-4600 HEAT TREATMENT**

### **WB-4610 WELDING PREHEAT REQUIREMENTS**

#### **WB-4611 When Preheat Is Necessary**

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Section III Appendices, Nonmandatory Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Section III Appendices, Nonmandatory Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

### **WB-4612 Preheating Methods**

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied, or which does not introduce deleterious material into the welding area which is harmful to the weld.

### **WB-4613 Interpass Temperature**

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

## **WB-4620 POSTWELD HEAT TREATMENT**

### **WB-4621 Heating and Cooling Methods**

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

### **WB-4622 PWHT Time and Temperature Requirements**

**WB-4622.1 General Requirements.** Except as otherwise permitted in [WB-4622.7](#), all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in [Table WB-4622.1-1](#), except as otherwise permitted in [WB-4622.4\(c\)](#). P-Number groups in [Table WB-4622.1-1](#) are in accordance with Section IX, QW-420. Except as provided in [WB-4624.3](#), PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens. In addition, the requirements of the following subparagraphs shall apply. (17)

**WB-4622.2 Time-Temperature Recordings.** Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the weld or containment, as applicable. A summary of the time-temperature recording may be provided for permanent records in accordance with [WA-4134](#).

**WB-4622.3 Definition of Nominal Thickness Governing PWHT.** Nominal thickness in [Table WB-4622.7\(b\)-1](#) is the thickness of the weld, the containment material for structural attachment welds or the thinner of the containment materials being joined, whichever is least. It is not intended that nominal thickness

**Table WB-4622.1-1**  
**Mandatory Requirements for Postweld Heat Treatment of Welds**

P-No. (Sec. IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		1/2 in. (13 mm) or less	Over 1/2 in. to 2 in. (13 mm to 50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
1, 3	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
P-Nos. 8, 10 H Gr. 1, 34, 42, 43, 45 and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in [WB-4622.7](#).

NOTE:

(1) All temperatures are metal temperatures.

include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed  $\frac{1}{8}$  in. (3 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

#### **WB-4622.4 Holding Times at Temperature.**

(a) The holding time at temperature as specified in [Table WB-4622.1-1](#) shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of [Table WB-4622.1-1](#) may be used, provided that specimens so heat treated are tested in accordance with [WB-2200](#), [WB-2400](#), and [WB-4300](#).

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in [Table WB-4622.1-1](#), it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with [Table WB-4622.4\(c\)-1](#) and (1), (2), and (3) below.

**Table WB-4622.4(c)-1**  
**Alternative Holding Temperatures and Times**

Material P-No.	Alternative Minimum Holding Temperatures, °F (°C)	Alternative Minimum Holding Times [Note (1)]
1, 3	1,050 (565)	2 hr/in. (4 min/mm) thick
1, 3	1,000 (540)	4 hr/in. (8 min/mm) thick

NOTE:

(1) All other requirements of [WB-4622](#) shall apply.

(1) Except for P-No. 1 materials, when welds in the materials listed in [Table WB-4622.4\(c\)-1](#) are to be postweld heat treated at the lower minimum temperatures, the impact test specimens for the welding procedure qualification required by [WB-4300](#) shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in [Table WB-4622.1-1](#) and at the lower temperature and increased minimum holding time permitted by [Table WB-4622.4\(c\)-1](#), are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from [Table WB-4622.1-1](#) and the alternative requirements from [Table WB-4622.4\(c\)-1](#).

(2) Except for P-No. 1 materials, when welds in the materials listed in [Table WB-4622.4\(c\)-1](#) are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by [WB-2400](#) shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in [Table WB-4622.1-1](#) and at the lower minimum temperatures and increased minimum holding time permitted by [Table WB-4622.4\(c\)-1](#) are also certified for any temperature in between.

(3) Base material certified in accordance with [WB-2200](#) may be postweld heat treated at the lower minimum temperature ranges and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation provided a higher tempering temperature is not required by the material specification.

**WB-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.** When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in [Table WB-4622.1-1](#) for the material requiring the higher PWHT temperature range.

**WB-4622.6 PWHT Requirements for Noncontainment Parts.** When noncontainment material is welded to containment material, the postweld heat treatment temperature range of the containment material shall control.

**WB-4622.7 Exemptions to Mandatory Requirements.** Postweld heat treatment in accordance with this subarticle is not required for:

- (a) nonferrous material;
- (b) welds exempted in [Table WB-4622.7\(b\)-1](#);
- (c) welds subjected to temperatures above the PWHT temperature range specified in [Table WB-4622.1-1](#), provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld filler material have been heat treated at the higher temperature;

(d) welds connecting nozzles to containments provided the requirements in [WB-4622.8](#) are met;

(e) weld repairs to containments provided the requirements of [WB-4622.9](#) are met;

(f) weld repairs to cladding after final postweld heat treatment provided the requirements of [WB-4622.10](#) are met;

(g) weld repairs to dissimilar metal welds after final postweld heat treatment provided the requirements of [WB-4622.11](#) are met.

**WB-4622.8 Requirements for Exempting PWHT of Nozzles to Containment Welds.** Welds connecting nozzles of P-No. 1 materials to containments of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in [Table WB-4622.7\(b\)-1](#) need not be given a postweld heat treatment if the requirements of (a) below are met for partial penetration and (b) below are met for full penetration welds.

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after:

**Table WB-4622.7(b)-1  
Exemptions to Mandatory PWHT**

P-No. (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness, in. (mm) (WB-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)
1	All welds, where the materials being joined are 1½ in. (38 mm) and less	1¼ (32) and less	0.30 and less	...
		Over 1¼ to 1½ (32 to 38)	0.30 and less	200 (95)
		¾ (19) or less	Over 0.30	...
		Over ¾ to 1½ (19 to 38)	Over 0.30	200 (95)
	All welds in material over 1½ in. (38 mm)	¾ (19) or less	...	200 (95)
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. (38 mm) or less	...	0.30	100 (38)
	Over 1½ in. to 3 in. (38 mm to 75 mm)	...	0.30	200 (95) [Note (4)]
	Over 3 in. (75 mm)	...	0.30	250 (120) [Note (5)]
3	For containment repair without required PWHT, see <a href="#">WB-4622.9</a> or <a href="#">WB-4622.10</a>	...	...	350 (175)
3 except Gr. 3	All welds, except repair welds in containments, provided weld procedure qualification is made using equal or greater thickness base material than production weld [Note (6)]	5/8 (16) or less	0.25 or less	200 (95)
	Attachment welds joining containment to noncontainment material	1/2 (13) or less	0.25 or less	200 (95)

GENERAL NOTE: The exemptions noted in this Table do not apply to electron beam welds in ferritic materials over 1/8 in. (3 mm) in thickness.

NOTES:

- (1) Where the thickness of material is identified in the column Type of Weld, it is the thickness of the base material at the welded joint.
- (2) Carbon level of the pressure-retaining materials being joined.
- (3) The maximum resulting hardness of the heat-affected zone, in the procedure qualification test plate shall not exceed 35 Rc.
- (4) Intermediate postweld soak at not less than 200°F (95°C) for 2 hr minimum.
- (5) Intermediate postweld soak at not less than 300°F (150°C) for 2 hr minimum.
- (6) Weld Procedure Qualification coupon need not exceed 1.5 in. (38 mm) in thickness.

(1) the ferritic materials to be joined are buttered or built-up with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of  $\frac{1}{4}$  in. (6 mm), and

(2) the heat-affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with [WB-4620](#), without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal provided that:

(1) the containment is built-up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of  $\frac{1}{4}$  in. (6 mm);

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with [WB-4620](#) for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the containment thickness;

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle to the containment does not exceed  $1\frac{1}{2}$  in. (38 mm) and the maximum reported carbon content of the nozzle does not exceed 0.30%;

(6) a 200°F (95°C) minimum preheat is maintained during welding whenever the nominal thickness of the weld exceeds:

(-a)  $1\frac{1}{4}$  in. (32 mm) and the maximum reported carbon content of the material of the nozzle is 0.30% or less, or

(-b)  $\frac{3}{4}$  in. (19 mm) and the maximum reported carbon content of material of the nozzle exceeds 0.30%.

**WB-4622.9 Temper Bead Weld Repair.** Limited weld repairs to P-No. 1 and P-No. 3 material, and A-Nos. 1, 2, 10, or 11 weld filler metal (Section IX, Table QW-442), may be made without PWHT or after the final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met:

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with [Article WB-5000](#).

(b) *Maximum Extent of Repair.* The maximum area of an individual repair based on the finished surface shall be 100 in.<sup>2</sup> (65 000 mm<sup>2</sup>) and the depth of repair shall not be greater than one-third of the base material thickness.

(c) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Subsection and shall include the requirements of (1) through (6) below.

(1) The area to be repaired shall be suitably prepared for welding in accordance with a written procedure.

(2) The weld metal shall be deposited by the manual shielded metal arc process using low hydrogen type electrode. The maximum bead width shall be four times the electrode core diameter.

(3) Welding electrodes shall meet the requirements for supplemental designators “R” indicating a moisture-resistant coating and “H4” indicating that they are low in diffusible hydrogen as defined in the applicable specifications in Section II, Part C. Welding electrodes shall also be supplied in unopened hermetically sealed containers.

(4) After a hermetically sealed container is opened, the electrodes shall be stored in holding ovens at 225°F to 350°F (105°C to 175°C). When electrodes are removed from elevated storage, they may be exposed to the atmosphere for a maximum of 8 hr.

(5) Electrodes, which are exposed to the atmosphere for more than 8 hr, shall be discarded or baked to remove any absorbed moisture for the time and temperature recommended by the electrode manufacturer. After baking and before the electrodes are allowed to cool below 225°F (105°C), they shall be transferred immediately into holding ovens at 225°F to 350°F (105°C to 175°C). When the once-baked electrodes are removed from elevated storage, they may be exposed to the atmosphere for an additional 8 hr after which they shall be discarded.

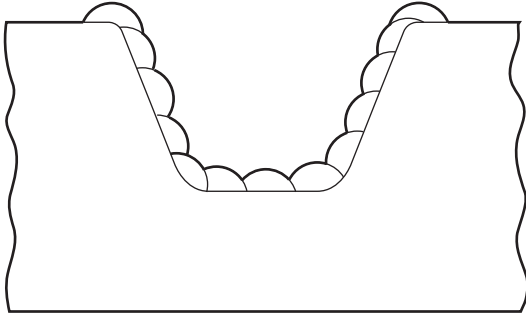
(6) If the repair area is to be subjected to a significant fast neutron fluence (greater than  $10^{19}$  nvt  $E_0 > 1$  MeV), electrode shall be limited to Cu content of 0.10% maximum (as deposited).

(7) The weld area plus a band around the repair area of at least  $1\frac{1}{2}$  times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding. The maximum interpass temperature shall be 450°F (230°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with [WB-4435\(b\)](#).

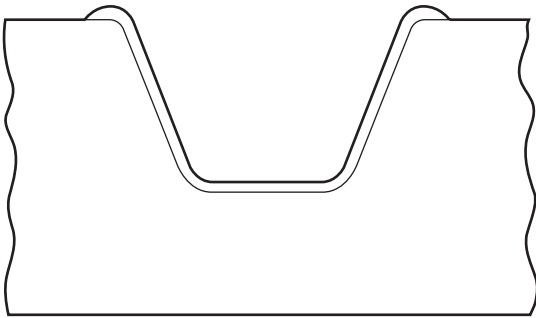
(8) The cavity shall be buttered, using a  $\frac{3}{32}$  in. (2.5 mm) diameter electrode as shown in [Figure WB-4622.9\(c\)\(8\)-1](#). The weld bead crown surface shall be removed by grinding or machining before depositing the second layer [see [Figure WB-4622.9\(c\)\(8\)-1](#), Step 2]. The second layer shall be deposited with a  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers shall be deposited with a welding electrode no larger than  $\frac{5}{32}$  in. (4 mm) diameter. Bead deposition shall be performed in a manner shown in [Figure WB-4622.9\(c\)\(8\)-1](#), Step 3. The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the repair substantially flush with the surface of the containment surrounding the repair [[Figure WB-4622.9\(c\)\(8\)-2](#)]. The technique described in this paragraph shall be performed in the procedure qualification test.



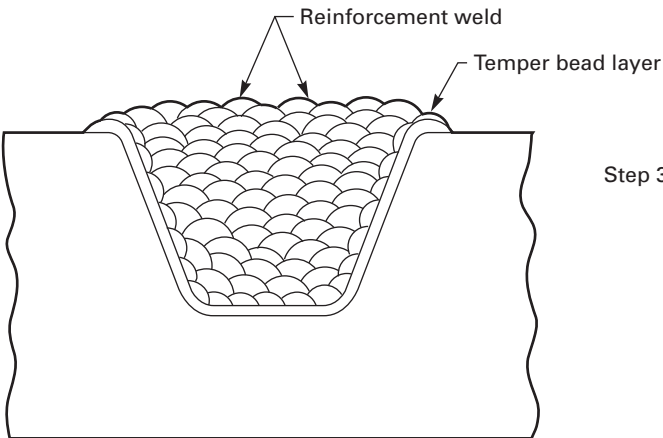
**Figure WB-4622.9(c)(8)-1  
Temper Bead Weld Repair and Weld Temper Bead Reinforcement**



Step 1: Butter cavity with one layer of weld metal using  $\frac{3}{32}$  in. (2.5 mm) diameter coated electrode.



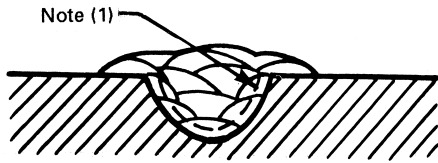
Step 2: Remove the weld bead crown of the first layer of grinding.



Step 3: The second layer shall be deposited with a  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers shall be deposited with welding electrodes no larger than  $\frac{5}{32}$  in. (4.0 mm) maximum diameter. Bead deposition shall be performed in the manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points as well as its removal to ensure that the heat-affected zone of the base metal and the deposited weld metal is tempered and the resulting surface is substantially flush.



**Figure WB-4622.9(c)(8)-2  
Temper Bead Reinforcement**



**NOTE:**

(1) Apply temper bead reinforcement weld metal to a level above the surface and then remove it substantially flush to the surface as required by WB-4622.9(c)(8).

(9) The weld area shall be maintained at a temperature of 450°F to 550°F (230°C to 290°C) for a minimum period of 2 hr after completion of the weld repair in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

(d) *Examination of Repair Welds.* The second (temper bead) layer shall be examined by the magnetic particle or liquid penetrant method. The completed weld shall have the weld reinforcement, including the final layer, removed substantially flush with the surface prior to performing the required nondestructive examination. The nondestructive examination shall be performed after the completed weld has been at ambient temperature for a minimum period of 48 hr to detect the presence of possible delayed cracking of the weldment. The nondestructive examination of the repair welded and preheated region shall be in accordance with WB-4453.4. In addition, all repairs shall be ultrasonically examined. All nondestructive examination shall be in accordance with Article WB-5000.

(e) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with WB-4130, exclusive of the size requirements.

(f) *Welding Procedure Qualification Test Plate.* The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair, but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repair section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (150 mm). The qualification test plate shall be prepared in accordance with Figure WB-4622.9(f)-1.

(g) This test assembly may be used to qualify procedures for weld buildup repairs of pressure-retaining materials. In this case, the depth of the cavity shall not be less than the thickness of the weld buildup or 1 in. (25 mm), whichever is greater, and the area of the weld buildup to be applied or 54 in.<sup>2</sup> (35 000 mm<sup>2</sup>), whichever is less.

(h) In all cases, the test assembly and cavity shall be of sufficient size to permit removal of the required test specimens.

(i) *Performance Qualifications.* If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

**WB-4622.10 Repair Welds to Cladding After Final Postweld Heat Treatment.** Nonpostweld heat-treated weld repairs may be made to P-No. 8 or P-No. 43 cladding of P-No. 1 and P-No. 3 material after final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met:

(a) *Maximum Extent of Repair.* This procedure may be used with the base material exposed to a depth not greater than  $\frac{1}{4}$  in. (6 mm) or 10% of the base material thickness, whichever is less, nor to an individual area greater than 100 in.<sup>2</sup> (65 000 mm<sup>2</sup>). Areas with greater base material exposure depth shall be repaired in accordance with WB-4622.9 to within this limit before implementing the cladding repair.

(b) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Division, and shall include the requirements of (1) through (7) below.

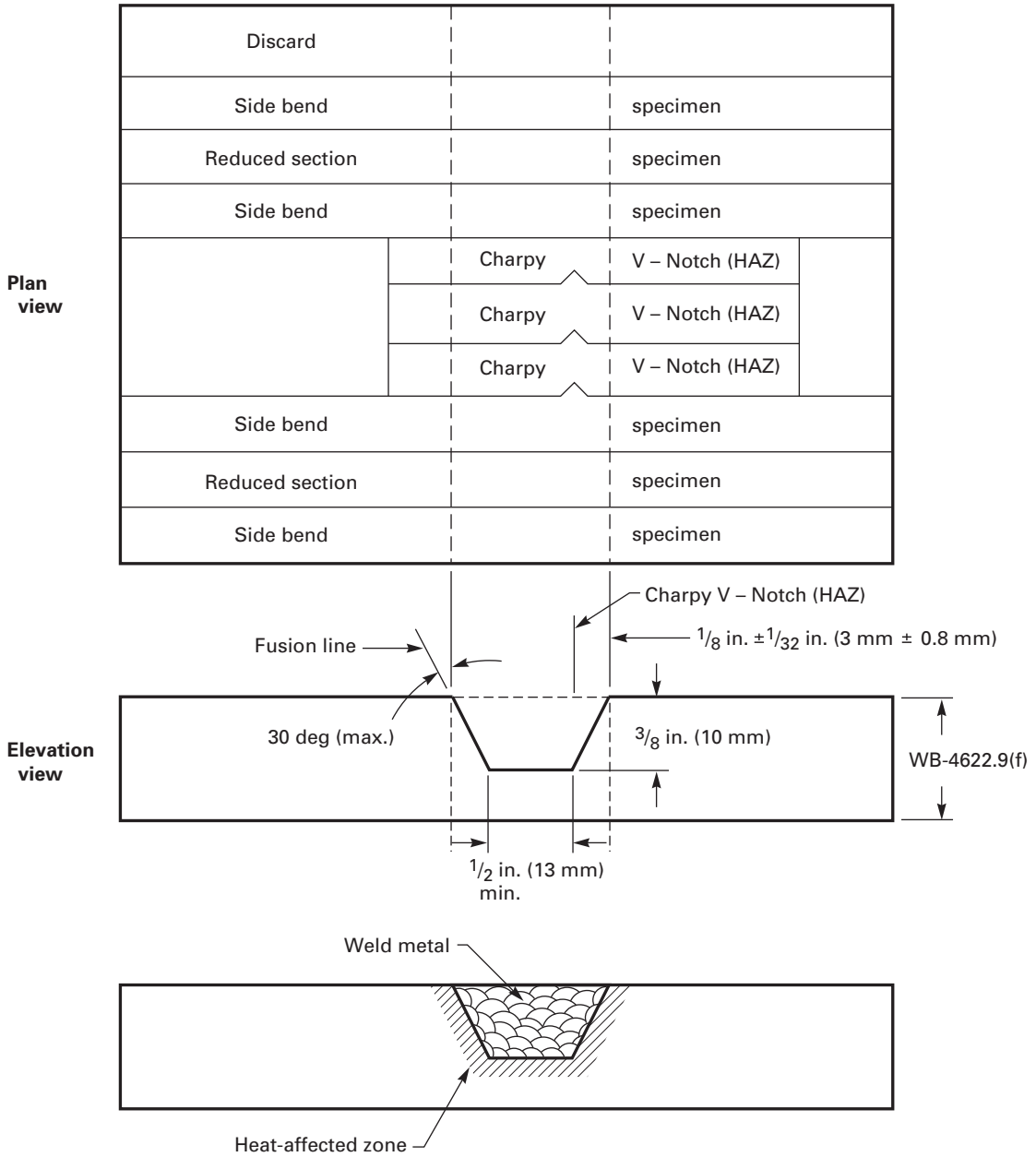
(1) The repairs shall be made using A-No. 8 weld metal (Section IX, Table QW-442) for P-No. 8 cladding or F-No. 43 weld metal (Section IX, Table QW-432) for either P-No. 8 or P-No. 43 cladding.

(2) The manual shielded metal arc process shall be used for welding with a bead width not to exceed four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (105°C) and 350°F (175°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(4) During the repair, the electrodes may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (105°C) and 350°F (175°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded, or baked once at

**Figure WB-4622.9(f)-1  
Qualification Test Plate**



the time and temperature recommended by the electrode manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(5) The weld area plus a band around the clad repair of  $1\frac{1}{2}$  times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding. The maximum interpass temperature shall be 450°F (230°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with [WB-4435](#).

(6) All areas of the base material on which weld metal is to be deposited shall be covered with a single layer of weld deposit using  $\frac{3}{32}$  in. (2.5 mm) diameter electrode, followed by a minimum of one layer of weld deposit using  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers may be deposited with electrode no larger than  $\frac{5}{32}$  in. (4 mm). The weld bead crown surface of the first layer shall be removed by grinding.

(7) After completion of welding, the weld area shall be maintained at a temperature of 450°F to 550°F (230°C to 290°C) for a period of 2 hr for P-No. 1 material and 4 hr for P-No. 3 material.

(c) *Examination of Repair Welds.* The weld repair as well as the preheated band shall be examined by the liquid penetrant method. All nondestructive examination shall be in accordance with [Article WB-5000](#).

(d) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with [WB-4130](#), exclusive of the size requirements.

(e) *Welding Procedure Qualification Test Plate*

(1) The test assembly material for the welding procedure qualification test shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature of that applied to the material being repaired. If the repair involves two different P-Number or Group Number materials, the test assembly shall duplicate the combination.

(2) The test assembly base material shall be at least 12 in. (300 mm) by 12 in. (300 mm), 2 in. (50 mm) min. thickness, with a clad surface area of at least 8 in. (200 mm) by 8 in. (200 mm), in the area from which the bend test specimens will be removed.

(3) The qualification test plate assembly shall be prepared and tested in accordance with the requirements of Section IX. The guided bend test acceptance standards described in Section IX for cladding shall also be applicable to the HAZ of the base material.

(f) *Performance Qualifications.* If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

**WB-4622.11 Temper Bead Weld Repair to Dissimilar Metal Welds or Buttering.** Whenever PWHT is impractical or impossible, limited weld repairs to dissimilar metal welds of P-No. 1 and P-No. 3 material or weld filler metal A-No. 8 (Section IX, Table QW-442) or F-No. 43 (Section IX, Table QW-432) may be made without PWHT or after the final PWHT provided the requirements of the following subparagraphs are met:

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with [Article WB-5000](#).

(b) *Maximum Extent of Repair.* Repairs made to this paragraph are limited to those along the fusion line of a nonferritic weld to ferritic base material where  $\frac{1}{8}$  in. (3 mm) or less of nonferritic weld deposit exists above the original fusion line after defect removal. If the defect penetrates into the ferritic base material, repair of the base material may be performed in accordance with [WB-4622.11](#) provided the depth of repair in the base material does not exceed  $\frac{3}{8}$  in. (10 mm). The repairs to a completed joint shall not exceed one-half the joint thickness. The surface of the completed repair shall not exceed 100 in.<sup>2</sup> (65 000 mm<sup>2</sup>).

(c) *Repair Welding Procedure.* The welding procedure and welder qualification shall meet all of the requirements of Section IX and the additional requirements of this Article. In addition, the Welding Procedure Specification shall include the following requirements.

(1) The area to be repaired shall be suitably prepared for welding in accordance with the written procedure to be used for the repair.

(2) The weld metal shall be deposited by the shielded metal arc welding process (SMAW) using A-No. 8 weld metal (Section IX, Table QW-442) for P-No. 8 to P-No. 1 or P-No. 3 weld joints or F-No. 43 weld metal (Section IX, Table QW-432) for either P-No. 8 or P-No. 43 to P-No. 1 or P-No. 3 weld joints. The maximum bead width shall be four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (105°C) and 350°F (175°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(4) During the repair, the electrode may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (105°C) and 350°F (175°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode

manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(5) The weld area plus a band around the weld repair of  $1\frac{1}{2}$  times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding. The maximum interpass temperature shall be 450°F (230°C). Thermocouples and recording instruments shall be used to monitor the metal temperature during welding. Their removal shall be in accordance with [WB-4435](#).

(6) All areas of the ferritic base material, exposed or not, on which weld metal is to be deposited, shall be covered with a single layer of weld deposit using  $\frac{3}{32}$  in. (2.5 mm) diameter electrode. The weld bead crown surface shall be removed by grinding before depositing the second layer. The second layer shall be deposited with  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers may be deposited with  $\frac{5}{32}$  in. (4 mm) maximum diameter electrode. The techniques described in this paragraph shall be duplicated in the procedure qualification. [See [Figure WB-4622.11\(c\)\(6\)-1.](#)]

(7) After at least  $\frac{3}{16}$  in. (5 mm) of weld metal has been deposited, the preheated area as defined in (5) above shall be maintained in the range of 450°F to 550°F (230°C to 290°C) for 4 hr as a minimum.

(8) Subsequent to the above heat treatment, the balance of the welding may be performed at a minimum preheat temperature of 100°F (40°C) and at a maximum interpass temperature of 350°F (175°C).

*(d) Examination of Repair Areas*

(1) After the heat treatment specified in (c)(7) above has been completed, the repaired area shall be examined by the liquid penetrant method.

(2) The repaired area and the preheated band as defined in (c)(5) above shall be examined by the liquid penetrant method after the completed weld has been at ambient temperature for a minimum of 48 hr. The repaired region shall be examined by the radiographic method and, if practical, by the ultrasonic method.

(3) For repairs to partial penetration welds, the radiographic and ultrasonic examinations specified in (2) above need not be performed, if meaningful results cannot be obtained. For these cases, liquid penetrant examination only shall be performed. For weld repair depths approximately  $\frac{3}{16}$  in. (5 mm), liquid penetrant examination shall be performed at the time specified in (2) above. For weld repair depths greater than  $\frac{3}{16}$  in. (5 mm), liquid penetrant examination shall be performed after approximately  $\frac{3}{16}$  in. (5 mm) thickness has been deposited and the post heat specified in (c)(7) above has been completed. Additional incremental deposit thicknesses shall be liquid penetrant examined in accordance with [WB-5245](#). The final weld surface shall be liquid penetrant examined at the time specified in (2) above.

(4) All nondestructive examination shall be in accordance with [Article WB-5000](#).

*(e) Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with [WB-4130](#), exclusive of the size requirements.

*(f) Welding Procedure Qualification Test Plate.* The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repaired section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (150 mm). The qualification test plate shall be prepared in accordance with [Figure WB-4622.9\(f\)-1](#).

*(g) Performance Qualifications.* If the repair weld is to be performed where physical constructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

### **WB-4623 PWHT Heating and Cooling Rate Requirements**

Above 800°F (425°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (55°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.5 m) interval of weld length.

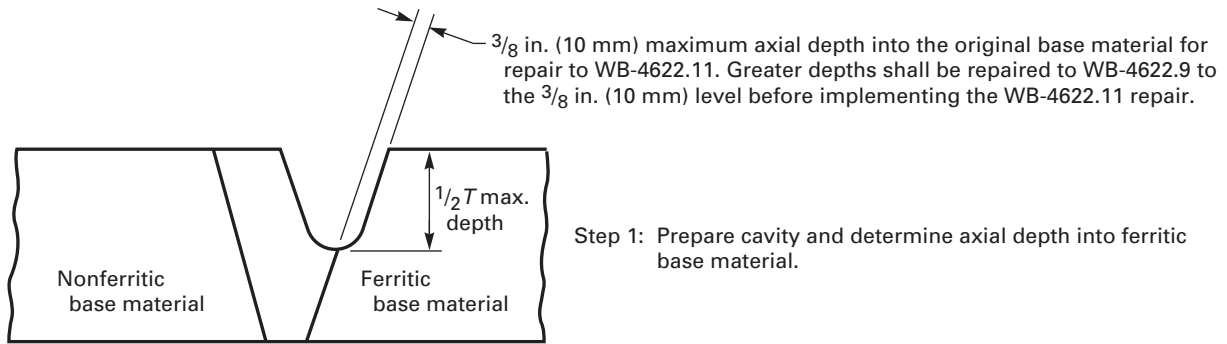
### **WB-4624 Methods of Postweld Heat Treatment**

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

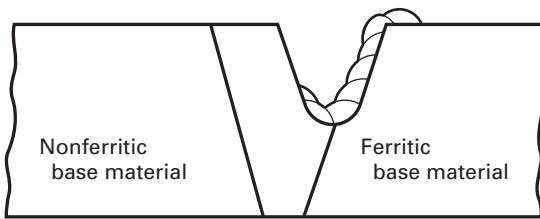
**WB-4624.1 Furnace Heating — One Heat.** Heating the item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation and direct impingement of flame on the containment is prohibited.

**WB-4624.2 Furnace Heating — More Than One Heat.** The item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of [WB-4624.1](#) apply and overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that

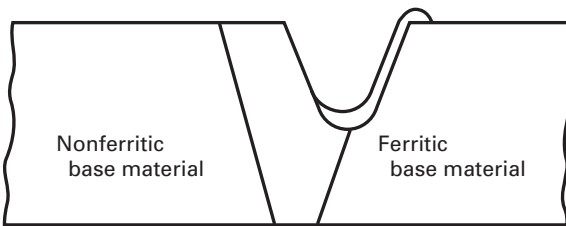
**Figure WB-4622.11(c)(6)-1**  
**Temper Bead Weld Repair and Weld Temper Bead Reinforcement of Dissimilar Metal Welds or Buttering**



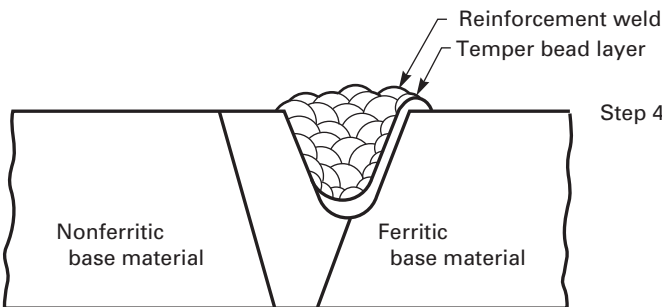
Step 1: Prepare cavity and determine axial depth into ferritic base material.



Step 2: Butter cavity with one layer of weld metal using  $\frac{3}{32}$  in. (2.5 mm) diameter coated electrode.



Step 3: Remove the weld bead crown of the first layer by grinding.



Step 4: The second layer shall be deposited with a  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layer shall be deposited with welding electrodes no larger than  $\frac{5}{32}$  in. (4.0 mm) diameter. Bead deposition shall be performed in the manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in point with the ferritic material as well as its removal to ensure that the base metal and the deposited weld metal are tempered and the resulting surface is substantially flush.

the temperature gradient is not harmful. The cross section where the containment projects from the furnace shall not intersect a nozzle or other structural discontinuity.

**WB-4624.3 Local Heating.** Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the containment at temperature within the ranges specified in this subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

**WB-4624.4 Heating Items Internally.** The containment may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the containment. Previous to this operation, the item should be fully enclosed with insulating material.

**WB-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT**

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

**WB-4700 MECHANICAL JOINTS**

**WB-4710 BOLTING AND THREADING**

**WB-4711 Thread Engagement**

The threads of all bolts or studs shall be engaged in accordance with the design.

**WB-4712 Thread Lubricants**

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any containment material in the system.

**WB-4713 Removal of Thread Lubricants**

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

**WB-4720 BOLTING FLANGED JOINTS**

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.



## ARTICLE WB-5000 EXAMINATION

### WB-5100 GENERAL REQUIREMENTS FOR EXAMINATION

### WB-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

#### WB-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be performed in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2, and the image quality indicators (IQIs) of Table WB-5111-1 shall be used in lieu of those shown in Section V, Article 2, Table T-276. The requirements for the retention of electronic and digital radiographic images are the same as that for radiographic film. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; and liquid penetrant examination shall be in accordance with Section V, Article 6. The examinations required by this Article, or by reference to this Article, shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

#### WB-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopy images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

#### WB-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

#### WB-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by WB-5200 shall be performed at the times stipulated in (a) through (f) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate<sup>12</sup> or final postweld heat treatment, when required, except that radiographic examination of welds in containments fabricated of P-No. 1 or P-No. 3 materials may be performed prior to an intermediate or final postweld heat treatment, provided the welds are ultrasonically examined after an intermediate or final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material, or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall, shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations may be performed before PWHT.

(e) Weld metal cladding shall be examined after either an intermediate<sup>12</sup> or final postweld heat treatment, except the examination of weld metal cladding on P-Nos. 1 and 3 materials may be performed before or after the intermediate<sup>12</sup> or final postweld heat treatment.



**Table WB-5111-1  
Thickness, IQI Designations, Essential Holes, and Wire Diameters**

U.S. Customary Units								
Single Wall Material Thickness Range, in.	IQI(s) — Hole or Wire Type [Note (1)]							
	Source Side				Film Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to 0.25 incl.	5	0.040	4 T	0.006	5	0.040	4 T	0.006
Over 1/4-3/8	7	0.040	4 T	0.006	7	0.040	4 T	0.006
Over 3/8-1/2	10	0.040	4 T	0.010	10	0.040	4 T	0.010
Over 1/2-5/8	12	0.050	4 T	0.013	12	0.050	4 T	0.013
Over 5/8-3/4	15	0.060	4 T	0.016	12	0.050	4 T	0.013
Over 3/4-1	20	0.040	2 T	0.016	17	0.035	2 T	0.013
Over 1-1 1/4	25	0.050	2 T	0.020	17	0.035	2 T	0.013
Over 1 1/4-1 1/2	30	0.060	2 T	0.025	20	0.040	2 T	0.016
Over 1 1/2-2	35	0.070	2 T	0.032	25	0.050	2 T	0.020
Over 2-2 1/2	40	0.080	2 T	0.040	30	0.060	2 T	0.025
Over 2 1/2-3	45	0.090	2 T	0.040	35	0.070	2 T	0.032
Over 3-4	50	0.100	2 T	0.050	40	0.080	2 T	0.040
Over 4-6	60	0.120	2 T	0.063	45	0.090	2 T	0.040
Over 6-8	80	0.160	2 T	0.100	50	0.100	2 T	0.050
Over 8-10	100	0.200	2 T	0.126	60	0.120	2 T	0.063
Over 10-12	120	0.240	2 T	0.160	80	0.160	2 T	0.100
Over 12-16	160	0.320	2 T	0.250	100	0.200	2 T	0.126
Over 16-20	200	0.400	2 T	0.320	120	0.240	2 T	0.160

SI Units								
Single Wall Material Thickness Range, mm	IQI(s) — Hole or Wire Type [Note (1)]							
	Source Side				Film Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to 6 incl.	5	1.02	4 T	0.15	5	1.02	4 T	0.15
Over 6-10	7	1.02	4 T	0.15	7	1.02	4 T	0.15
Over 10-13	10	1.02	4 T	0.25	10	1.02	4 T	0.25
Over 13-16	12	1.27	4 T	0.33	12	1.27	4 T	0.33
Over 16-19	15	1.52	4 T	0.41	12	1.27	4 T	0.33
Over 19-25	20	1.02	2 T	0.41	17	0.89	2 T	0.33
Over 25-32	25	1.27	2 T	0.51	17	0.89	2 T	0.33
Over 32-38	30	1.52	2 T	0.64	20	1.02	2 T	0.41
Over 38-50	35	1.78	2 T	0.81	25	1.27	2 T	0.51
Over 50-64	40	2.03	2 T	1.02	30	1.52	2 T	0.64
Over 64-75	45	2.29	2 T	1.02	35	1.78	2 T	0.81
Over 75-100	50	2.54	2 T	1.27	40	2.03	2 T	1.02
Over 100-150	60	3.05	2 T	1.60	45	2.29	2 T	1.02
Over 150-200	80	4.06	2 T	2.54	50	2.54	2 T	1.27
Over 200-250	100	5.08	2 T	3.20	60	3.05	2 T	1.60
Over 250-300	120	6.10	2 T	4.06	80	4.06	2 T	2.54
Over 300-400	160	8.13	2 T	6.35	100	5.08	2 T	3.20
Over 400-500	200	10.16	2 T	8.13	120	6.10	2 T	4.06

NOTE:

(1) Hole (plaque) type IQIs may be used on flat plates and on objects with geometries such that the IQI hole image is not distorted.

(f) All of the joints in austenitic stainless steel and non-ferrous material shall be examined by the liquid penetrant method after an intermediate or final postweld heat treatment, if any, is performed.

### **WB-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES**

All full penetration weld edge preparation surfaces for joint Categories A, B, C, D, and similar joints in material 2 in. (50 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of  $\frac{3}{8}$  in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than  $\frac{3}{16}$  in. (5 mm) long;

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm);

(3) four or more indications, in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Category A, B, C, D, or similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

### **WB-5140 EXAMINATION OF ADJACENT BASE MATERIAL**

When performing the surface examinations of weld joint Categories A, B, C, and D as required by WB-5200, the external and accessible internal weld surfaces and adjacent base material for at least  $\frac{1}{2}$  in. (13 mm) on each side of the weld shall be included in the examination. Acceptance standards for the weld shall be as stated in this Article while the acceptance standards for base material shall be as stated in WB-2500.

## **WB-5200 REQUIRED EXAMINATION OF WELDS**

### **WB-5210 CATEGORY A WELDED JOINTS**

Category A welded joints in containments shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

### **WB-5220 CATEGORY B WELDED JOINTS**

Category B welded joints in containments shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

### **WB-5230 CATEGORY C WELDED JOINTS**

#### **WB-5231 General Requirements**

(a) Category C full penetration butt-welded joints in containments shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

(b) Category C full penetration corner-welded joints in containments shall be ultrasonically or radiographically examined and either liquid penetrant or magnetic particle examined.

(c) Type 2 Category C full penetration corner-welded joints similar to Figure WB-4243-1 sketches (c) and (d) also require the fusion zone and the parent metal beneath the attachment surface to be ultrasonically examined after welding to verify freedom from lack of fusion and laminar defects.

### **WB-5240 CATEGORY D WELDED JOINTS**

#### **WB-5241 General Requirements**

All Category D welded joints in containments shall be examined as stated in the following paragraphs.

#### **WB-5242 Full Penetration Butt-Welded Nozzles**

Nozzles attached by full penetration butt-welded joints as shown in Figure WB-4244(a)-1 shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

#### **WB-5243 Corner-Welded Nozzles**

Full penetration corner-welded nozzles in containments as shown in Figure WB-4244(b)-1 shall be examined by either the ultrasonic or the radiographic method, and either the liquid penetrant or magnetic particle method. If radiographed, the weld fusion zone and the parent metal beneath the weld for details shown in Figure WB-4244(b)-1 sketches (a) and (b) and the weld fusion zone and parent material beneath the attachment surface for details shown in Figure WB-4244(b)-1 sketches (c), (d), (e), and (g) shall be ultrasonically examined after welding to assure freedom from lack of fusion and laminar defects.

**WB-5244 Weld Metal Buildup at Openings for Nozzles**

When weld metal buildup is made to a surface as shown in Step 1 of [Figure WB-4244\(c\)-1](#), the weld metal buildup and the parent metal beneath the weld metal buildup shall be ultrasonically examined. The parent material beneath the weld metal buildup shall be ultrasonically examined to detect laminar defects after weld metal buildup. Nozzles may then be attached by a full penetration weld as shown in Step 2 of [Figure WB-4244\(c\)-1](#). The full penetration butt-welded joint shall be examined by either the ultrasonic or radiographic method, and either the liquid penetrant or magnetic particle method and the weld metal buildup shall be examined by either the magnetic particle or liquid-penetrant method.

**WB-5245 Partial Penetration Welded Joints**

Partial penetration welded joints, as permitted in [WB-3252.4\(b\)](#), and as shown in [Figure WB-4244\(d\)-1](#), shall have the surface of the finished welded joint examined by either the magnetic particle or liquid penetrant method.

**WB-5260 FILLET, PARTIAL PENETRATION, SOCKET, AND ATTACHMENT WELDED JOINTS****WB-5261 Fillet, Partial Penetration, and Socket Welded Joints**

Fillet and partial penetration welded joints, except for nonstructural attachments ([WB-1132.1](#)), and socket welds shall be examined by the magnetic particle or liquid penetrant method.

**WB-5262 Structural Attachment Welded Joints**

Structural attachment welded joints made to containment material shall be examined by either the magnetic particle or liquid penetrant method.

**WB-5270 SPECIAL WELDED JOINTS****WB-5272 Weld Metal Cladding**

Weld metal cladding shall be examined by the liquid penetrant method.

**WB-5273 Hard Surfacing**

Hard surfacing weld metal shall be examined by the liquid penetrant method in accordance with [WB-2546](#), and the acceptance standards applicable to materials less than  $\frac{5}{8}$  in. (16 mm) thick shall apply.

**WB-5277 Electron Beam Welds**

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electron beam welding process shall be ultrasonically examined.

**WB-5279 Special Exceptions**

When the joint detail, or environmental conditions (i.e., background radiation), does not permit radiographic examination to be performed in accordance with this Article, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Division. The non-destructive examination shall be in accordance with [WB-5110](#) and meet the acceptance standards of [WB-5300](#).

**WB-5300 ACCEPTANCE STANDARDS****WB-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS**

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration;

(b) any indication characterized as incomplete penetration or incomplete fusion, except that such indications in welds between P-8 metals that were made using GTAW or SMAW in which the deposit analysis in A-8 or A-9 are acceptable provided they do not exceed the length in (c).

(c) any other elongated indication which has a length greater than:

(1)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(2)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. to  $2\frac{1}{4}$  in. (19 mm to 57 mm), inclusive

(3)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm)

where  $t$  is the thickness of the thinner portion of the weld;

(d) internal root weld conditions are acceptable when the density change or image brightness difference as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (c) above;

(e) any group of aligned indications having an aggregate length greater than  $t$  in a length of  $12t$ , unless the minimum distance between successive indications exceeds  $6L$ , in which case the aggregate length is unlimited,  $L$  being the length of the largest indication;

(f) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

## **WB-5330 ULTRASONIC ACCEPTANCE STANDARDS**

All imperfections that produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

(1)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(2)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. to  $2\frac{1}{4}$  in. (19 mm to 57 mm), inclusive

(3)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm)

where  $t$  is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld,  $t$  is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

## **WB-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS**

### **WB-5341 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

### **WB-5342 Acceptance Standards**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks and linear indications;

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm);

(3) four or more rounded indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

## **WB-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS**

### **WB-5351 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

### **WB-5352 Acceptance Standards**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.6 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm);

(3) four or more rounded indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

## **WB-5400 FINAL EXAMINATION OF CONTAINMENTS**

### **WB-5410 EXAMINATION AFTER HYDROSTATIC TEST**

After the pressure testing of a containment, all weld joints and heat-affected zones of Categories A, B, C, and D, used to join ferritic material and repair welds in ferritic material that exceed in depth either  $\frac{3}{8}$  in. (10 mm) or

10% of the section thickness, whichever is less, shall be examined when physically accessible by the magnetic particle or liquid penetrant method.

## **WB-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL**

### **WB-5510 GENERAL REQUIREMENTS**

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by [WB-5520](#). When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of [WB-5520](#). All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

### **WB-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION**

#### **WB-5521 Qualification Procedure**

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.<sup>13, 14</sup> The ACCP Level II and III provisions for qualification and certification and the ASNT administered Level II certification provision for qualification and certification of NDE Personnel shall not be used for Section III. The Employer's<sup>15</sup> written practice, required by paragraph 5 of SNT-TC-1A, shall identify the requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered as minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by Employer,<sup>15</sup> ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A of SNT-TC-1A. The time of training and experience shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times for visual examination personnel identified in Table 6.3.1 A of SNT-TC-1A for Level II certification may be reduced from 16 hr to 8 hr.

(4) For the near-vision acuity examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions, and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

### **WB-5522 Certification of Personnel**

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [[WB-5521\(a\)\(1\)\(-a\)](#)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

**WB-5523 Verification of Nondestructive Examination Personnel Certification**

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations

and qualified by them in accordance with [WA-3820](#) and subcontractors who provide nondestructive examination services to them.

**WB-5530 RECORDS**

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.



# ARTICLE WB-6000 TESTING

## WB-6100 GENERAL REQUIREMENTS

### WB-6110 SCOPE

(a) This Article contains the testing requirements for transportation containments constructed in accordance with the rules of this Subsection.

(b) The terms test and testing as used in this Article include hydrostatic testing (WB-6200), pneumatic testing (WB-6300), and leak testing (WB-6700).

### WB-6120 TESTING OF CONTAINMENTS

Except for final closure welds and final mechanical closures made on inner containments meeting the requirements of this Subsection and made after the inner containment is loaded (e.g., dual-purpose containments that are totally enclosed in a transportation containment meeting the requirements of this Subsection), all transportation containments shall be pressure tested and then leak tested in accordance with WB-6700. Final closure welds and final mechanical closures made after inner containments are loaded shall be tested as required by WB-6700.

### WB-6121 Pneumatic Testing

A pneumatic test in accordance with WB-6300 may be substituted for the hydrostatic test when permitted by the Design Specification.

**WB-6121.1 Pneumatic Test Limitations.** A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

**WB-6121.2 Precautions to Be Employed in Pneumatic Testing.** Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

### WB-6122 Witnessing of Tests

All testing required by this Article shall be performed in the presence of the Inspector.

### WB-6123 Time of Testing

**WB-6123.1 Containments.** Completed containments shall have all the testing required by this Article completed prior to initial service.

**WB-6123.2 Material Pressure Test.** The containment test may be used in lieu of any pressure test required by the material specification for material used in the containment provided

(a) nondestructive examinations, if required by the material specification, can be performed subsequent to the containment test

(b) the material can be repaired by welding in accordance with the rules of WB-4130

(c) postweld heat treatment, when required after repairs, can be performed in accordance with WB-4620

### WB-6124 Machining After Testing

An additional amount of material, not to exceed 10% of the wall thickness or  $\frac{3}{8}$  in. (10 mm), whichever is less, is permitted on the completed item after testing where critical dimensions and tolerances is required.

## WB-6130 PREPARATION FOR TESTING

### WB-6131 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

### WB-6132 Addition of Temporary Supports

Containments may be provided with additional temporary supports, if necessary, to support the weight of the test liquid when hydrostatic testing is performed.

### WB-6133 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

### WB-6136 Precautions Against Test Medium Expansion

If a test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

### WB-6137 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.



**WB-6200 HYDROSTATIC TESTS****WB-6210 HYDROSTATIC TEST PROCEDURE****WB-6211 Venting During Fill Operation**

The containment in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

**WB-6212 Test Medium and Test Temperature**

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (Section III Appendices, Nonmandatory Appendix G). The test pressure shall not be applied until the containment and the pressurizing fluid are at approximately the same temperature.

**WB-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS****WB-6221 Minimum Hydrostatic Test Pressure**

(a) The containment shall be hydrostatically tested at not less than 1.50 times Design Pressure.

**WB-6222 Maximum Permissible Test Pressure**

The stress limits specified in [WB-3225](#) shall be used in determining the maximum permissible test pressure. In multichamber containments, pressure may be simultaneously applied to the appropriate adjacent chamber to satisfy these stress limits.

**WB-6223 Hydrostatic Test Pressure Holding Time**

The hydrostatic test pressure shall be maintained a minimum of 10 minutes prior to initiation of the examination for leakage required by [WB-6224](#).

**WB-6224 Examination for Leakage After Application of Pressure**

Following the application of the hydrostatic test pressure for the required time ([WB-6223](#)), all joints, connections, and regions of high stress, such as regions around openings and thickness transition sections, shall be examined for leakage. This examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain test pressure for the required amount of time. Other leaks, such as those from permanent seals, seats, and gasketed joints in containments, may be permitted when specifically allowed by the Design Specification. Leakage from temporary seals or leakage permitted by

the Design Specification shall be directed away from the surface of the containment to avoid masking leaks from other joints.

**WB-6300 PNEUMATIC TESTS****WB-6310 PNEUMATIC TESTING PROCEDURES****WB-6311 General Requirements**

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of [WB-6100](#) and this Article.

**WB-6312 Test Medium and Test Temperature**

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with [WB-6212\(b\)](#).

**WB-6313 Procedure for Applying Pressure**

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

**WB-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS****WB-6321 Minimum Required Pneumatic Test Pressure**

The containment shall be pneumatically tested at not less than 1.5 times Design Pressure.

**WB-6322 Maximum Permissible Test Pressure**

The maximum test pressure shall be limited as defined in [WB-6222](#).

**WB-6323 Test Pressure Holding Time**

The test pressure of [WB-6321](#) shall be maintained for a minimum total time of 10 minutes.

**WB-6324 Examination for Leakage After Application of Pressure**

Following the application of pressure for the time specified in [WB-6323](#), the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure and held for a sufficient time to permit examination as defined in accordance with [WB-6224](#).

**WB-6400 TEST GAGES****WB-6410****WB-6411 Types of Gages to Be Used and Their Location**

Test gages used in testing shall be indicating pressure gages and shall be connected directly to the item being tested. If the indicating gage is not readily visible to the operator controlling the test, an additional indicating gage shall be provided where it will be visible to the operator for the duration of the test.

**WB-6412 Range of Indicating Gages**

(a) Analog type indicating gages used in testing shall be graduated over a range not less than  $1\frac{1}{2}$  times nor more than 4 times the test pressure.

(b) Digital type gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

**WB-6413 Calibration of Pressure Test Gages**

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages which is conducted at the same site within a period not exceeding 2 weeks.

**WB-6600 SPECIAL TEST PRESSURE SITUATIONS****WB-6610 CONTAINMENTS DESIGNED FOR EXTERNAL PRESSURE**

Containments designed for external pressure only shall be subjected to an internal test pressure at 1.5 times the Design External Pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more than 6%.

**WB-6620 TESTING OF COMBINATION UNITS****WB-6621 Pressure Chambers Designed to Operate Independently**

Pressure chambers of combination units that have been designed to operate independently shall be tested as separate containments; that is, each chamber shall be tested without pressure in the adjacent chamber.

**WB-6622 Common Elements Designed for a Maximum Differential Pressure**

(a) When chambers of combination units have their common elements designed for the maximum differential pressure and the differential pressure is less than the higher of the Design Pressure of the adjacent chambers, the common elements shall be subjected to a test pressure of at least  $1\frac{1}{4}$  times the maximum differential pressure.

(b) Following the test of the common elements, as required by (a) above and their inspection, the adjacent chambers shall be tested. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

**WB-6700 LEAK TESTING****WB-6710 HELIUM LEAK TESTING**

Requirements for helium leak testing:

(a) Helium leak testing shall be conducted in accordance with Section V, Article 10, and ANSI N14.5.<sup>16</sup> Personnel performing helium leak testing shall be qualified in accordance with [Article WB-5000](#).

(b) The allowable volumetric leakage rate shall be defined in the Design Specification. An acceptable method to determine the maximum, permissible volumetric leakage rate can be found in ANSI N14.5.

(c) If a single leak-rate test is conducted, the conversion methods in ANSI N14.5 shall be used to determine if the leakage rates specified in the Design Specification have been met.

# **ARTICLE WB-8000 NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORTS**

## **WB-8100 GENERAL REQUIREMENTS**

The requirements for nameplates, stamping with the Certification Mark, and reports shall be as given in [Article WA-8000](#).

# SUBSECTION WC

## CLASS SC STORAGE CONTAINMENTS

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### ARTICLE WC-1000 INTRODUCTION

#### (17) WC-1100 SCOPE

(a) *Subsection WC* contains rules for the material, design, fabrication, examination, testing, marking, stamping, and preparation of reports by the Certificate Holder for Class SC storage containments for spent nuclear fuel and high-level radioactive material.

(b) The rules of *Subsection WC* cover the strength and containment integrity of items where their failure could breach the containment boundary. The rules cover load stresses but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of containment materials. *WA-1130* further limits the rules of this Subsection.

#### (17) WC-1120 LIMITS OF RULES FOR CLASS SC STORAGE CONTAINMENTS

(a) *Subsection WC* does not contain rules to cover all details of construction of Class SC containments. Where complete details are not provided in this Subsection, it is intended that the N3 Certificate Holder, subject to review by the Inspector (*Article WA-5000*), shall provide the details of construction which will be consistent with those provided by the rules of this Subsection.

(b) Valves, classified as part of the containment by the Design Specification, shall be classified as Class 1 or Class 2 and shall meet the requirements of Division 1 in lieu of all other requirements of this Division.

#### WC-1130 BOUNDARIES OF JURISDICTION

##### WC-1131 Boundary of Containments

The Design Specification shall define the boundary of a containment. The containment includes the vessel and any penetration assemblies attached to the vessel.

#### WC-1132 Boundary Between a Containment and Attachments

##### WC-1132.1 Attachments.

(a) An *attachment* is an element in contact with or connected to the inside or outside of a containment, which may perform a containment function, and either a structural or nonstructural function.

(b) Attachments that do not perform a containment function include items such as stiffeners or containment opening reinforcement.

(c) Attachments that do not perform a containment function include items in the containment support load path such as support and shear lugs, brackets, trunnions and skirts.

(d) Attachments with a structural function (structural attachments) perform a containment function or are in the containment support load path.

(e) Attachments with a nonstructural function (non-structural attachments) do not perform a containment function nor are they in the containment support load path. Nonstructural attachments include nameplates and lifting lugs.

**WC-1132.2 Jurisdictional Boundary.** The jurisdictional boundary between a containment and an attachment defined in the Design Specification shall not be any closer to the containment than as defined in (a) through (g) below.

(a) Attachments forged with the containment or weld buildup on the containment surface shall be considered part of the containment.

(b) Attachments, welds, and fasteners having a containment function shall be considered part of the containment.

(c) Except as provided in (d) and (e) below, the boundary between a containment and an attachment not having a containment function shall be at the surface of the containment.

*(d)* The first connecting weld of a structural attachment that does not perform a containment function to a containment shall be considered part of the containment.

*(e)* The first connecting weld of a welded nonstructural attachment to a containment shall be considered part of the attachment.

*(f)* Mechanical fasteners used to connect an attachment that does not perform a containment function to the containment shall be considered part of the attachment.

*(g)* The boundary may be located further from the containment portion of the containment than as defined in (a) through (f) above when specified in the Design Specification.

# ARTICLE WC-2000

## MATERIAL

### WC-2100 GENERAL REQUIREMENTS FOR MATERIAL

### WC-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in [WA-1220](#). The term *Material Organization* is defined in Division 1, Article NCA-9000.

(b) The term *containment materials*, as used in this Subsection applies to containment shells, heads, nozzles and bolting that form part of the containment boundary.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate*: the thickness is the dimension of the short transverse direction;

(2) *forgings*: the thickness is the dimension defined as follows:

(-a) *hollow forgings*: the nominal thickness is measured between the inside and outside surfaces (radial thickness);

(-b) *disk forgings* (axial length less than the outside diameter): the nominal thickness is the axial length;

(-c) *flat ring forgings* (axial length less than the radial thickness): for axial length  $\leq 2$  in. (50 mm), the axial length is the nominal thickness. For axial length  $\geq 2$  in. (50 mm), the radial thickness is the nominal thickness.

(-d) *rectangular solid forgings*: the least rectangular dimension is the nominal thickness.

(3) *castings*: thickness for fracture toughness testing and heat treatment purposes is defined as the wall thickness of the containment.

### WC-2120 CONTAINMENT MATERIAL

### WC-2121 Permitted Material Specifications

(a) Containment materials shall conform to the requirements of one of the specifications for materials given in Section II, Part D, Subpart 1, Tables 2A and 2B including all applicable reference notes in the table, and to all of the requirements of this Article that apply to the product form in which the material is used. Attachments that perform a containment function shall be containment material. As an additional control, only the following materials shall be used:

(1) materials whose P-Numbers are listed in [Table WC-4622.1-1](#)

(2) ductile cast iron castings per specifications SA-874 or SA/JIS G5504

(3) SA-263, Specification for Corrosion-Resisting Chromium-Steel Clad Plate, Sheet, and Strip

(4) SA-264, Specification for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip

(5) SA-265, Specification for Nickel and Nickel-Base Alloy Clad Steel Plate

(b) The requirements of this Article do not apply to material for items not associated with the containment function of a component such as seals, gaskets, and ceramic insulating materials and special alloys used as seal materials in electrical penetration assemblies.

(c) Material for line fittings, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, Subpart 1, provided that the fittings are in conformance with the requirements of NC-3671.4 and the material is determined to be adequate for the service conditions by the piping system designer.

(d) Welding and brazing materials used in manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

(e) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay that is 10% or less of the thickness of the base material ([WC-3122](#)).

### WC-2122 Special Requirements Conflicting With Permitted Material Specifications (17)

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements (NCA-4256). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in [WC-2500](#). Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Manufacturer or the Certificate Holder as provided in [WC-4121.1](#). Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the

material is identified as not having been pressure tested and it is subsequently pressure tested in accordance with [WC-6123](#), except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

(b) In addition to tension testing required by the material specification, forgings produced for flat heads with hubs, for butt welding to the adjacent shell, head, or other pressure part, shall have tensile tests performed in accordance with [WC-4265\(d\)](#). The tension test specimen shall be located in accordance with [WC-4265\(d\)](#) and [Figure WC-4265-3](#).

#### (17) **WC-2124 Material Size Ranges and Tolerances**

In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-4256).

(a) Plate material shall be ordered not thinner than the design thickness. Components, except for piping, made of plate furnished with an undertolerance of not more than the lesser value of 0.01 in. (0.25 mm) or 6% of the ordered thickness, may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the lesser of 0.01 in. (0.25 mm) or 6% under the design thickness.

(b) If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable tables in Section II, Part D, Subpart 1. After the minimum wall thickness is determined ([Article WC-3000](#)), it shall be increased by an amount sufficient to provide for the manufacturing undertolerance allowed in the pipe or tube specification.

#### (17) **WC-2125 Material in Combination**

A containment may be designed and constructed of any combination of materials permitted in [Article WC-2000](#), provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

When components have different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction in order to avoid difficulties in service under extreme temperature conditions, or with

unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.

#### **WC-2126 Ductile Cast Iron for Containment**

The containment body shall be cast by a single pouring controlled by a casting plan to ensure reproducibility. The casting plan shall be agreed upon between the manufacturer and purchaser and shall become a lifetime quality assurance record in accordance with [WA-4134](#).

#### **WC-2127 Additional Requirements When Strain-Based Acceptance Criteria Have Been Implemented**

In order to satisfy the strain-based acceptance criteria of [WC-3700](#) regarding sufficient ductility, all material specified to be used in the construction of the containment and implementing the strain-based acceptance criteria shall meet the requirements of Section III Appendices, Nonmandatory Appendix FF, FF-1122 and FF-1140(a) or FF-1140(b). Assurance of satisfying these requirements shall be documented in the final Design Report. Per Section III Appendices, Nonmandatory Appendix FF, FF-1140(a), when temperature-dependent material test data are not available, the Certified Material Test Report(s) shall include reduction of area values in order to have the necessary data to ensure sufficient material ductility. This requirement is only necessary when strain-based acceptance criteria have been employed in the design of the containment.

#### **WC-2128 Bolting Material**

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

#### **WC-2130 CERTIFICATION OF MATERIAL**

All materials used in the construction of containments shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for containment material except as provided by NCA-3861. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.



**WC-2140 WELDING MATERIALS**

For the requirements governing the materials to be used for welding, see [WC-2400](#).

**(17) WC-2150 MATERIAL IDENTIFICATION**

The identification of containment material shall meet the requirements of NCA-4256. Material for small items shall be controlled during manufacture and installation of the containment so that they are identifiable as acceptable material at all times. Welding and brazing materials shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process.

**WC-2160 DETERIORATION OF MATERIAL IN SERVICE**

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the N3 Certificate Holder to select material suitable for the conditions stated in the Design Specifications ([WA-3351](#)), with specific attention being given to the effects of service conditions upon the properties of the material.

**WC-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES**

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

**WC-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL**

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

**WC-2190 ATTACHMENT MATERIAL**

(a) Material in the containment support load path and not performing a containment function (see [WC-1130](#)) welded to containment material shall meet the requirements of Division 1, NF-2000.

(b) Material not performing a containment function and not in the containment support load path (nonstructural attachments) welded at or within  $2t$  of the outside

surface of the containment shell portion of the component need not comply with [Article WC-2000](#) or Division 1, Article NF-2000, provided the requirements of [WC-4430](#) are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6/SA-6M.

**WC-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL AND DUCTILE CAST IRON****WC-2210 HEAT TREATMENT REQUIREMENTS****WC-2211 Test Coupon Heat Treatment for Ferritic Material****(17)**

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a containment, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the containment, except that test coupons and specimens for P-No. 1 material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated where nominal thickness for flanges refers to the wall thickness at the weld joint to the containment. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

**WC-2212 Test Coupon Heat Treatment for Quenched and Tempered Material**

**WC-2212.1 Cooling Rates.** Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings ([WC-2223.3](#) and [WC-2226](#)). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in [WC-2212.2](#) or one of the specific procedures described in [WC-2220](#) shall be used for each product form.

**WC-2212.2 General Procedures.** One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with WC-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ( $\frac{1}{4}t$ ) and no nearer any heat-treated edge than a distance equal to the nominal thickness  $t$  being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in WC-2220 are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least  $t$  from a quenched edge, where  $t$  equals the material thickness;

(2) attaching a steel pad at least  $t$  wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

### **WC-2213 Test Coupon Heat Treatment for Ductile Cast Iron**

The tensile and impact coupon shall receive the same heat treatment as the casting.

### **WC-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL AND FOR DUCTILE CAST IRON**

#### **WC-2221 General Requirements**

The procedure for obtaining test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this subarticle. References to dimensions signify nominal values.

### **WC-2222 Plates**

#### **WC-2222.1 Orientation and Location of Coupons.**

Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from a rolled surface and with the midlength of the specimen at least  $t$  from any heat-treated edge, where  $t$  is the nominal thickness of the material.

#### **WC-2222.2 Requirements for Separate Test Coupons.**

Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least  $\frac{1}{4}t$  deep and  $t$  from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with WC-2212.2, the dimensions of the coupon shall be not less than  $3t \times 3t \times t$ , where  $t$  is the nominal material thickness.

### **WC-2223 Forgings**

#### **WC-2223.1 Forgings With 2 in. (50 mm) Maximum Thickness.**

For forgings with a maximum thickness of 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at the midplane of the thickness or the center of the cross section and with the midlength of the specimens at least 2 in. (50 mm) from any second surface.

#### **WC-2223.2 Forgings With Thickness Exceeding 2 in. (50 mm).**

For forgings exceeding a thickness of 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  of the maximum heat-treated thickness from any surface and with the midlength of the specimens at least  $t$  from any second surface. This is normally referred to as  $\frac{1}{4}t \times t$ , where  $t$  is the maximum heat-treated thickness. A thermal buffer may be used to achieve the above conditions [WC-2212.2(c)(3)] unless cooling rates applicable to the bulk forgings are simulated in accordance with WC-2212.2.

#### **WC-2223.3 Very Thick and Complex Forgings.**

Test coupons for forgings that are both very thick and complex, such as contour nozzles, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface, equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the

longitudinal axes of the specimens shall not be nearer than  $\frac{3}{4}$  in. (19 mm) to any heat-treated surface and the midlength of the specimens shall be at least  $1\frac{1}{2}$  in. (38 mm) from any heat-treated surface.

**WC-2223.4 Coupons From Separately Produced Test Forgings.** Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the forging thickness, except when the thickness-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with WC-2223.3.

**WC-2223.5 Test Specimens for Forgings.** When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamp on them, and witnessing the testing of these specimens.

## WC-2224 Bars and Bolting Material

**WC-2224.1 Bars With 2 in. (50 mm) Maximum Thickness.** For bars with diameters or thicknesses 2 in. (50 mm) or less, the coupons shall be taken so that specimens shall have their longitudinal axes on a line representing the center of the thickness and with the midlength of the specimens at least one diameter or thickness from a heat-treated end.

**WC-2224.2 Bars With Thicknesses Exceeding 2 in. (50 mm).** For bars with diameters or thicknesses over 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from the outside or rolled surface and with the midlength of the specimens at least  $t$  from a heat-treated end, where  $t$  is either the bar diameter or thickness.

**WC-2224.3 Bolting Material.** For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a

heat-treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

## WC-2225 Tubular Products

**WC-2225.1 Tubular Products With 2 in. (50 mm) Maximum Thickness.** For tubular products with 2 in. (50 mm) maximum wall thickness, the coupons shall be taken so that specimens shall have their longitudinal axes on a surface midway between the outside and inside surfaces and with the midlength of the specimens at least one wall thickness from a heat-treated end.

**WC-2225.2 Tubular Products Exceeding 2 in. (50 mm) Nominal Thickness.** For tubular products with nominal wall thicknesses exceeding 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from the outside surface and with the midlength of the specimens at least one wall thickness from a heat-treated end.

**WC-2225.3 Separately Produced Coupons Representing Fittings.** Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of WC-2223.4 shall be met.

## WC-2226 Tensile Test Specimen Location for Ductile Cast Iron

Tensile specimens shall be taken from each containment casting or its excess length part that has the same or equivalent solidification property. The location shall be near the center of the thickness and shall be at a distance from the end of the excess length part that is not less than one-half of the maximum casting thickness. The excess length part shall be at least the same thickness as the maximum casting thickness.

## WC-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

### WC-2310 MATERIAL TO BE IMPACT TESTED

#### WC-2311 Material for Which Impact Testing Is Required (17)

(a) Containment material shall be impact tested in accordance with the requirements of WC-2330, except that impact testing of materials described in (1) through (8) below is not a requirement of this Subsection.

(1) material with a nominal section thickness of  $\frac{5}{8}$  in. (16 mm) and less where thicknesses shall be taken as defined in (-a) through (-c) below.

(-a) for containments, use the nominal thickness of the shell or head, as applicable;

(-b) for nozzles or parts welded to containments, use the lesser of the containment shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(-c) for flat heads, or flanges, use the maximum shell thickness associated with the butt welding hub.

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) or less;

(3) bar with a nominal cross-sectional area that does not exceed 1 in.<sup>2</sup> (650 mm<sup>2</sup>);

(4) all thicknesses of material for pipe, tube, fittings, with a NPS 6 (DN 150) diameter and smaller;

(5) austenitic stainless steels, including precipitation hardened austenitic Grade 660 (UNS S66286);

(6) nonferrous materials;

(7) materials listed in Table WC-2311(a)-1 for which the listed value of  $T_{NDT}$ <sup>17</sup> is lower than the Lowest Service Temperature (LST) by an amount established by the rules in Section III Appendices, Nonmandatory Appendix R. This exemption does not exempt either the weld metal (WC-2430) or the welding procedure qualification (WC-4335) from impact testing.

(8) materials for containments for which the LST exceeds 150°F (65°C).

(b) The Design Specification shall state the LST for the containments.

(c) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Table 2A. The other requirements of WC-2331 and WC-2332 apply for these steels. For nominal wall thicknesses greater than 2½ in. (64 mm), the required  $C_v$  values shall be 40 mils (1.0 mm) lateral expansion.

## WC-2320 IMPACT TEST PROCEDURES

### WC-2321 Types of Tests

**WC-2321.1 Drop Weight Tests.** The drop weight test, when required, shall be performed in accordance with ASTM E208-91. Specimen types P-1, P-2, or P-3 may be used. When drop weight tests are performed to meet the requirements of WC-2300, the test temperature and the results shall be reported on the Certified Material Test Report.

**WC-2321.2 Charpy V-Notch Tests.** The Charpy V-notch test ( $C_v$ ), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of WC-2330 shall be reported in the Certified Material Test Report.

**WC-2321.3 Fracture Toughness Tests.** Fracture toughness tests, when required, shall be performed in accordance with ASTM E399. The tests shall be performed at the LST. A test shall consist of two test specimens. (17)

### WC-2322 Test Specimens

#### WC-2322.1 Location of Test Specimens.

(a) Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that specified for tensile test specimens in the material specification. For bolting, the  $C_v$  impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat-treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

(b) For fracture toughness requirements, toughness test specimens for ductile cast iron shall be taken from each containment casting or its excess length part. The location shall be the same as that for the tensile specimens.

**Table WC-2311(a)-1  
Exemptions From Impact Testing Under  
WC-2311(a)(7)**

Material [Note (1)]	Material Condition		$T_{NDT}$ , °F (°C) [Notes (3) and (4)]
	[Note (2)]		
SA-537, Class 1	N		-30 (-34)
SA-516, Grade 70	Q & T		-10 (-23)
SA-516, Grade 70	N		0 (-18)
SA-508, Class 1	Q & T		+10 (-12)
SA-533, Grade B	Q & T		+10 (-12)
SA-299 [Note (5)]	N		+20 (-7)
SA-36 (Plate)	HR		+40 (+4)
SA-508, Class 2	Q & T		+40 (+4)

#### NOTES:

(1) These materials are exempt from toughness testing when  $LST - T_{NDT}$  is satisfied in accordance with the rules established in Section III Appendices, Nonmandatory Appendix R.

(2) Material Condition letters refer to:

N = normalize

Q & T = quench and temper

HR = hot rolled

(3) These values for  $T_{NDT}$  were established from data on heavy section steel [thickness greater than 2½ in. (64 mm)]. Values for sections less than 2½ in. (64 mm) thick are held constant until additional data are obtained.

(4)  $T_{NDT}$  = temperature at or above nil-ductility transition temperature NDT (ASTM E208);  $T_{NDT}$  is 10°F (5°C) below the temperature at which at least two specimens show no-break performance.

(5) Materials made to a fine grain melting practice.



**WC-2322.2 Orientation of Impact Test Specimens.**

(a) Specimens for  $C_v$  impact tests shall be oriented as required in WC-2200 for the tensile test specimen or, alternatively, the orientation may be in the direction of maximum stress. The notch of the  $C_v$  specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction.

(c) Toughness test specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens (WC-2226).

(d) The plane of the toughness test specimen notch shall be normal to the surface of the material. The fracture toughness specimen orientation of ductile cast iron shall be L-R, as identified in ASTM E399, Fig. 1 (Crack Plane Identifications for Cylindrical Bars and Tubes).

**WC-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS****(17) WC-2331 Containment Material Test Methods and Temperature**

(a) Containment material shall be impact tested in accordance with one of the test methods indicated below:

(1) Charpy V-notch testing at or below the LST<sup>18</sup>

(2) drop weight testing to show that the value of  $(LST - T_{NDT}^{17} + A)$  is satisfied in accordance with the rules established in Section III Appendices, Nonmandatory Appendix R

(3) fracture toughness test for ductile cast iron at  $-40^\circ\text{F}$  ( $-40^\circ\text{C}$ )

**(17) WC-2332 Specific Test Methods and Acceptance Standards for Containment Material for Tests Based on Lowest Service Temperatures**

**WC-2332.1 Containment Material Other Than Bolt- ing With  $2\frac{1}{2}$  in. (64 mm) Maximum Thickness.** For containments, use the lesser of the: maximum radial thickness of the item, exclusive of integral butt-welded projections; the containment shell thickness to which the item is welded; and the maximum shell thickness associated with the item for flat heads or flanges. Except as limited in WC-4335, apply one of the methods of WC-2331 to test: base material; the base material, the heat-affected zone, and weld metal for the weld procedure qualification tests of WC-4335; and the weld metal for WC-2431. The impact test results shall meet one of the acceptance standards applicable to the specified test method.

(a) *Charpy V-Notch Testing for Lateral Expansion Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table WC-2332.1-1.

**Table WC-2332.1-1  
Required  $C_v$  Lateral Expansion Values for  
Containment Material Other Than Bolting**

Nominal Wall Thickness, in. (mm) [Note (1)]	Lateral Expansion, mils (mm)	
	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ (16) or less [Note (2)]	...	...
Over $\frac{5}{8}$ to 1 (16 to 25), incl.	20 (0.50)	15 (0.38)
Over 1 to $1\frac{1}{2}$ (25 to 38), incl.	25 (0.64)	20 (0.50)
Over $1\frac{1}{2}$ to $2\frac{1}{2}$ (38 to 64), incl.	35 (0.89)	30 (0.75)
Over $2\frac{1}{2}$ (64) [Note (3)]	45 (1.14)	40 (1.0)

## GENERAL NOTES:

- (a) Where weld metal tests of WC-2400 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
- (b) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of WC-4330 shall conform to the requirements of either of the base materials.

## NOTES:

- (1) For containment use the least of:
- (a) the maximum radial thickness of the item exclusive of integral butt-welded projections;
- (b) the containment shell thickness to which the item is welded;
- (c) the maximum shell thickness associated with the item for flat heads or flanges.
- (2) No test required.
- (3) For use with WC-2332.2(b).

(b) *Charpy V-Notch Testing for Absorbed Energy Values.* The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table WC-2332.1-2.

(c) *Drop Weight Testing.* An acceptance test shall consist of at least two no-break specimens as described in ASTM E208.

**WC-2332.2 Containment Material Other Than Bolt- ing With Thickness Exceeding  $2\frac{1}{2}$  in. (64 mm).** For containments, use the lesser of the: maximum radial thickness of the item, exclusive of integral butt-welded projections; the containment shell thickness to which the item is welded; and the maximum shell thickness associated with the item for flat heads or flanges.

(a) The base material, and the weld procedure qualification weld metal tests of WC-4335, shall be tested by the drop weight method as specified in WC-2321.1 and WC-2331(a)(2).

(b) Except as limited in WC-4335, apply one of the methods of WC-2331(a) to test: the base material and the heat-affected zone of the weld procedure qualification tests for WC-4335; and the weld metal for WC-2431.

(c) The acceptance standards shall be as given in WC-2332.1(a), WC-2332.1(b), or WC-2332.1(c), as applicable.

**Table WC-2332.1-2**  
**Required  $C_v$  Energy Values for Containment Material Other Than Bolting**

Nominal Wall Thickness, in. (mm) [Note (2)]	Energy, ft-lb (J) for Base Materials [Note (1)] of Specified Minimum Yield Strength, ksi (MPa)					
	55 ksi (380 MPa) or Below		Over 55 ksi to 75 ksi (380 MPa to 515 MPa), incl.		Over 75 ksi to 105 ksi (515 MPa to 725 MPa), incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$\frac{5}{8}$ (16) or less [Note (3)]	...	...	...	...	...	...
Over $\frac{5}{8}$ to 1 (16 to 25), incl.	20 (27)	15 (20)	25 (34)	20 (27)	30 (41)	25 (34)
Over 1 to $1\frac{1}{2}$ (25 to 38), incl.	25 (34)	20 (27)	30 (41)	25 (34)	35 (47)	30 (41)
Over $1\frac{1}{2}$ to $2\frac{1}{2}$ (38 to 64), incl.	35 (47)	30 (41)	40 (54)	35 (47)	45 (61)	40 (54)
Over $2\frac{1}{2}$ (64) [Note (4)]	45 (61)	40 (54)	50 (68)	45 (61)	55 (75)	50 (68)

GENERAL NOTE: Where weld metal tests of WC-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NOTES:

- (1) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of WC-4330 shall conform to the requirements of either of the base materials.
- (2) For containment vessels use the least of:
  - (a) the maximum radial thickness of the item exclusive of integral butt-welded projections;
  - (b) the containment shell thickness to which the item is welded;
  - (c) the maximum shell thickness associated with the item for flat heads or flanges.
- (3) No test required.
- (4) For use with WC-2332.2(b).

(d) *Fracture Toughness Testing for Ductile Cast Iron.* A rapid-load fracture toughness test shall be performed in accordance with WC-2321.3, except that ASTM E1820 shall be used. A test shall consist of at least four test specimens. The test shall be performed at  $-40^\circ\text{F}$  ( $-40^\circ\text{C}$ ).

(e) *Acceptance Standards for Ductile Cast Iron.* The rapid-load fracture toughness value shall satisfy the following inequality at  $-40^\circ\text{F}$  ( $-40^\circ\text{C}$ ):

$$(\text{average}) K_{IC,R} - 3\sigma_{SD} \geq 46 \text{ ksi-in.}^{1/2} (50 \text{ MPa-m}^{1/2})$$

where

$$K_{IC,R} = \text{rapid-load fracture toughness, ksi-in.}^{1/2} \\ (\text{MPa-m}^{1/2})$$

$$\sigma_{SD} = \text{standard deviation, ksi-in.}^{1/2} (\text{MPa-m}^{1/2})$$

The average value and standard deviation shall be established assuming Weibull distribution of the measurements.

**WC-2332.3 Bolting Material.** For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. The tests shall be performed at or below the LST, and all three specimens shall meet the requirements of Table WC-2332.3-1.

**WC-2340 NUMBER OF IMPACT TESTS REQUIRED**

**WC-2341 Plates**

One test shall be made from each plate as heat treated. Where plates are furnished in the non-heat-treated condition and qualified by heat-treated test specimens, one test

shall be made for each plate as rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

**WC-2342 Forgings**

(a) Where an individual forging is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment charge.

(b) When heat treatment is performed in a continuous-type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

(c) One test shall be made for each forging of 1,000 lb to 10,000 lb (450 kg to 4 500 kg).

**Table WC-2332.3-1**  
**Required  $C_v$  Values for Bolting Material**  
**Tested in Accordance With WC-2332.3**

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
Over 1 through 4 (25 through 100)	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

(d) As an alternative to (c), a separate test forging may be used to represent forgings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or  $C_v$  test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging 180 deg apart.

### WC-2343 Bars

One test shall be made for each lot of bars with a cross-sectional area greater than 1 in.<sup>2</sup> (650 mm<sup>2</sup>) where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

### WC-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than  $\frac{1}{4}$  in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

### WC-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed the following:

Diameter	Weight
1 $\frac{3}{4}$ in. (44 mm) and less	1,500 lb (680 kg)
Over 1 $\frac{3}{4}$ in. to 2 $\frac{1}{2}$ in. (44 mm to 64 mm)	3,000 lb (1 350 kg)
Over 2 $\frac{1}{2}$ in. to 5 in. (64 mm to 127 mm)	6,000 lb (2 700 kg)
Over 5 in. (127 mm)	10,000 lb (4 500 kg)

### WC-2350 RETESTS

#### WC-2351 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by WC-2330, one retest at the same temperature may be conducted, provided

(1) the average value of the test results meets the average of three requirements specified in Table WC-2332.1-1 or Table WC-2332.1-2, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table WC-2332.1-1 or Table WC-2332.1-2, as applicable;

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table WC-2332.1-1 or Table WC-2332.1-2, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table WC-2332.1-1 or Table WC-2332.1-2, as applicable.

### WC-2352 Retests for Bolting Material

(a) For Charpy V-notch tests required by WC-2330, one retest at the same temperature may be conducted, provided

(1) not more than one specimen per test is below the acceptance requirements;

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the acceptance requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

### WC-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT (17)

Calibration of temperature instruments and  $C_v$  impact test machines used in impact testing shall be performed at the frequency specified in (a) or (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-4258.2 at least once in each three month interval.

(b)  $C_v$  impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-4258.2. The calibrations shall be performed at least once per year using methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology, or any supplier of subcontracted calibration services accredited in accordance with the requirements of WA-3123 and NCA-4255.3(c).

### WC-2400 WELDING MATERIAL

#### WC-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of containments or material, except welding material used for cladding or hard surfacing, shall conform to



the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this subarticle and to the rules covering identification in [WC-2150](#).

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

- (1) welding process;
- (2) SFA specification and classification;
- (3) other identification if no SFA specification applies;
- (4) minimum tensile strength [[WC-2431.1\(e\)](#)] in either the as-welded or heat-treated condition, or both [[WC-2431.1\(c\)](#)];
- (5) drop weight test for material in either the as-welded or heat-treated condition, or both ([WC-2332](#));
- (6) Charpy V-notch test for material as-welded, or heat treated, or both ([WC-2331](#)); the test temperature and the lateral expansion or the absorbed energy shall be provided;
- (7) the preheat and interpass temperatures to be used during welding of the test coupon [[WC-2431.1\(c\)](#)];
- (8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [[WC-2431.1\(c\)](#)];
- (9) elements for which chemical analysis is required per the SFA specification or WPS, and [WC-2432](#);
- (10) minimum delta ferrite ([WC-2433](#)).

## WC-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrode gas welding) processes (Section IX); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electrode slag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by [Article WC-4000](#) and this subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes.

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch (a) or dry blend (b) and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) *Chemically controlled tube, wire, or strip* is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed except that those coils which are splice free need only be analyzed on one end of the coil.

(2) *Chemically controlled mixes of flux* are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a heat may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced

coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A lot of submerged arc or electroslag flux is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A dry blend of supplementary powdered filler metal is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9 000 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A chemically controlled mix of powdered filler metal is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

## WC-2430 WELD METAL TESTS

### WC-2431 Mechanical Properties Test

Tensile and impact tests shall be made in accordance with this paragraph, of welding materials which are used to join P-Nos. 1 and 3 base materials in any combination, with the exceptions listed in (a) through (d) below.

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base materials exempted from impact testing by WC-2311(a)(1) through WC-2311(a)(6) or WC-2311(a)(8) shall also be exempted from the impact testing required by this paragraph.

- (17) **WC-2431.1 General Test Requirements.** The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to substantially eliminate the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat-treated condition when the production welds are to be postweld heat-treated. The postweld heat treatment holding time shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Table WC-4622.1-1 or Table WC-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table WC-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) The tensile specimens, and the C<sub>v</sub> impact specimens when required, shall be located and prepared in accordance with the requirements of SFA-5.1 or the applicable SFA specification. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld, with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of WC-2321.1 and WC-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of  $\frac{1}{4}t$  from a surface, where  $t$  is the thickness of the test weld.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to be welded, the

tensile strength requirements shall conform to the specified minimum tensile strength requirement of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of WC-2331 or WC-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the requirements for either base material.

**WC-2431.2 Standard Test Requirements.** In lieu of the use of the General Test Requirements specified in WC-2431.1, tensile and impact tests may be made in accordance with this Subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in WC-2431, shall apply for this option. The limitations and testing under this option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this Subparagraph shall be limited to electrode classifications included in SFA-5.1 or SFA-5.5.

(b) The assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of impact specimens required by WC-2331 or WC-2332, as applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and the postweld heat-treated condition. The postweld heat treatment temperatures shall be in accordance with Table WC-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). When the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required, the general test of WC-2431.1 shall be used.

(d) The tensile and C<sub>v</sub> specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in WC-2431.1(d).

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA specification for the applicable electrode classification.

(f) The requirements of WC-2431.1(f) shall be applicable to the impact testing.

**WC-2432 Chemical Analysis Test**

Chemical analysis of filler metal or weld deposits shall be made in accordance with WC-2420 and as required by the following Subparagraph.

**WC-2432.1 Test Method.** The chemical analysis test shall be performed in accordance with this Subparagraph and Table WC-2432.1-1, and the results shall conform to WC-2432.2. (17)

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or the *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The methods given in the Appendix of SFA-5.9 shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the

**Table WC-2432.1-1  
Sampling of Welding Materials for Chemical Analysis**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by WC-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of WC-2431.1(c) do not apply.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the welding procedure specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214. The removal of chemical analysis samples shall conform to QW-453 for the minimum thickness for which the Welding Procedure Specification is qualified.

**WC-2432.2 Requirements for Chemical Analysis.** The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, Table QW-442) shall be analyzed for the elements listed in Table WC-2432.2-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3862.1. Elements listed in Table WC-2432.2-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

Table WC-2432.2-1 Welding Material Chemical Analysis	
Materials	Elements
Cr-Ni stainless	C, Cr, Mo, Ni, Mn, Si, Cb

**WC-2433 Delta Ferrite Determination**

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4 Type 16-8-2 or A-No. 8 weld filler metal to be used for weld metal cladding.

**WC-2433.1 Method.** Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of the chemical analysis of WC-2432 in conjunction with Figure WC-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS A 4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with WC-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number.

**WC-2433.2 Acceptance Standards.** The minimum acceptable delta ferrite shall be 5FN (Ferrite Number). The results of the delta ferrite determination shall be included in the Certified Material Test Report of WC-2130 or WC-4120.

**WC-2440 STORAGE AND HANDLING OF WELDING MATERIAL**

Suitable storage and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

**WC-2500 EXAMINATION AND REPAIR OF CONTAINMENT MATERIAL**

**WC-2510 CONTAINMENT MATERIAL**

Containment material shall be examined and repaired in accordance with the material specification and as otherwise required by this subarticle.

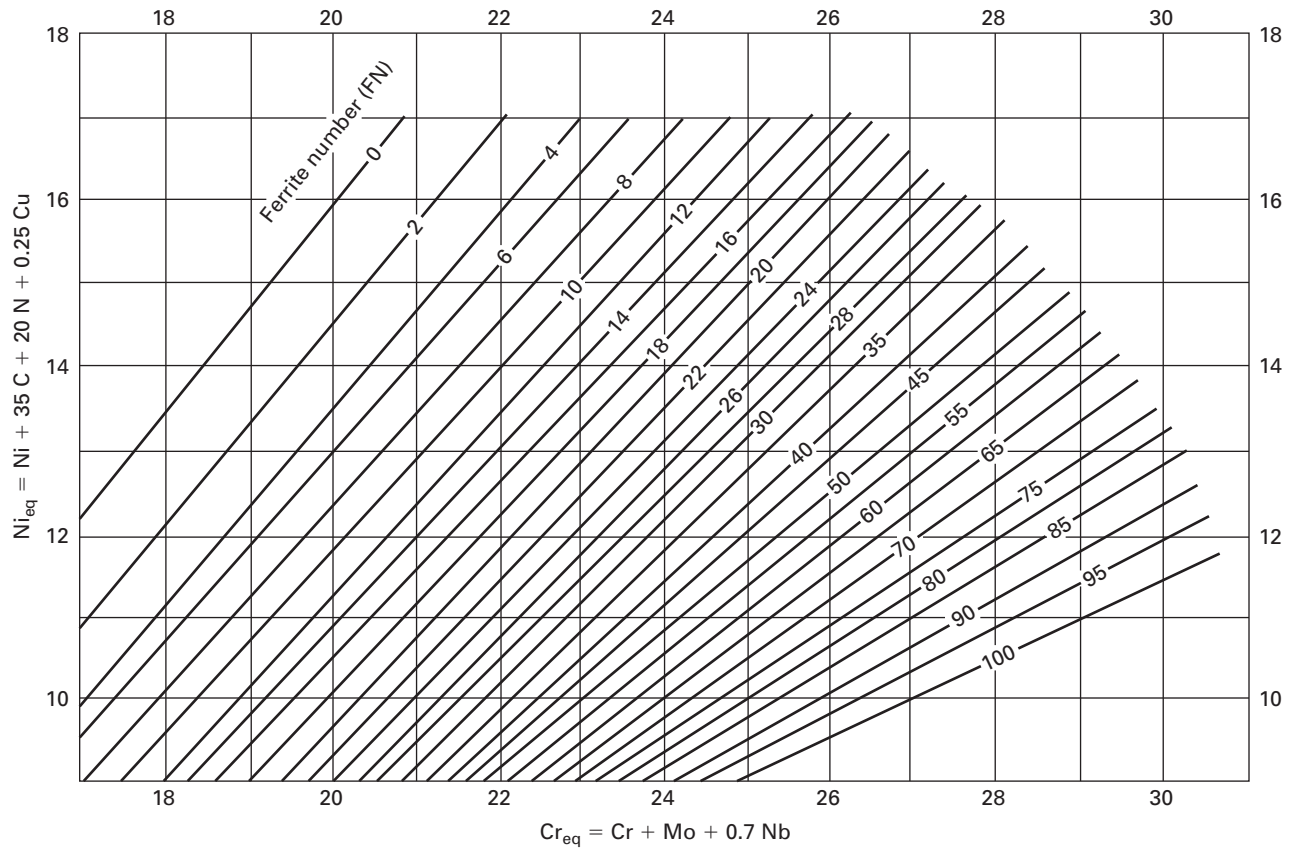
**WC-2530 EXAMINATION AND REPAIR OF PLATE**

**WC-2531 Required Examination**

Plates shall be examined in accordance with the requirements of the material specification. In addition, for ferritic steels, the containment shell in the area of the closure welds made, after loading the containment (Figure WC-4265-3) shall be examined by the ultrasonic method in accordance with WC-2532.



**Figure WC-2433.1-1**  
**Weld Metal Delta Ferrite Content**



**GENERAL NOTES:**

- (a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:
- (1) GMAW welds — 0.08%, except that when self-shielding flux-cored electrodes are used — 0.12%
  - (2) Welds made using other processes — 0.06%
- (b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

**WC-2532 Ultrasonic Examination Procedures**

**WC-2532.1 Straight Beam Examination.** The requirements for straight beam examination shall be in accordance with SA-578/SA-578M, Specification for Straight Beam Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in (a) and (b) below.

(a) *Extent of Examination.* The examination shall include the area adjacent to the closure weld to a distance of at least three times the nominal shell thickness. One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

(b) *Acceptance Standards*

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (75 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

**WC-2537 Time of Examination**

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) *Ultrasonic examination* shall be performed after rolling to size and after heat treatment, except for post-weld heat treatment.

(b) *Radiographic examination* of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) *Magnetic particle or liquid penetrant examination* of repair welds shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No. 1 material 2 in. (50 mm) and less nominal thickness.

**WC-2538 Elimination of Surface Defects**

Surface defects shall be removed by grinding or machining, provided the requirements of (a) and (b) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) When the elimination of the defect reduces the thickness of the section below the minimum required by the design, the material shall be repaired in accordance with WC-2539.

**WC-2539 Repair by Welding**

The Material Organization may repair by welding materials from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of containment vessels.

**WC-2539.1 Defect Removal.** The defect shall be removed or reduced to an imperfection of acceptable limit by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (WC-4211.1).

**WC-2539.2 Qualification of Welding Procedures and Welders.** The welding procedure and welders or welding operators shall be qualified in accordance with Article WC-4000 and Section IX.

**WC-2539.3 Blending of Repaired Areas.** After repair, the surface shall be blended uniformly into the surrounding surface.

**WC-2539.4 Examination of Repair Welds.** Each repair weld shall be examined by the magnetic particle method (WC-2545) or by the liquid penetrant method (WC-2546). In addition, when the depth of the repair cavity exceeds the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with and to the applicable acceptance standards of WC-5320. The image quality indicator (IQI) shall be based upon the section thickness of the repaired area.

**WC-2539.5 Heat Treatment After Repairs.** The product shall be heat treated after repair in accordance with the requirements of WC-4620.

**WC-2539.6 Material Report Describing Defects and Repair.** Each defect repair that is required to be radiographed shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographic film.

**WC-2539.7 Repair of Cladding by Welding.** The Material Organization may repair defects in cladding by welding, provided the requirements of (a) through (d) below are met.

(a) *Qualification of Welding Procedures and Welders.* The welding procedure and the welders or welding operators shall be qualified in accordance with Article WC-4000 and Section IX.

(b) *Defect Removal and Examination of Cavity.* The defect shall be removed, and the cavity prepared for repair shall be examined by the liquid penetrant method (WC-2546).

(c) *Examination of Repaired Areas.* The repaired area shall be examined by a liquid penetrant method (WC-2546).

(d) *Report of Repairs.* Each defect repair shall be described in the Certified Material Test Report for each piece, including a chart which shows the location and size of the repair, the welding material identification, welding procedure, heat treatment, and examination results.

**WC-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS****WC-2541 Required Examinations**

Forgings and bars shall be examined in accordance with the requirements of the material specification, except when magnetic particle or liquid penetrant examination is specifically required by the rules of this Subsection, in which case the examination shall conform to the requirements of WC-2545 or WC-2546, as applicable.

**WC-2545 Magnetic Particle Examination**

**WC-2545.1 Examination Procedure.** The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

**WC-2545.2 Evaluation of Indications.**

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the [WC-2545.3](#) acceptance standards which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

### **WC-2545.3 Acceptance Standards.**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for material less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for material from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

## **WC-2546 Liquid Penetrant Examinations**

**WC-2546.1 Examination Procedure.** The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

### **WC-2546.2 Evaluation of Indications.**

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks or surface conditions, may produce similar indications which are not relevant.

(b) Any indication in excess of the [WC-2546.3](#) acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width.

Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

### **WC-2546.3 Acceptance Standards.**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for material less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for material from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

## **WC-2547 Time of Examination**

The requirements for time of examination shall be the same as stated in [WC-2537](#).

## **WC-2548 Elimination of Surface Defects**

Elimination of surface defects shall be made in accordance with [WC-2538](#).

## **WC-2549 Repair by Welding**

Repair by welding shall be performed in accordance with [WC-2539](#), except that the depth of repair that is permitted is not limited.

## **WC-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS**

### **WC-2551 Required Examination**

(a) All seam welds in welded (without filler metal) tubular products shall be examined by one of the following methods:

(1) ultrasonic examination in accordance with [WC-2552](#)

(2) radiographic examination in accordance with [WC-2553](#)

(3) eddy current examination in accordance with [WC-2554](#)



(b) Wrought seamless and welded (without filler metal) tubular products and fittings, except copper alloy and nickel alloy tubular products and fittings, shall comply with the requirements of WC-2557, WC-2558, and WC-2559, in addition to the basic material specification.

(c) Copper alloy and nickel alloy wrought seamless and welded (without filler metal) tubular products and fittings shall comply with the requirements of WC-2558, in addition to the basic material specification.

## (17) WC-2552 Ultrasonic Examination

The volumetric examinations required by this paragraph need only be conducted from one surface.

### WC-2552.1 Examination Procedure for Welds in Pipe and Tubing.

(a) *Circumferential Direction* —  $6\frac{3}{4}$  in. (170 mm) O.D. and Smaller. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213, Standard Method for Ultrasonic Examination of Pipe and Tubing for Longitudinal Discontinuities, and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to or greater than the indications produced by standard defects included in the reference specimens specified in WC-2552.3.

(b) *Pipe and Tubing Larger Than  $6\frac{3}{4}$  in. (170 mm) O.D.* The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing larger than  $6\frac{3}{4}$  in. (170 mm) O.D. shall be in accordance either with the requirements of SA-388 for angle beam scanning in the circumferential direction, or with the requirements of SE-213. The reference standard shall be in accordance with WC-2552.3 below.

(c) *Acceptance Standard.* Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with WC-2558 or WC-2559.

### WC-2552.2 Examination Procedure for Welds in Fittings.

(a) *Procedure.* The procedure for ultrasonic examination of welds in fittings shall be in accordance with the requirements of Recommended Practice SA-388 for angle beam examination in two circumferential directions.

(b) *Acceptance Standard.* Fittings shall be unacceptable if angle beam examination results show one or more reflectors that produce indications exceeding in amplitude the indications from the calibrated notch.

### WC-2552.3 Reference Specimens.

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat-treated condition as the product which is being examined. For circumferential scanning, the

standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed  $\frac{1}{16}$  in. (1.5 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

### WC-2552.4 Checking and Calibration of Equipment.

The proper functioning of the examination equipment shall be checked, and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

(a) at the beginning of each production run of a given size and thickness of a given material;

(b) after each 4 hr or less during the production run;

(c) at the end of the production run;

(d) at any time that malfunctioning is suspected.

If, during any check, it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

## WC-2553 Radiographic Examination

(a) *General.* When radiographic examination is performed as an alternative to ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) *Examination Procedure.* The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by WC-5111.

(c) *Acceptance Standard.* Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication which has a length greater than:

(-a)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(-b)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. (19 mm) to  $2\frac{1}{4}$  in. (57 mm), inclusive

(-c)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm)

where  $t$  is the thickness of the thinner portion of the weld;

(3) any group of aligned indications having an aggregate length greater than  $t$  in a length of  $12t$ , unless the minimum distance between successive indications exceeds  $6L$ , in which case the aggregate length is unlimited,  $L$  being the length of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

### WC-2554 Eddy Current Examination

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

**WC-2554.1 Examination Procedure.** The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in WC-2554.2. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with WC-2558 or WC-2559 as applicable.

**WC-2554.2 Reference Specimens.** The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat-treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a  $\frac{1}{16}$  in. (1.5 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed  $\frac{1}{16}$  in. (1.5 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in WC-2552.3.

**WC-2554.3 Checking and Calibration of Equipment.** The checking and calibration of examination equipment shall be the same as in WC-2552.4.

### WC-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows:

(1) ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment;

(2) radiographic examination, when required, may be performed prior to any required postweld heat treatment;

(3) magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after final heat treatment, except that the examination

may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (50 mm) and less nominal thickness;

(4) forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading; fittings shall be examined after final forming;

(5) when surface examination is required, all external surfaces and all accessible internal surfaces shall be examined, except for bolt holes and threads.

### WC-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article WC-3000, the product shall be repaired in accordance with WC-2559.

### WC-2559 Repair by Welding

Repair of defects shall be in accordance with WC-2539.

## WC-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

### WC-2561 Required Examination

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with SA-358, SA-409, SA-671, SA-672, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with a Certification Mark with NPT Designator shall be in accordance with Section III requirements. In addition to the Certification Mark with NPT Designator, a numeral 1 shall be stamped below and outside the official Certification Mark.

(b) In addition to the requirements of the material specification and of this Article, all welds shall be examined 100% by radiography in accordance with the basic material specification. When radiographic examination is not specified in the basic material specification, the welds shall be examined in accordance with WC-2563.

(c) Tubular products and fittings which have been radiographed shall be marked to indicate that radiography has been performed. The radiographs and a radiographic report showing exposure locations shall be provided with the Certified Material Test Report.

(d) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 (see Section III Appendices, Mandatory Appendix V) in accordance with NCA-5290.

**WC-2563 Radiographic Examination**

The radiographic examination shall be performed in accordance with the requirements of WC-2553.

**WC-2567 Time of Examination**

The time of examination shall be in accordance with the requirements of WC-2557.

**WC-2568 Elimination of Surface Defects**

Unacceptable surface defects shall be removed in accordance with the requirements of WC-2558.

**WC-2569 Repair by Welding**

When permitted by the basic material specification, base material defects shall be repair welded in accordance to the requirements of WC-2559. Repair welding of weld seam defects shall be in accordance with WC-4450.

**WC-2570 EXAMINATION AND REPAIR OF CAST PRODUCTS**

**WC-2571 Required Examination**

For examination of the containment casting, the following shall apply:

(a) All cast products shall be examined by the ultrasonic method as specified in WC-2574.

(b) All external and accessible internal surfaces, except threaded surfaces, shall be examined using either the liquid penetrant method (WC-2576) or the magnetic particle method (WC-2577).

**WC-2572 Time of Nondestructive Examination**

All examinations shall be performed after final machining except that ultrasonic testing shall be performed at the time when the configuration is best suited for scanning and the most meaningful results can be obtained.

**WC-2573 Provisions for Repair of Base Material by Welding**

Castings shall not be repaired by plugging, welding, brazing, impregnation, or any other means.

**WC-2574 Ultrasonic Examination of Castings**

Ultrasonic examination shall be performed in accordance with Section V, Article 5, T-471.4. Each manufacturer shall certify that the procedure is in accordance with the following requirements and shall make the procedure available for approval upon request.

The following acceptance standards shall be applied:  
 (a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thickness indicated.

(1) Quality Level 1 for thicknesses up to 2 in. (50 mm)

(2) Quality Level 3 for thicknesses 2 in. to 4 in. (50 mm to 100 mm)

(3) Quality Level 4 for thicknesses greater than 4 in. (100 mm)

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation shall be unacceptable:

UT Quality Level	Longest Dimension of Area, in. (mm)
	[Notes (1), (2), and (3)]
1	1.5 (38)
2	2.0 (50)
3	2.5 (64)
4	3.0 (75)

NOTES:  
 (1) The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which continuous indication, exceeding the transfer-corrected distance amplitude curve, is maintained.  
 (2) Areas shall be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.  
 (3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread shall be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm), whichever is less, shall be unacceptable.

(4) Two or more indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications shall be unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (1).

(5) Two or more indications greater than permitted for Quality Level 1 for castings less than 2 in. (50 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. through 4 in. (50 mm through 100 mm), and greater than permitted for Quality Level 3 for thicknesses greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the

larger of the adjacent indications, shall be unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (1).

### WC-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be regarded as a defect until it is reexamined to verify whether actual defects are present. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those that result from mechanical discontinuities. Linear indications are those whose length is more than 3 times the width. Rounded indications are those that are circular or elliptical with the length less than 3 times the width. Indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) are considered relevant.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for materials less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for materials from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge-to-edge

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated

### WC-2577 Magnetic Particle Examination (for Ductile Cast Iron)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may

produce indications that are not relevant. Any indication in excess of the acceptance standards that is believed to be nonrelevant shall be regarded as a defect until it is reexamined to verify whether actual defects are present. Nonrelevant indications that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those that result from unacceptable mechanical discontinuities and have a major dimension greater than  $\frac{1}{16}$  in. (1.5 mm). Linear indications are those whose length is more than 3 times the width. Rounded indications are those that are circular or elliptical with the length less than 3 times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for materials less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for materials from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) long for materials from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated

### WC-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

#### WC-2581 Requirements

All bolting material shall be visually examined in accordance with WC-2582.

#### WC-2582 Visual Examination

(17)

The final surfaces of threads, shanks, and heads shall be visually examined for workmanship, finish, and appearance in accordance with the requirements of ASTM F788 for bolting material and ASTM F812 for nuts. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to WC-5100 or by personnel qualified in accordance with WC-5500.

**WC-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS****WC-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS**

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program or an Identification and Verification Program, as applicable, which meets the requirements of [WA-3800](#).

(b) The requirements of NCA-3862 shall be met as required by [WC-2130](#). The other requirements of [WA-3800](#) need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program ([Article WA-4000](#)) shall include measures

to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (3) below:

(1) pipe, tube, pipe fittings, and flanges NPS 2 (DN 50) and less;

(2) bolting materials, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 in.<sup>2</sup> (650 mm<sup>2</sup>) and less.

**WC-2700 DIMENSIONAL STANDARDS**

Dimensions of standard items shall comply with the standards and specifications listed in [Table WA-7100-1](#).



# ARTICLE WC-3000 DESIGN

## WC-3100 GENERAL DESIGN

### WC-3110 LOADING CRITERIA

#### WC-3111 Loading Conditions

The loadings considered in designing a containment as identified in the Design Specification shall include, but are not limited to, those in (a) through (g) below.

- (a) internal and external pressures
- (b) impact loads, either internal or external, that may be caused by operational drop events, nonmechanistic tip-over, missile impact, design-basis aircraft crash, earthquake-induced impact, or other dynamic events
- (c) weight of the containment and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids
- (d) superimposed loads such as other components, operating equipment, impact limiting devices, shielding, and linings
- (e) external environments such as wind loads, snow loads, vibrations, handling loads, and earthquake loads, where specified
- (f) reaction loads from attachments and supports
- (g) temperature effects caused by contents or the external environment

#### WC-3112 Design Loadings

The Design Loadings shall be established in accordance with [WA-2123.1](#) and the following subparagraphs.

**WC-3112.1 Design Pressure.** The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with [WA-2123.1\(a\)](#).

**WC-3112.2 Design Temperature.** The specified Design Temperature shall be established in accordance with [WA-2123.1\(b\)](#). It shall be used in conjunction with the Design Pressure. If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in the applicability column of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, nor exceed the maximum temperature limitations specified elsewhere in this Subsection.

**WC-3112.3 Design Mechanical Loads.** The specified Design Mechanical Loads shall be established in accordance with [WA-2123.1\(c\)](#). They shall be used in conjunction with the Design Pressure.

**WC-3112.4 Design Allowable Stress Intensity Values.** Design stress intensity values for Section III, Class SC materials listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 shall be used. The materials shall not be used at temperatures that exceed the temperature limit established in the stress tables. The stress intensity values in the tables may be interpolated for intermediate temperatures. As an additional control on permitted storage containment materials listed in Section II, Part D, Subpart 1, Tables 2A and 2B, only the following materials shall be used:

- (a) materials whose P-numbers are listed in [Table WC-4622.1-1](#), or
- (b) ductile cast iron castings per specifications SA-874 or SA/JIS G5504 of Section II, Part D, Subpart 1, Table 2A

#### WC-3113 Operating and Test Conditions

(a) Storage containments ([WA-1110](#)) are subject to operating and test conditions that are required to be considered in the design of the containment in order to satisfy applicable safety criteria.

(b) The selection of operating and test conditions is beyond the scope of this Division. The Design Specification shall specify these conditions using appropriate guidance from safety criteria documents for storage containments and the requirements of regulatory and enforcement authorities having jurisdiction.

(c) Each operating and test condition to which the containment may be subjected shall be classified in accordance with [WA-2123](#), and Service Limits [[WA-2123.4\(b\)](#)] shall be designated in the Design Specification in such detail as will provide a complete basis for design in accordance with this Subsection.

(d) When any loading for which Level A, C, or D Service Limits are specified in the Design Specification, they shall be evaluated in accordance with [WA-2120](#) and in compliance with the applicable design and stress intensity limits of this Article.

**WC-3120 SPECIAL CONSIDERATIONS****WC-3121 Corrosion**

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made in the Design Specification for these effects by indicating the increase in the thickness of the base metal over that determined by the design analysis ([WC-3200](#)). Other suitable methods of protection may be used. Material added or included for these purposes need not be of the same thickness for all areas of the containment if different rates of attack are expected for the various areas.

**WC-3122 Cladding**

The rules of this Paragraph apply to the design of clad containments constructed of materials permitted in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

**WC-3122.1 Stresses.** Except as permitted by [WC-3214](#), no structural strength shall be attributed to the cladding.

**WC-3122.2 Design Dimensions.** The dimensions given in (a) and (b) below shall be used in the design of the containment.

(a) For containments subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For containments subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

**WC-3123 Welds Between Dissimilar Metals**

In satisfying the requirements of this subarticle, caution shall be exercised in construction involving dissimilar metals having different chemical compositions, mechanical properties, and coefficients of thermal expansion in order to avoid difficulties in service.

**WC-3130 GENERAL DESIGN RULES**

The design shall be such that the rules of this Article are satisfied for all configurations and loadings using the stress intensity values of [WC-3112.4](#) and including the use of standard products listed in [Table WA-7100-1](#).

**WC-3131 Design Reports**

The Certificate Holder shall provide a Design Report conforming to the requirements of [WC-3211](#).

**WC-3132 Dimensional Standards for Standard Products**

Dimensions of standards products shall comply with the standards and specifications listed in [Table WA-7100-1](#) when the standard or specification is referenced in the specific design subarticle. However,

compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design subarticle for a specific containment.

**WC-3133 Containments Under External Pressure**

**WC-3133.1 General.** Rules are given in this paragraph for determining the thickness under external pressure loading in spherical and cylindrical shells without stiffening rings. Charts for determining the stresses in shells and hemispherical heads are given in Section II, Part D, Subpart 3.

**WC-3133.2 Nomenclature.** The symbols used in this paragraph are defined as follows:

- $A$  = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having  $D_o/T$  values less than 10, see [WC-3133.3\(b\)](#).
- $B$  = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell at the design metal temperature, psi (MPa)
- $D_o$  = outside diameter of the cylindrical shell
- $E$  = modulus of elasticity of material at Design Temperature, psi (MPa). For external pressure and axial compression design in accordance with this Article, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Section II, Part D, Subpart 2, Tables TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.
- $L$  = the design length of a containment taken as the distance between head tangent lines plus one-third of the depth of each head
- $P$  = external Design Pressure, psi (MPa) (gage or absolute, as required)
- $P_a$  = allowable external pressure, psi (MPa) (gage or absolute, as required)
- $R$  = inside radius of spherical shell
- $S$  = the lesser of 1.5 times the stress intensity at design metal temperature from Section II, Part D, Subpart 1, Tables 2A and 2B or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1, psi (MPa)
- $T$  = minimum required thickness of cylindrical shell or spherical shell
- $T_n$  = nominal thickness used, less corrosion allowance, of a cylindrical shell



**WC-3133.3 Cylindrical Shells.** The thickness of cylinders under external pressure shall be determined by the procedure given in (a) or (b) below.

(a) *Cylinders Having  $D_o/T$  Values  $\geq 10$*

*Step 1.* Assume a value for  $T$  and determine the ratios  $L/D_o$  and  $D_o/T$ .

*Step 2.* Enter Section II, Part D, Subpart 3, Figure G at the value of  $L/D_o$  determined in [Step 1](#). For values of  $L/D_o$  greater than 50, enter the chart at a value of  $L/D_o = 50$ . For values of  $L/D_o$  less than 0.05, enter the chart at a value of  $L/D_o$  of 0.05.

*Step 3.* Move horizontally to the line for the value of  $D_o/T$  determined in [Step 1](#). Interpolation may be made for immediate values of  $D_o/T$ . From this point of intersection move vertically downward to determine the value of factor  $A$ .

*Step 4.* Using the value of  $A$  calculated in [Step 3](#), enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material/temperature line, see [Step 7](#).

*Step 5.* From the intersection obtained in [Step 4](#), move horizontally to the right and read the value of  $B$ .

*Step 6.* Using this value of  $B$ , calculate the value of the maximum allowable external pressure  $P_a$  using the following equation:

$$P_a = \frac{4B}{3(D_o/T)}$$

*Step 7.* For values of  $A$  falling to the left of the applicable material/temperature line, the value of  $P_a$  can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/T)}$$

*Step 8.* Compare  $P_a$  with  $P$ . If  $P_a$  is smaller than  $P$ , select a larger value for  $T$  and repeat the design procedure until a value of  $P_a$  is obtained that is equal to or greater than  $P$ .

(b) *Cylinders Having  $D_o/T$  Values  $< 10$*

*Step 1.* Using the same procedure as given in (a) above, obtain the value of  $B$ . For values of  $D_o/T$  less than 4, the value of factor  $A$  can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of  $A$  greater than 0.10, use a value of 0.10.

*Step 2.* Using the value of  $B$  obtained in [Step 1](#), calculate a value  $P_{a1}$  using the following equation:

$$P_{a1} = \left[ \frac{2.167}{(D_o/T)} - 0.0833 \right] B$$

*Step 3.* Calculate a value  $P_{a2}$  using the following equation:

$$P_{a2} = \frac{2S}{D_o/T} \left[ 1 - \frac{1}{D_o/T} \right]$$

*Step 4.* The smaller of the values of  $P_{a1}$  calculated in [Step 2](#), or  $P_{a2}$  calculated in [Step 3](#) shall be used for the maximum allowable external pressure  $P_a$ . Compare  $P_a$  with  $P$ . If  $P_a$  is smaller than  $P$ , select a larger value for  $T$  and repeat the design procedure until a value for  $P_a$  is obtained that is equal to or greater than  $P$ .

### WC-3133.4 Spherical Shells and Formed Heads.

(a) *Spherical Shells.* The minimum required thickness of a spherical shell under external pressure shall be determined by the procedure given in [Steps 1](#) through [6](#).

*Step 1.* Assume a value for  $T$  and calculate the value of factor  $A$  using the following equation:

$$A = \frac{0.125}{(R/T)}$$

*Step 2.* Using the value of  $A$  calculated in [Step 1](#), enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material/temperature line, see [Step 5](#).

*Step 3.* From the intersection obtained in [Step 2](#), move horizontally to the right and read the value of factor  $B$ .

*Step 4.* Using the value of  $B$  obtained in [Step 3](#), calculate the value of the maximum allowable external pressure  $P_a$  using the following equation:

$$P_a = \frac{B}{(R/T)}$$

*Step 5.* For values of  $A$  falling to the left of the applicable material/temperature line for the Design Temperature, the value of  $P_a$  can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6. Compare  $P_a$  obtained in Step 4 or Step 5 with  $P$ . If  $P_a$  is smaller than  $P$ , select a larger value for  $T$  and repeat the design procedure until a value for  $P_a$  is obtained that is equal to or greater than  $P$ .

(b) The nomenclature defined below is used in the equations of (c) through (e) below.

$D$  = inside length of the major axis of an ellipsoidal head  
 $D_o$  = outside diameter of the head skirt at the point under consideration

$h$  = one-half of the length of the minor axis of the ellipsoidal head, or the inside depth of the ellipsoidal head measured from the tangent line, head bend line

$K_1$  = a factor depending on the ellipsoidal head proportions, given in Table WC-3133.4-1

$R$  = for hemispherical heads, the inside radius in the corroded condition

= for ellipsoidal heads, the equivalent inside spherical radius taken as  $K_1 D_o$  in the corroded condition

= for torispherical heads, the inside radius of the crown portion of the head in the corroded condition

$T$  = minimum required thickness of head after forming, exclusive of corrosion allowance

(c) *Hemispherical Heads.* The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in (a) above for determining the thickness for a spherical shell.

(d) *Ellipsoidal Heads.* The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1. Assume a value for  $T$  and calculate the value of factor  $A$  using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of  $A$  calculated in Step 1, follow the same procedure as that given for spherical shells in (a) Step 2 through (a) Step 6.

(e) *Torispherical Heads.* The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall

not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for  $R$ .

**WC-3133.6 Cylinders Under Axial Compression.** The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below:

(a) the  $S_m$  value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 2A and 2B;

(b) the value of the  $B$  determined from the applicable chart in Section II, Part D, Subpart 3 using the following definitions for the symbols on the charts:

$R$  = inside radius of the cylindrical shell

$T$  = selected thickness of the shell, exclusive of the corrosion allowance

The value of  $B$  shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5.

Step 1. Using the selected values of  $T$  and  $R$ , calculate the value of factor  $A$  using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of  $A$  calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor  $B$ . This is the maximum allowable compressive stress for the values of  $T$  and  $R$  used in Step 1.

Step 4. For values of  $A$  falling to the left of the applicable material/temperature line, the value of  $B$  shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

Step 5. Compare the value of  $B$  determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell, using the selected values of  $T$  and  $R$ . If the value of  $B$  is smaller than the computed compressive stress, a greater value of  $T$  must be selected and the design procedure repeated until a value of  $B$  is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell.

(17)

Table WC-3133.4-1 Values of Spherical Radius Factor, $K_1$											
$D/2h$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
$K_1$	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Equivalent spherical radius =  $K_1 D$ ;  $D/2h$  = axis ratio; interpolation permitted for intermediate values.

**WC-3135 Attachments**

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the containment as defined in WC-1130 shall meet the stress limits of the containment.

(b) The design of the containment shall include consideration of the interaction effects and loads transmitted through the attachment to and from the containment. Thermal stresses, stress concentrations, and restraint of the containment shall be considered.

(c) Beyond  $2t$  from the outside surface of the containment shell, where  $t$  is the nominal thickness of the containment shell, the appropriate design rules of Division 1, Article NF-3000 may be used as a substitute for the design rules of Article WC-3000 for portions of attachments that are in the containment support load path.

(d) Nonstructural attachments shall meet the requirements of WC-4435.

**WC-3200 DESIGN RULES FOR CONTAINMENTS****WC-3210 GENERAL REQUIREMENTS****WC-3211 Basis for Use****(17) WC-3211.1 Scope.**

(a) This subarticle contains design rules for containments used for storage of spent nuclear fuel and high-level radioactive material. The design shall be such that stress intensities will not exceed the limits described in this subarticle and in WC-3700 using the  $S_m$  values tabulated in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(b) A stress analysis of containment shall be performed considering all the loadings of WC-3111 and the Design Specification. This analysis shall be done in accordance with Section III Appendices, Mandatory Appendix XIII<sup>19</sup> for all applicable stress categories. Alternatively, an experimental stress analysis may be performed in accordance with Section III Appendices, Mandatory Appendix II.

(c) As an alternative, for energy-limited dynamic events for which Level D Service Limits have been established, the strain-based acceptance criteria of WC-3700 may be used rather than satisfying stress criteria as discussed above.

(d) A Design Report shall be prepared by the Certificate Holder showing compliance with this subarticle. This Design Report shall meet the requirements of WA-3350 for a Design Report (Section III Appendices, Nonmandatory Appendix C).

**WC-3211.2 Requirements for Acceptability.**

(a) The design shall be such that the requirements of WC-3100 and this subarticle are satisfied. In cases of conflict, the requirements of this subarticle shall govern.

(b) The design shall be such that stress intensities do not exceed the limits given in WC-3217.

(c) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account. The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stress in the shell shall be the smaller of the following values:

(1) the  $S_m$  value from Section II, Part D, Subpart 1, Tables 2A and 2B

(2) the value of factor  $B$  determined from WC-3133.6

(d) For the special case of external pressure, the rules of WC-3133 shall be met.

**WC-3211.3 Material in Combination.** A containment may be designed for and constructed of combinations of materials permitted in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, provided the applicable rules are followed, including WC-3112.4, and the requirements in Section IX for welding dissimilar metals are met.

**WC-3211.4 Multiple Chamber Containment.** When a containment consists of more than one independent chamber, operating at the same or different pressures and temperatures, each chamber shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected.

**WC-3211.5 Minimum Thickness of Shell or Head.** The thickness after forming and without allowance for corrosion of any containment shell or head subject to pressure shall be not less than  $\frac{1}{4}$  in. (6 mm) for carbon and low alloy steels or  $\frac{1}{8}$  in. (3 mm) for stainless steel.

**WC-3211.6 Selection of Material Thickness.** The selected thickness of material shall be such that the forming, heat treatment, and other fabrication processes will not reduce the thickness of the material at any point below the minimum value required by these rules.

**WC-3214 Cladding**

**WC-3214.1 Primary Stresses.** No structural strength shall be attributed to the cladding in satisfying WC-3217 primary stress limits.

**WC-3214.2 Secondary and Peak Stresses.** In satisfying the secondary stress limits of WC-3217 and the fatigue requirements of WC-3219, the presence of cladding shall be considered with respect to both thermal analysis and stress analysis. The stresses in both materials shall be limited to the values that meet the requirements of both WC-3217 and WC-3219. However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the containment, the presence of the cladding may be neglected.

**WC-3214.3 Bearing Stresses.** In satisfying WC-3216.3, the presence of cladding shall be included.

## WC-3215 Design Basis

**WC-3215.1 Pressure and Temperature Relationships.** The design shall take into account the maximum differences in pressure, temperature, and loadings, which exist under the specified operating conditions, between the inside and outside of the containment at any point or between chambers of a multiple chamber containment. The design thickness for evaluating stresses due to pressure and other loadings shall not include any metal added as corrosion or erosion allowance.

## WC-3216 Design Stress Intensity Values

**WC-3216.1 Stress Tables.** The design stress intensity values  $S_m$  are given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. Values for intermediate temperatures may be found by interpolation. These  $S_m$  values form the basis for the various stress limits that are described in Section III Appendices, Mandatory Appendix XIII, and are used in determining the membrane stress intensity limits for the various load combinations given in [Table WC-3217-1](#).

**WC-3216.2 Coefficient of Thermal Expansion and Modulus of Elasticity.** Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Tables TE and values of the moduli of elasticity are in Section II, Part D, Subpart 2, Tables TM.

- (17) **WC-3216.3 Special Stress Limits.** The deviations between (a), (b), and (c) below from the basic stress limits are provided to cover special conditions or configurations.

*(a) Bearing Loads*

(1) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength  $S_y$  at temperature except that, when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of  $1.5S_y$  at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact or the area of the base metal supporting the contact surface.

(2) When bearing loads are applied on parts having free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to  $0.6S_m$  in the case of design load stress [Section III Appendices, Mandatory Appendix XIII, XIII-1300(m)] and  $0.5S_y$  in the case of design load stress plus secondary stress [Section III Appendices, Mandatory Appendix XIII, XIII-1300(ab)]. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad

material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(3) When considering bearing stresses in pins and similar members, the  $S_y$  value at temperature is applicable, except that a value of  $1.5S_y$  may be used if no credit is given to bearing area within one pin diameter from a plate edge.

*(b) Pure Shear.* The average primary shear stress across a section under Design Loadings in pure shear, for example, keys, shear rings, and screw threads, shall be limited to  $0.6S_m$ . The maximum primary shear under Design Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to  $0.8S_m$ .

*(c) Progressive Distortion of Nonintegral Connections.* Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouting or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (Section III Appendices, Mandatory Appendix XIII, XIII-3420), which result in slippage between parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value  $S_y$  given in Section II, Part D, Subpart 1, Table Y-1.

## WC-3217 Design Criteria

These design requirements provide specific rules for containments. Simplified criteria are included for determining whether analysis for cyclic operation is required. Stress analysis of the containment shall be performed using the most severe combination of loadings expected to occur simultaneously during design and operating conditions. Allowable stress intensities,  $kS_m$ , for primary stresses shall be satisfied for all Service Limits. [Table WC-3217-1](#) lists values of  $k$  that are appropriate for various load combinations.

*(a)* The theory of failure used in this subarticle is the maximum shear stress theory. Stress intensity is defined as two times the maximum shear stress.

*(b)* The average value of the general primary membrane stress intensity across the thickness of the section under consideration,  $P_m$ , due to any combination of pressure and mechanical loadings expected to occur simultaneously, should not exceed the design stress intensity value  $kS_m$ .

*(c)* The local primary membrane stress intensity,  $P_L$ , due to any combination of pressure and mechanical loadings expected to occur simultaneously is limited to



(17)

**Table WC-3217-1**  
**Stress Intensity  $k$  Factors for Design and**  
**Operating Load Combinations**

Service Limits [Note (1)]	$k$ [Note (2)]
Design	1.0
Level A [Note (3)]	1.0
Level C	1.2
Level D	[Note (4)]

## NOTES:

- (1) For Design Limits, use Design Pressure at design metal temperature; for Service Limits, use operating pressure at operating metal temperature.
- (2) The condition of structural instability or buckling must be considered.
- (3) See WC-3219 and Section III Appendices, Mandatory Appendix XIII.
- (4) The stress limits of Section III Appendices, Mandatory Appendix XXVII shall be applied. As an alternative, the requirements of WC-3700 may be used to evaluate inelastic containment responses to energy-limited dynamic events.

$1.5kS_m$ . The distance over which the stress intensity exceeds  $1.1kS_m$  shall not extend in the meridional direction more than  $1.0\sqrt{Rt}$ , where  $R$  is the mean radius at the mid-surface of the containment shell or head and  $t$  is the nominal thickness of the shell or head at the point under consideration.

(d) The general or local primary membrane plus bending stress intensity ( $P_m$  or  $P_L$ ) +  $P_b$  due to any combination of pressure and mechanical loadings expected to occur simultaneously, shall not exceed  $1.5kS_m$ . The provisions of Section III Appendices, Mandatory Appendix XIII apply.

**WC-3217.1 Secondary Stresses.** Secondary stresses may exist in containments designed and fabricated in accordance with the rules of this subarticle. Secondary stresses shall be evaluated in accordance with the rules of Section III Appendices, Mandatory Appendix XIII. Secondary stresses need be evaluated only for Level A Service Limits.

- (17) **WC-3217.2 Peak Stresses.** As described in Section III Appendices, Mandatory Appendix XIII, the peak stresses do not cause any noticeable distortion and are objectionable only as a possible source of a fatigue crack or a brittle fracture. The allowable value of peak stress intensity is dependent on the stress intensity range and on the number of times it is to be applied. If a fatigue analysis is required, peak stresses shall be evaluated in accordance with the fatigue analysis rules provided in Section III Appendices, Mandatory Appendix XIII.<sup>19</sup>

**WC-3217.3 Nomenclature.**

- $P_b$  = primary bending stress intensity, psi (MPa). This stress intensity is the component of the primary stress proportional to the distance from the centroid of the solid section. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
- $P_L$  = local primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It considers discontinuities but not concentrations.
- $P_m$  = general primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
- $S_m$  = design stress intensity values given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, psi (MPa)
- $S_y$  = yield strength values in Section II, Part D, Subpart 1, Table Y-1, psi (MPa)

**WC-3218 Upper Limits of Test Pressure**

The evaluation of pressure test loadings shall be in accordance with (a) through (d) below.

(a) *Test Pressure Limit.* If the calculated pressure at any point in a containment including static head, exceeds the required test pressure defined in WC-6221 or WC-6321 by more than 6%, the resulting stresses shall be calculated using all the loadings that may exist during the test. The stress allowables for this situation are given in (b) and (c) below.

(b) *Hydrostatically Tested Containments.* The hydrostatic test pressure of a completed containment shall not exceed that value which results in the following stress intensity limits:

(1) a calculated primary membrane stress intensity  $P_m$  of 90% of the tabulated yield strength  $S_y$  at test temperature as given in Section II, Part D, Subpart 1, Table Y-1

(2) a calculated primary membrane plus primary bending stress intensity  $P_m + P_b$  shall not exceed the applicable limits given in (-a) or (-b) below:

$$(-a) P_m + P_b \leq 1.35 S_y \text{ for } P_m \leq 0.67 S_y$$

$$(-b) P_m + P_b \leq (2.15 S_y - 1.2 P_m) \text{ for } 0.67 S_y < P_m \leq 0.90 S_y$$

where  $S_y$  is the tabulated yield strength at test temperature. For other than rectangular sections,  $P_m + P_b$  shall not exceed a value of  $\alpha$  times  $0.90S_y$ , where the factor  $\alpha$  is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section.

(c) *Pneumatically Tested Containments.* The limits given in (b) above shall apply to pneumatically tested containments, except that the calculated membrane stress intensity shall be limited to 80% of the yield strength at the test temperature. For other than rectangular sections,  $P_m + P_b$  shall not exceed a value of  $\alpha$  times  $0.8S_y$ , where the factor  $\alpha$  is defined in (b)(2) above.

(d) *Multichamber Containments.* In case of multichamber containments, pressure may be applied simultaneously to the appropriate adjacent chamber to maintain the stress intensity limits given in (b) and (c) above (WC-6600).

the factor given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential, °F (°C)	Factor
50 (28) or less	0
51 to 100 (29 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12
Excess of 450 (250)	20

**WC-3219 Fatigue Evaluation**

If cyclic loadings are identified in the Design Specifications, the need for a fatigue analysis shall be determined in accordance with WC-3219.1.

(17) **WC-3219.1 Rules to Determine Need for Fatigue Analysis of Integral Parts of Containments.**

A fatigue analysis need not be made, provided all of Condition A (WC-3219.1.1) or all of Condition B (WC-3219.1.2) is met. If neither Condition A nor Condition B is met, a detailed fatigue analysis shall be made in accordance with the rules of Section III Appendices, Mandatory Appendix XIII for those parts which do not satisfy the conditions. The rules of Condition A or Condition B are applicable to all integral parts of the containment, including integrally reinforced type nozzles.

**WC-3219.1.1 Condition A.** Fatigue analysis is not mandatory for materials having a specified minimum tensile strength not exceeding 80.0 ksi (550 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 1,000 cycles:

(a) is the expected design number of full range pressure cycles;

(b) is the expected number of operating pressure cycles in which the range of pressure variation exceeds 20% of the Design Pressure. Cycles in which the pressure variation does not exceed 20% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered;

(c) is the effective number of changes in metal temperature between any two adjacent points<sup>10</sup> in the containment, including nozzles. The effective number of such changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

$\Delta T$ , °F (°C)	Cycles
40 (22)	1,000
90 (50)	250
400 (220)	5

the effective number of changes in metal temperature is

$$1,000(0) + 250(1) + 5(12) = 310$$

The number used as type (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.

(d) for containments with welds between materials having different coefficients of expansion, is the number of temperature cycles, which causes the value of  $(\alpha_1 - \alpha_2) \Delta T$  to exceed 0.00034, where  $\alpha_1$  and  $\alpha_2$  are the mean coefficients of thermal expansion, 1/°F (1/°C) (Section II, Part D, Subpart 2, Tables TE), and  $\Delta T$  is the operating temperature range, °F (°C). This does not apply to cladding.

**WC-3219.1.2 Condition B.** Fatigue analysis is not mandatory when all of the conditions of Section III Appendices, Mandatory Appendix XIII, XIII-3510 are met. (17)

**WC-3220 DESIGN CONSIDERATION**

**WC-3224 Containments Under Internal Pressure**

**WC-3224.1 General Requirements.** For calculating the required area of reinforcement of openings, the minimum thickness of the containment vessel and parts shall be determined using the Design Pressure and the equations in the following paragraphs. In addition, the other Design Loadings shall be considered in establishing the value of  $F$  as defined below.



**WC-3224.2 Nomenclature.** The symbols used are defined below. Except for test conditions, dimensions used or calculated shall be in the corroded condition.

- $D$  = inside diameter of a head skirt or inside length of the major axis of an ellipsoidal head at the point under consideration measured perpendicular to the axis of revolution
- $F$  = meridional membrane force in the shell wall at the point under consideration resulting from primary Design Loadings other than internal pressure, lb/in. (N/mm) length of circumference. If this force is not uniform, the loading requiring the greatest shell thickness shall be used where the tensile load is positive.
- $h$  = one-half the length of the minor axis of an ellipsoidal head or the inside depth of an ellipsoidal head, measured from the tangent line
- $k$  = stress intensity factor for design, Service Level A, and test load combination from [Table WC-3217-1](#)
- $L$  = inside spherical or crown radius of torispherical and hemispherical heads
- $P$  = internal pressure at the top of the containment vessel plus any pressure due to the static head of the fluid, at any point under consideration, psi (MPa)
- $R$  = inside radius of the shell under consideration, in. (mm). This radius is measured normal to the surface from the axis of revolution.
- $r$  = inside knuckle radius of torispherical heads
- $S$  = membrane stress intensity limit from Section II, Part D, Subpart 1, Tables 2A and 2B multiplied by the stress intensity factor in [Table WC-3217-1](#)  
=  $kS_m$  psi (MPa)
- $t$  = minimum thickness of shell

**WC-3224.3 Minimum Thickness of Cylindrical Shells.** The minimum thickness of cylindrical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{PR}{S - 0.5P}$$

If  $P > 0.4S$ , the following equation must be used:

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

where  $\ln$  is the natural log.

(b) If  $F$  is positive and exceeds  $0.5PR$ ,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If  $F$  is negative, the condition of axial structural instability or buckling shall be considered separately [see [WC-3211.2\(c\)](#)].

**WC-3224.4 Minimum Thickness of Spherical Shells.** The minimum thickness of spherical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{0.5PR}{S - 0.25P}$$

If  $P > 0.4S$ , the following equation may be used:

$$\ln \frac{(R + t)}{R} = \frac{0.5P}{S}$$

(b) If  $F$  is positive

$$t = \frac{0.5PR + F}{S - 0.25P}$$

(c) If  $F$  is negative, the condition of instability shall be considered. [WC-3211.2\(c\)](#) for cylinders may be used for spheres, provided biaxial compression does not exist.

**WC-3224.5 Minimum Thickness of Formed Heads.**

The minimum thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure acting against the concave surface shall be determined by the appropriate rule or equation in the following subparagraphs.

**WC-3224.6 Minimum Thickness of Ellipsoidal Heads<sup>20, 21</sup>** (17)

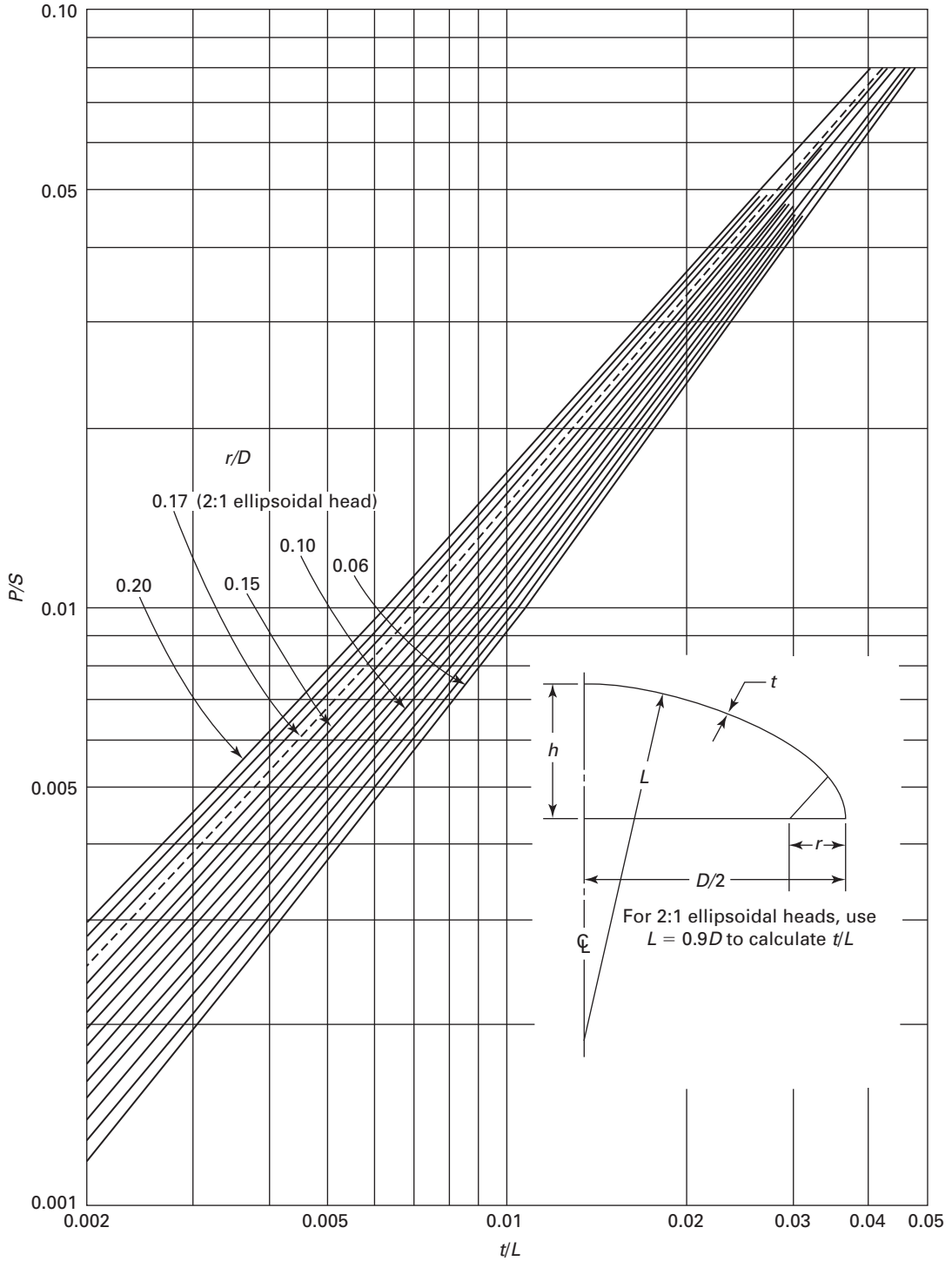
The minimum thickness of a 2:1 ellipsoidal head shall be established using the procedures given in [WC-3224.8](#) and the curve of [Figure WC-3224.6-1](#), which is labeled "2:1 ellipsoidal head." Ellipsoidal head designs which have  $D/2h$  values different from 2 shall be analyzed as equivalent torispherical heads or according to Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than  $\sqrt{Rt}$ . Transition joints to shells of thickness less than the required head thickness shall not be located within the minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with [WC-3260](#) and [Figure WC-3261-1](#).

**WC-3224.7 Minimum Thickness of Hemispherical Heads.** For hemispherical heads, the thickness shall be as required for spherical shells, [WC-3224.4](#). The requirements for the transition to cylindrical shells of different thickness, given in [WC-3260](#) and [Figure WC-3261-1](#) shall be met.

**WC-3224.8 Minimum Thickness of Torispherical Heads<sup>20</sup>** (17)

The minimum thickness of a torispherical head having  $t/L \geq 0.002$  up to a  $t/L$  where  $P/S \leq 0.08$  (approximately  $t/L = 0.04$  to  $0.05$ ) shall be established by using the curves in [Figure WC-3224.6-1](#). Interpolation may be used for  $r/D$  values which fall within the range

**Figure WC-3224.6-1**  
**Design Curves for Torispherical Heads and 2:1 Ellipsoidal Heads for Use With WC-3224.8 and WC-3224.6**



of curves; however, no extrapolation of the curves is permitted. For designs where  $P/S > 0.08$ , which is above the upper limit of [Figure WC-3224.6-1](#), the thickness shall be set by the following equation:

$$t = \frac{D}{2}(e^{P/S} - 1)$$

where  $t/L < 0.002$ , which is below the lower limit of [Figure WC-3224.6-1](#), the head design must be analyzed according to Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than  $\sqrt{Rt}$ . Transition joints to shells of thickness less than the required head thickness shall not be located within this minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with [WC-3260](#) and [Figure WC-3261-1](#).

**WC-3224.8.1 Crown and Knuckle Radii.** In connection with the design procedures of [WC-3224.8](#) and [Figure WC-3224.6-1](#), the inside crown radius to which an unstayed head is formed shall not be greater than the inside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than 6% of the outside diameter of the skirt nor less than three times the head thickness.

(17) **WC-3224.9 Loadings on Heads Other Than Pressure.** Provision shall be made for other loadings given in [WC-3111](#). For torispherical and ellipsoidal heads, the effect of other loadings must be determined in accordance with Section III Appendices, Mandatory Appendix II, or Mandatory Appendix XIII. For the spherical portion of heads, the effect of composite loading may be treated as in [WC-3224.3](#) and [WC-3224.4](#).

## WC-3225 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this Paragraph. Some acceptable types of flat heads and covers are shown in [Figures WC-3225-1](#), [WC-3225-2](#), and [WC-3225-3](#). The dimensions are exclusive of extra metal added for corrosion allowance.

**WC-3225.1 Nomenclature.** The notations used are defined as follows:

- $C$  = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in [Figures WC-3225-1](#) through [WC-3225-3](#), dimensionless
- $D$  = bolt circle diameter
- $d$  = diameter
- $h_G$  = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, ([Figure WC-3225-2](#))
- $L$  = distance from centerline of the head to shell weld to tangent line on formed heads, as indicated in [Figure WC-3225-2](#)
- $m$  = the ratio  $t_r/t_s$ , dimensionless
- $P$  = Design Pressure, psi (MPa)
- $r$  = inside corner radius on a head formed by flanging or forging
- $S$  = design stress intensity  $S_m$  from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, multiplied by the  $k$  factor tabulated in [Table WC-3217-1](#), psi (MPa)
- $T$  = minimum required thickness of flat head, cover, or flanges, exclusive of corrosion allowance
- $t_f$  = actual thickness of the flange on a formed head, at the large end, exclusive of corrosion allowance
- $t_p$  = the smallest dimension from the face of the head to the edge of the weld preparation
- $t_r$  = required thickness of shell or nozzle for pressure
- $t_s$  = actual thickness of shell or nozzle
- $W$  = total bolt load

## WC-3225.2 Equations for Minimum Thickness. (17)

(a) The thickness of flat heads as shown in [Figures WC-3225-1](#) through [WC-3225-3](#), shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S}$$

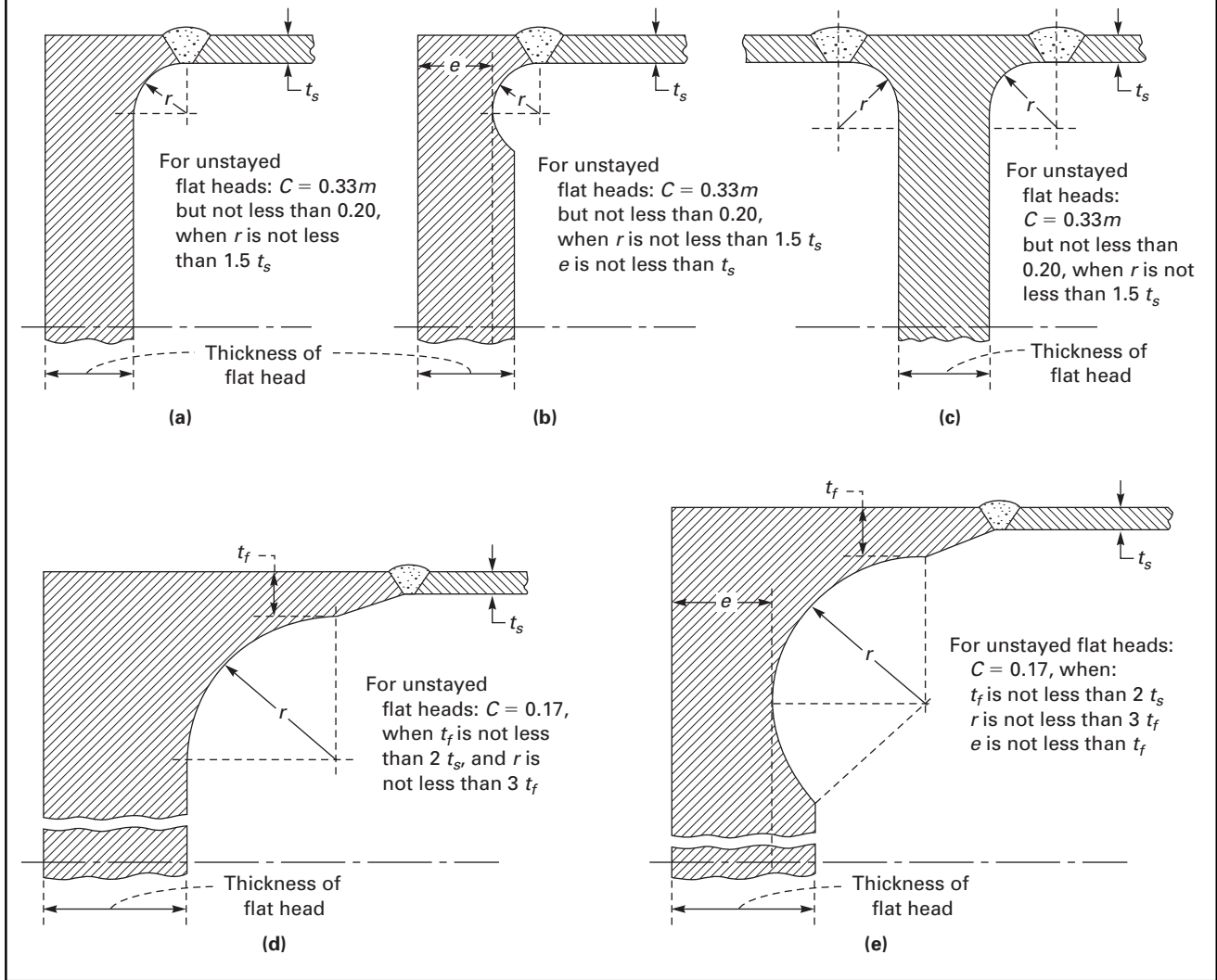
(b) The thickness of cover plates and blind flanges attached by bolts causing an edge moment as shown in [Figure WC-3225-2](#) shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S + 1.27 Wh_G/Sd^3}$$

(c) The thicknesses determined in (a) and (b) above, address stress requirements. In some cases, greater thickness may be necessary if deflection would cause leakage of threaded or gasketed joints

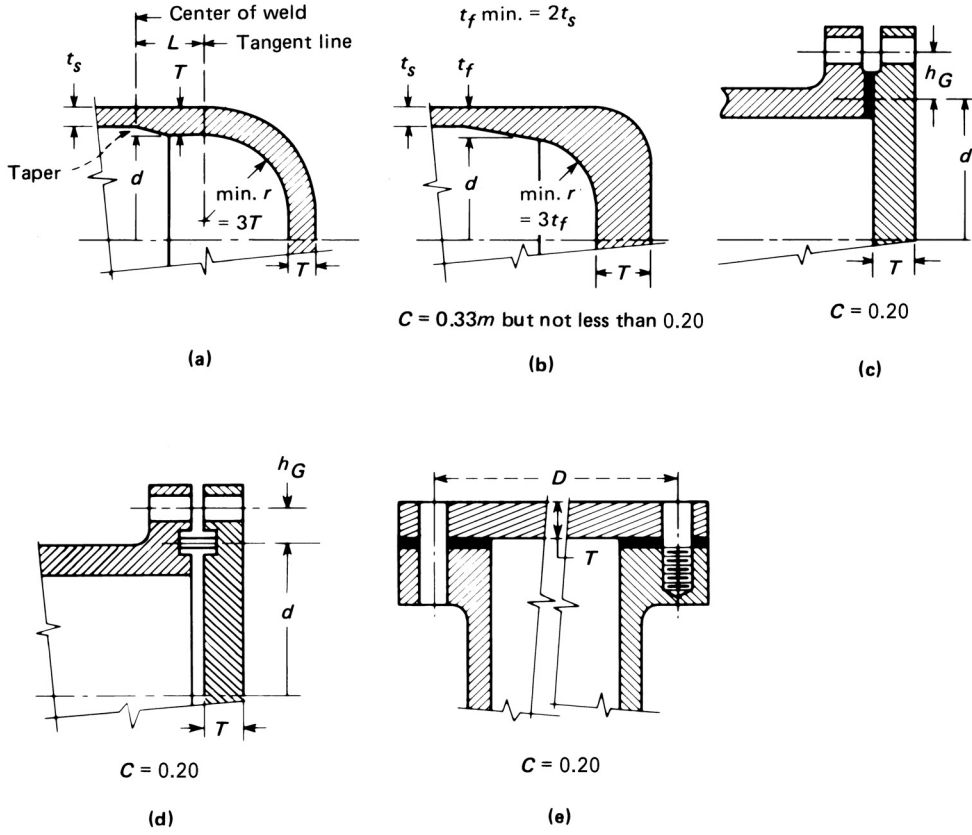
NOTE: In some cases, the initial bolt load required to seat the gasket is larger than the operating bolt load. The thickness should be checked for both the operating condition and the initial bolt load required to seat the gasket.

**Figure WC-3225-1  
Typical Flat Heads**



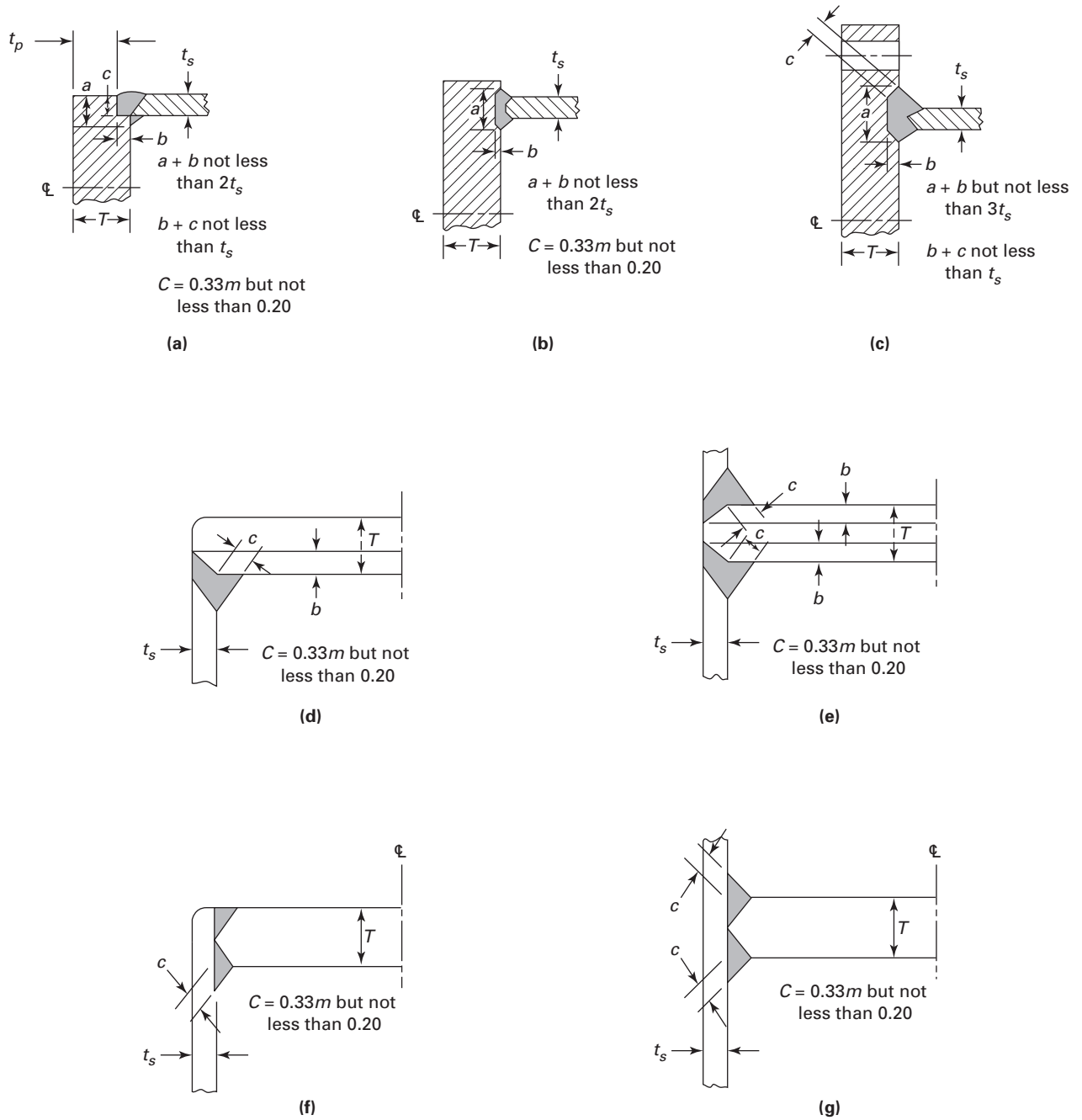
(17)

**Figure WC-3225-2**  
**Some Acceptable Types of Unstayed Flat Heads and Covers**



GENERAL NOTE: All these illustrations are diagrammatic only. Other designs that meet the requirements of [WC-3225.2](#) are acceptable.

**Figure WC-3225-3**  
**Attachment of Flat Heads to Containment Shell**



GENERAL NOTE:  $C$  min. =  $0.7t_s$  or  $1/4$  in. (6 mm), whichever is less;  $b$  = the lesser of  $t_s$  or  $T/2$ .



**WC-3230 OPENINGS AND REINFORCEMENT****WC-3231 General Requirements**

(a) If the fatigue analysis exemption requirements of [WC-3219.1](#) are met, no specific fatigue analysis is required for pressure loadings for locations in the vicinity of openings.

(b) The stress limits of Section III Appendices, Mandatory Appendix XIII may also be considered to be satisfied if, in the vicinity of an opening, the stress intensity resulting from external nozzle loads and thermal effects, including gross but not structural discontinuities, is shown by analysis to be less than  $1.5S_m$ .

(c) The provisions of (a) and (b) above are not intended to restrict the design to any specified section thicknesses or other design details provided the basic stress limits are satisfied. If it is shown by analysis that the stress requirements have been met, the rules of (d) through (g) are waived.

(d) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a containment vessel of the shapes permitted by this Division. If fatigue analysis is not required, the restrictions on hole spacing in [WC-3232.1](#) are applicable, unless there will be essentially no reaction loads at these locations.

(e) All references to dimensions apply to the finished dimensions excluding material added as corrosion allowance. Rules regarding metal available for reinforcement are given in [WC-3235](#).

(f) Any type of opening permitted by these rules may be located in a welded joint.

(g) Nozzles are limited to NPS 2 (DN 50) or smaller and shall be self-reinforcing.

**WC-3232 Reinforcement Requirements for Openings in Shells and Formed Heads****WC-3232.1 Openings Not Requiring Reinforcement.**

The rules for openings not requiring reinforcement are given in (a) through (c) below, where  $R$  is the mean radius and  $t$  is the nominal thickness of the containment shell or head at the location of the opening; and *locally stressed area* means any area in the containment boundary where the primary local membrane stress exceeds  $1.1S_m$ , but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

(a) A single opening has a diameter not exceeding  $0.2\sqrt{Rt}$ , or if there are two or more openings within any circle of diameter,  $2.5\sqrt{Rt}$ , then the sum of the diameters of such unreinforced openings shall not exceed  $0.25\sqrt{Rt}$ .

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the containment wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than  $2.5\sqrt{Rt}$  to the edge of a locally stressed area in the containment boundary.

**WC-3232.2 Required Area of Reinforcement.** The total cross-sectional area of reinforcement  $A$ , required in any given plane for a containment under internal pressure, shall not be less than:

$$A = dt_r F$$

where

$d$  = finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and oblong openings in corroded condition

$F$  = a correction factor that compensates for the variation in pressure stresses on different planes with respect to the axis of containment vessel (a value of 1.00 shall be used for all configurations, except that [Figure WC-3232.2-1](#) may be used for integrally reinforced openings in cylindrical shells

$t_r$  = the thickness that meets the requirements of [WC-3220](#) in the absence of the opening

Not less than half the required material shall be on each side of the centerline.

**WC-3233 Required Reinforcement for Openings in Flat Heads**

Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement  $A$ , not less than that given by the equation:

$$A = 0.5dt_r$$

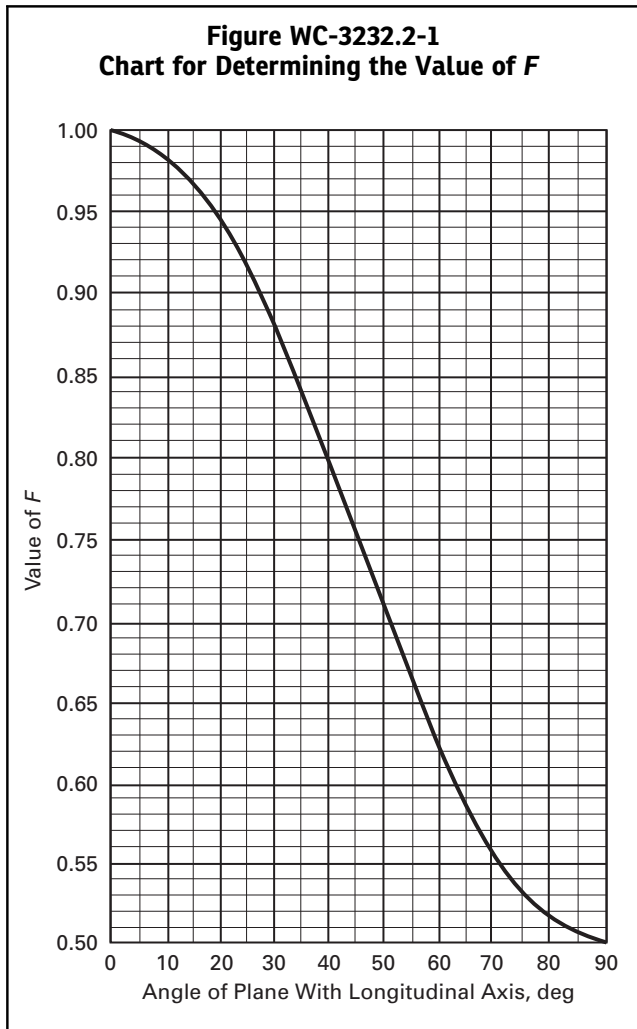
where

$d$  = the diameter as defined in [WC-3232.2](#)

$t_r$  = the thickness that meets the requirements of [WC-3225.2](#) and as defined in [WC-3232.2](#)

**WC-3234 Limits of Reinforcement**

The boundaries of the cross-sectional in any plane normal to the containment wall and passing through the center of the opening within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.



**WC-3234.1 Limits of Reinforcement Along the Containment Wall.** The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the containment, shall meet the following:

(a) 100% of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the containment wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1)  $r + 0.5\sqrt{Rt}$ , where  $R$  is the mean radius of shell or head,  $t$  is the nominal containment wall thickness, and  $r$  is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the containment wall and the nozzle wall.

### WC-3235 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcing called for in WC-3232, provided it lies within the limits of reinforcement specified in WC-3234, and shall be limited to material that meets the following requirements:

(a) metal forming a part of the containment wall, which is in excess of that required by WC-3232 and WC-3233, and is exclusive of corrosion allowance;

(b) weld metal that is fully continuous with the containment weld;

(c) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b) above shall be within 15% of the value of the containment wall material;

(d) metal not fully continuous with the shell, such as that in items attached by partial penetration welds, shall not be counted as reinforcement;

(e) metal available for reinforcement shall not be considered as applying to more than one opening.

### WC-3236 Strength of Reinforcing Material

Material used for reinforcement shall preferably be the same as that of the containment wall. If the material of the wall of the reinforcement has a lower design stress intensity value  $S_m$  than that for the containment material, the amount of area provided by the reinforcement in satisfying WC-3232 or WC-3233 shall be taken as the actual area provided multiplied by the ratio of attachment wall protrusion or reinforcement design stress intensity value to the containment material design stress intensity value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material or for weld metal having higher design stress intensity values than that of the material containment wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

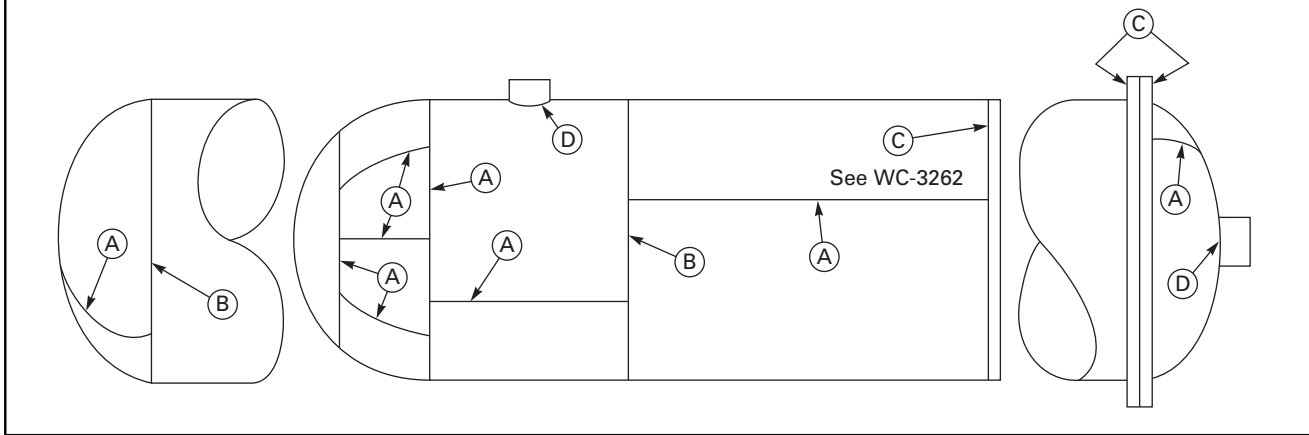
### WC-3250 DESIGN OF WELDED CONSTRUCTION

#### WC-3251 Welded Joint Categories

The term *category* defines the location of a joint in a containment vessel but not the type of joint. The categories are for use in specifying special requirements regarding joint type and method of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure WC-3251-1 illustrates typical joint locations included in each category.

**WC-3251.1 Category A.** Category A comprises longitudinal welded joints within the main shell or nozzles; any welded joint within a sphere within a formed or flat (17)

**Figure WC-3251-1**  
**Welded Joint Locations Typical of Categories A, B, C, and D**



head, or within the side plates of a flat-sided containment; and circumferential welded joints connecting hemispherical heads to main shell or to nozzles.

**WC-3251.2 Category B.** Category B comprises circumferential welded joints within the main shell or nozzles, circumferential welded joints connecting formed heads other than hemispherical to main shells or to nozzles.

**WC-3251.3 Category C.** Category C comprises welded joints connecting flanges to formed heads or flat heads, to main shell, and any welded joint connecting one side plate to another side plate of a flat-sided vessel.

**WC-3251.4 Category D.** Category D comprises welded joints connecting nozzles to main shells, to spheres, to heads, or to flat-sided containments.

### WC-3252 Permissible Types of Welded Joints

The design of the containment shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Figure WC-3251-2 shows typical butt welds for each category joint.

**WC-3252.1 Joints of Category A.** All welded joints of Category A as defined in WC-3251 shall meet the fabrication requirements of WC-4263 and shall be capable of being examined in accordance with WC-5210.

**WC-3252.2 Joints of Category B.** All welded joints of Category B as defined in WC-3251 shall meet the fabrication requirements of WC-4264 and shall be capable of being examined in accordance with WC-5220. When joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used, the suitability for cyclic service shall be analyzed by the method of WC-3219.1 Condition B using a fatigue strength reduction factor of not less than 2.

**WC-3252.3 Joints of Category C.** All welded joints of Category C, except for final closure welds (WC-3262), shall meet the fabrication requirements of WC-4265 and shall be capable of being examined in accordance with WC-5230. Minimum dimensions of welds and throat thickness shall be as shown in Figure WC-4265-1 where

(a) Figure WC-4265-1, sketches (a) and (b)

(1) for forged flat heads and forged flanges with the weld preparation bevel angle not greater than 45 deg. Measured from the face:

$$b = t_s/2 \text{ or } T/4, \text{ whichever is less}$$

$$c = 0.7t_s \text{ or } 1/4 \text{ in. (6 mm), whichever is less}$$

$T, t_s$  = nominal thickness of welded parts

(2) for all other material forms and for forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg. Measured from the face:

$$b = t_s \text{ or } T/2, \text{ whichever is less}$$

$$c = 0.7t_s \text{ or } 1/4 \text{ in. (6 mm), whichever is less}$$

$T, t_s$  = nominal thickness of welded parts

(b) Figure WC-4265-1, sketches (c) and (d)

$$c = 0.7t_s \text{ or } 1/4 \text{ in. (6 mm), whichever is less}$$

$T, t_s$  = nominal thickness of welded parts

(c) Figure WC-4265-1, sketch (e)

$$a + b = \text{not less than } 2t_s$$

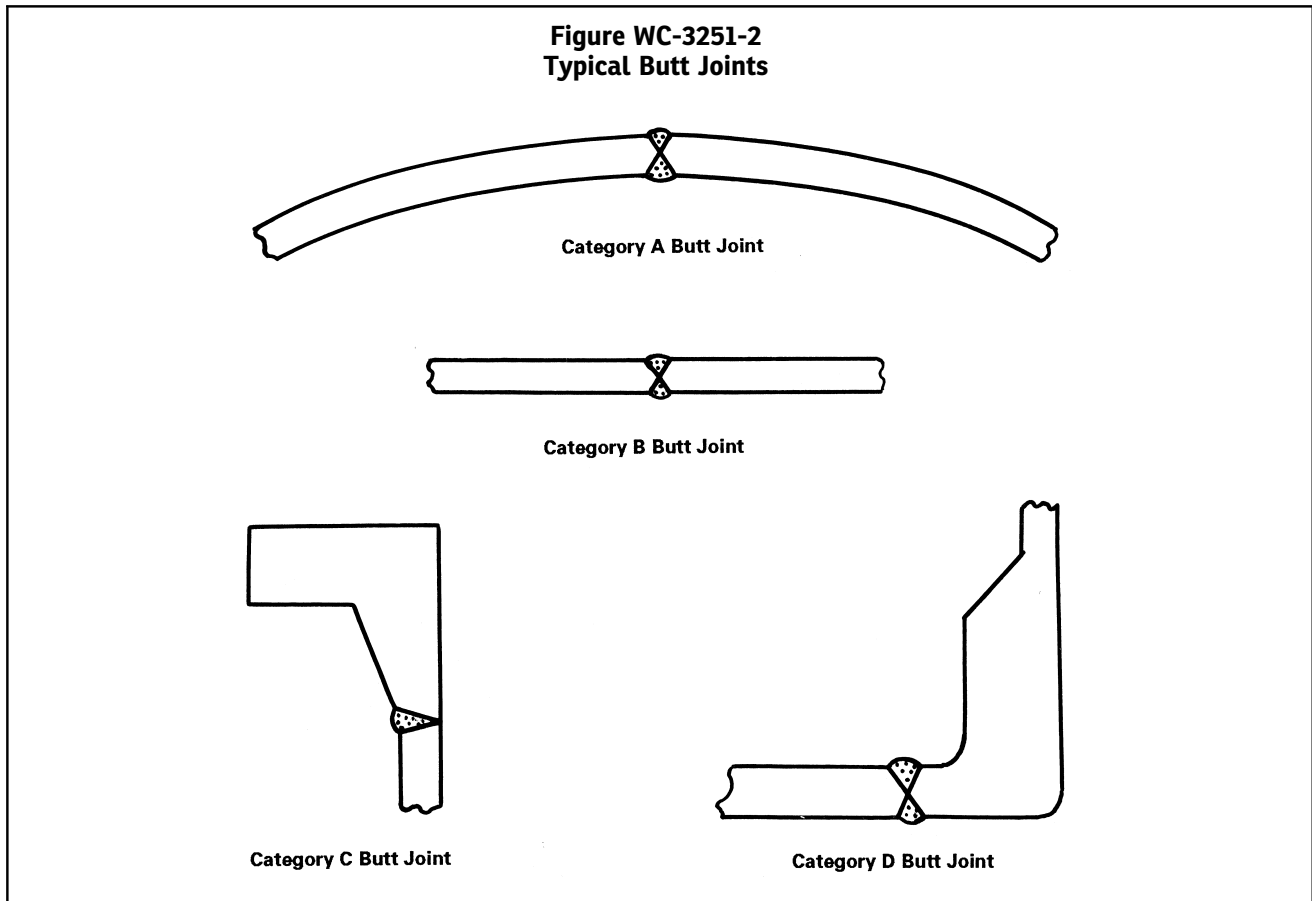
$$b = \text{not less than } t_s$$

$$t_p = \text{not less than } t_s$$

$$t_s = \text{actual thickness of shell}$$

(d) Hubs for butt welding to the adjacent shell, head, or other containment part, as in Figure WC-4265-3, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension

**Figure WC-3251-2  
Typical Butt Joints**



test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical. In [Figure WC-4265-3](#), the minimum dimensions are as follows:

- (1) sketch (a),  $r$  not less than  $1.5t_s$
- (2) sketch (b),  $r$  not less than  $1.5t_s$  and  $e$  not less than  $t_s$
- (3) sketch (c),  $r$  not less than  $1.5t_s$
- (4) sketch (d),  $t_f$  not less than  $2t_s$  and  $r$  not less than  $3t_f$
- (5) sketch (e),  $t_f$  not less than  $2t_s$ ,  $r$  not less than  $3t_f$ , and  $e$  not less than  $t_f$

**WC-3252.4 Joints of Category D.** All welded joints of Category D, as defined in [WC-3251](#), shall be in accordance with the requirements of (a) through (e).

(a) *Butt-Welded Nozzles.* Nozzles shall meet the fabrication requirements of [WC-4266\(a\)](#) and shall be capable of being examined in accordance with [WC-5242](#). The minimum dimensions and geometrical requirements of [Figure WC-4266\(a\)-1](#) shall be met, where

$$r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less}$$

$$r_2 = \frac{1}{4} \text{ in. (6 mm) min.}$$

$t$  = nominal thickness of part penetrated  
 $t_n$  = nominal thickness of penetrating part

(b) *Full Penetration Corner-Welded Nozzles.* Nozzles shall meet the fabrication requirements of [WC-4266\(b\)](#) and shall be capable of being examined in accordance with [WC-5243](#). The minimum dimensions and geometrical requirements of [Figure WC-4266\(b\)-1](#) shall be met, where

$$r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less}$$

$$r_2 = \frac{1}{4} \text{ in. (6 mm) min.}$$

$t$  = nominal thickness of part penetrated  
 $t_c = 0.7t_n \text{ or } \frac{1}{4} \text{ in. (6 mm), whichever is less}$   
 $t_n$  = nominal thickness of penetrating part

(c) *Use of Deposited Weld Metal for Openings and Nozzles.*

(1) Nozzles shall meet the fabrication requirements of [WC-4266\(c\)](#) and shall be capable of being examined in accordance with [WC-5244](#).

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the connection shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of [Figure WC-4266\(c\)-1](#) shall be met, where

$$r_1 = \frac{1}{4}t \text{ or } \frac{3}{4} \text{ in. (19 mm), whichever is less}$$

$t$  = nominal thickness of part penetrated  
 $t_c = 0.7t_n$  or  $1/4$  in. (6 mm), whichever is less  
 $t_n$  = nominal thickness of penetrating part

(4) The corners of the end of each connection extending less than  $\sqrt{dt_n}$  beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness  $t_n$  of the connection or  $3/4$  in. (19 mm), whichever is smaller.

(d) *Fittings With Internal Threads.* Internally threaded fittings shall be limited to NPS 2 (DN 50). Internally threaded fittings shall be attached by means of full penetration groove welds meeting the fabrication requirements of WC-4266(d) and shall be capable of being examined in accordance with WC-5245. The minimum dimensions and geometrical requirements of Figure WC-4266(d)-1 shall be met, where

$t_c = 0.7 t_n$  or  $1/4$  in. (6 mm), whichever is less  
 $t_n$  = nominal thickness of neck

(e) *Attachment of Nozzles Using Partial Penetration Welds.* Partial penetration welds shall meet the fabrication requirements of WC-4266(e) and shall be capable of being examined in accordance with WC-5245. They shall be used only for attachments such as instrumentation openings and inspection openings, which are subjected to essentially no external mechanical loadings and on which there will be no thermal stresses greater than those on the containment itself. Such attachments shall satisfy the requirements of WC-3231(g).

#### WC-3254 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of WC-4432.

#### WC-3255 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in WC-3252.4 or WC-3262.

#### WC-3259 Design Requirements for Nozzle Attachment Welds and Other Connections

The minimum design requirements for nozzle attachment welds and other connections are set forth in (a) and (b) below.

(a) *Permitted Types of Nozzles and Other Connections.* Nozzles and other connections may be any of the types for which rules are given in this subarticle, provided the requirements of (1) through (5) below are met.

(1) Nozzles shall meet requirements regarding location.

(2) The attachment weld shall meet the requirements of WC-3252.4.

(3) The requirements of WC-3230 shall be met.

(4) Type No. 1 full penetration joints shall be used when the openings are in shells  $2\frac{1}{2}$  in. (64 mm) or more in thickness.

(5) The welded joints shall be examined by the methods stipulated in WC-5240.

(b) *Attachments.* Typical attachments are shown in Figure WC-4433-2. The minimum dimensions in this figure are as follows:

$$a \geq t/4$$

$$b \geq t/2$$

$$c \geq t$$

where

$c$  = minimum thickness of weld metal from the root to the face of the weld

$t$  = thickness of attached member

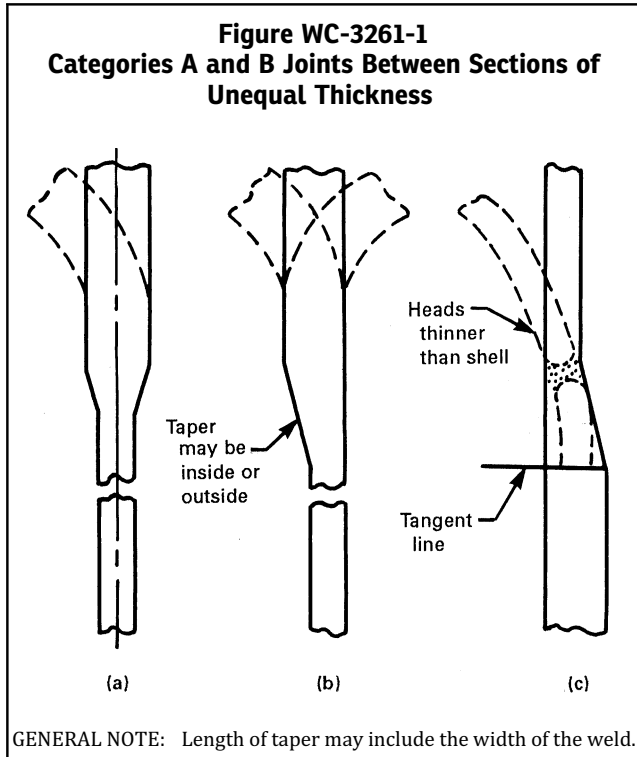
#### WC-3260 SPECIAL CONTAINMENT REQUIREMENTS

##### WC-3261 Category A or B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Figure WC-3261-1, shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head that has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter. A uniform taper is not required for flanged hubs. The adequacy of the transition shall be evaluated by stress analysis. Stress intensity limitations are given in Section III Appendices, Mandatory Appendix XIII. The requirements of this paragraph do not apply to flanged hubs.

##### WC-3262 Category C Full and Partial Penetration Closure Welds in Containments

**WC-3262.1** Welds in the end closures using a single cover plate [Figure WC-4265-3, sketch (a)] and made after the containment is loaded may be full or partial penetration and shall be examined in accordance with Table WC-3262-1 either by magnetic particle or liquid penetrant method. The allowable stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 shall be reduced by the stress reduction factor provided in Table WC-3262-1. The welds shall be tested in accordance with WC-6720.



**WC-3262.2** For welds in the end closures using two cover plates [Figure WC-4265-3, sketch (b)] and made after the containment is loaded, the following apply:

(a) The inner cover plate weld shall use a design stress reduction factor of 0.9. The root and final layers shall be examined by the liquid penetrant or magnetic particle method in accordance with Article WC-5000, and shall be tested in accordance with WC-6720.

(b) The outer cover plate weld shall use the stress reduction factors of Table WC-3262-1 and shall be examined to the requirements of Table WC-3262-1.

**WC-3262.3** Vent and drain cover plate welds may be full penetration welds examined in accordance with WC-5250 partial penetration welds using the examination and stress reduction factors of Table WC-3262-1.

**WC-3262.4** For partial penetration closure welds, a fatigue strength reduction factor of not less than 4.0 shall be used when fatigue analysis is required.

### WC-3700 STRAIN-BASED ACCEPTANCE CRITERIA

The strain-based acceptance criteria are applicable only to the metallic portions of storage containments subject to energy-limited dynamic events. It is not the intent of this subarticle to permit significant regions or major portions of the containment to experience strains at or near the limits of these strain-based acceptance criteria without consideration of the overall component deformation. These strain-based acceptance criteria are established to address the regions of the containment that experience high strains due to the effects of direct impacts. Deformation limits, if any, provided in the Design Specification shall be satisfied.

Section III Appendices, Nonmandatory Appendix FF provides the strain-based acceptance criteria.

<b>Table WC-3262-1</b> <b>Stress Reduction Factors and Examinations for Closure Welds</b>	
Examination Requirements [Note (1)]	Stress Reduction Factors
Volumetric Examination	1.00
Liquid Penetrant or Magnetic Particle Examination: Root and each successive 1/4 in. (6 mm) of weld thickness and the final layer	0.90
Liquid Penetrant or Magnetic Particle Examination: Root, mid, and final layer [Note (2)]	0.80
NOTES:	
(1) All examinations shall be performed and accepted to the requirements of Article WC-5000.	
(2) Mid layer is defined as approximately one-half of the maximum weld thickness.	



# ARTICLE WC-4000 FABRICATION

## WC-4100 GENERAL REQUIREMENTS

### WC-4110 INTRODUCTION

Containments and parts shall be fabricated and installed in accordance with the rules of this Article and shall be manufactured from materials that meet the requirements of [Article WC-2000](#).

### WC-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY CERTIFICATE HOLDER

#### WC-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Certification Mark and completion of the appropriate Data Report in accordance with [Article WA-8000](#), that the materials used comply with the requirements of [Article WC-2000](#) and that the fabrication or installation complies with the requirements of this Article.

- (17) **WC-4121.1 Certification of Treatments, Tests, and Examinations.** If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other paragraphs of this Article, the Certificate Holder shall certify that this requirement has been fulfilled ([WA-3800](#) or [WA-8410](#)). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

**WC-4121.2 Repetition of Tensile or Impact Tests.** If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons ([WC-2200](#)) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of [Article WC-2000](#).

**WC-4121.3 Repetition of Surface Examination After Machining.** During the fabrication or installation of an item, if containment materials are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with [WC-2500](#) when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with [WC-2500](#); and

(b) the amount of material removed from the surface exceeds the lesser of  $\frac{1}{8}$  in. (3 mm) or 10% of the minimum required thickness of the part.

### WC-4122 Materials Identification

(a) Material for performing a containment function shall carry identification markings which will remain distinguishable until the containment is assembled. If the original identification markings are cut off or the material is divided, either the marks shall be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, when applicable, and the coded marking. For studs, bolts, and nuts it is permissible to identify the Certified Material Test Reports for material in each containment in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance and welding and brazing materials shall be identified and controlled so that they can be traced to each containment or else a control procedure shall be used that ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be remarked upon establishing positive identification.

**WC-4122.1 Marking Materials.** Material shall be marked in accordance with [WC-2150](#).

### WC-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of [Article WC-4000](#), may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to [WC-5100](#) and [WC-5500](#), respectively, unless so specified.

### WC-4124 Additional Requirements When Strain-Based Acceptance Criteria Have Been Implemented

In order to satisfy the strain-based acceptance criteria of WC-3700 regarding the locations of unique material heats used in containment fabrication, traceability of all unique material heats and their specific location(s) of use shall be established and documented in the final Design Report and the as-built Design Drawings. This requirement is only necessary when strain-based acceptance criteria have been employed in the design of the containment.

### WC-4125 Testing of Welding and Brazing Materials

All welding and brazing materials shall meet the requirements of WC-2400.

## (17) WC-4130 REPAIR OF MATERIAL

Material originally accepted on delivery in which defects exceeding the limits of WC-2500 are known or discovered during the process of fabrication is unacceptable. The material may be used, provided the condition is corrected in accordance with the requirements of WC-2500 for the applicable product form, except that:

(a) the limitation on the depth of the weld repair does not apply;

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with WC-5130;

(c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is  $\frac{1}{4}$  in. (6 mm) or less.

(d) When the repair by welding provisions of WC-2539 are used within  $\frac{1}{2}$  in. (13 mm) on each side of the final closure welds, on canisters that are loaded with spent fuel or high-level radioactive material, progressive examination of each deposited weld layer by the magnetic particle method (WC-2545) or liquid penetrant method (WC-2546), in addition to a final surface examination, may be substituted for the radiographic examination required by WC-2539.4. The thickness of each layer shall not exceed  $\frac{1}{4}$  in. (6 mm).

### WC-4200 FORMING, CUTTING, AND ALIGNING

#### WC-4210 CUTTING, FORMING, AND BENDING

##### WC-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

**WC-4211.1 Preheating Before Thermal Cutting.** When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to

preheating the material, using preheat schedules such as suggested in Section III Appendices, Nonmandatory Appendix D.

### WC-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend containment materials, including weld metal, provided the required dimensions are attained (see WC-4214 and WC-4220), and provided the impact properties of the materials, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (55°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in WC-4213.

### WC-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications, a procedure qualification test shall be conducted using specimens taken from materials of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component. Applicable tests shall be conducted to determine that the required impact properties of WC-2300 are met after straining.

**WC-4213.1 Exemptions.** Procedure qualification tests are not required for material listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed materials represented by test coupons required in either WC-2211 or WC-4121.2 that have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) materials which do not require impacts in accordance with WC-2300;

(d) materials which have a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing required by WC-2300 is performed on each heat and lot, as applicable, after forming.

**WC-4213.2 Procedure Qualification Test.** The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material, both before straining and after straining and heat treatment, to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of [Article WC-2000](#) and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

(1) For cylinders

$$\% \text{ strain} = \frac{50t}{R_f} \left( 1 - \frac{R_f}{R_o} \right)$$

(2) For spherical or dished surfaces

$$\% \text{ strain} = \frac{75t}{R_f} \left( 1 - \frac{R_f}{R_o} \right)$$

(3) For pipe

$$\% \text{ strain} = \frac{100r}{R}$$

where

$R$  = nominal bending radius to the center line of the pipe

$R_f$  = final radius to center line of shell

$R_o$  = original radius (equal to infinity for a flat part)

$r$  = nominal radius of the pipe

$t$  = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient  $C_V$  test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both the lateral expansion and energy level data ([WC-2300](#)). In addition, drop weight tests shall be made when required by [WC-2300](#).

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(-a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(-b) the maximum change in temperature at the lateral expansion and energy levels under consideration; or

(2) where lateral expansion is the acceptance criteria ([WC-2300](#)), either the maximum change in temperature or the maximum change in lateral expansion.

**WC-4213.3 Acceptance Criteria for Formed Material.** To be acceptable, the formed material used in the component shall have impact properties, before forming, sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

**WC-4213.4 Requalification.** A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering [WC-2211](#). If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Where preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

## WC-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of [WC-2124](#) and [Article WC-3000](#), the material may be repaired in accordance with [WC-4130](#).

## WC-4220 FORMING TOLERANCES

### WC-4221 Tolerance for Containment Shells

Cylindrical, conical, or spherical shells of a completed containment, except formed heads covered by [WC-4222](#), shall meet the requirements of the following subparagraphs at all cross sections.

**WC-4221.1 Maximum Difference in Cross-Sectional Diameters.** (17) The difference in inches (mm) between the maximum and minimum diameters at any cross-section shall not exceed the smaller of

(U.S. Customary Units)

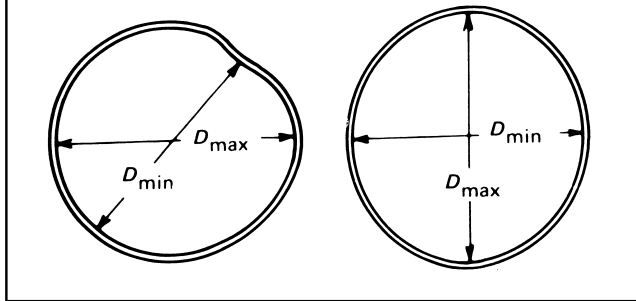
$$\frac{D + 50}{200} \quad \text{and} \quad \frac{D}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \quad \text{and} \quad \frac{D}{100}$$

where  $D$  is the nominal inside diameter, in. (mm), at the cross section under consideration. The diameters may be measured on the inside or outside of the containment. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration ([Figure WC-4221.1-1](#)). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening.

**Figure WC-4221.1-1**  
**Maximum Difference in Cross-Sectional**  
**Diameters**



**WC-4221.2 Maximum Deviation From True Theoretical Form for External Pressure.** Containments designed for external pressure shall meet the tolerances given in (a) through (e) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the containment, shall not exceed the maximum permissible deviation obtained from Figure WC-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Figure WC-4221.2(a)-2. For Figure WC-4221.2(a)-1, the maximum permissible deviation  $e$  need not be less than  $0.3t$ . For Figure WC-4221.2(a)-2, the arc length need not be greater than  $0.30D_o$ . Measurements shall not be taken on welds or other raised parts.

(b) The value of  $t$ , in. (mm), at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of  $L$  in Figures WC-4221.2(a)-1 and WC-4221.2(a)-2 is determined by (1) and (2) below.

(1) For cylinders,  $L$  is as given in WC-3133.2.

(2) For spheres,  $L$  is one-half of the outside diameter  $D_o$ , in. (mm).

(d) The dimensions of a completed containment may be brought within the requirements by any process which will not impair the strength of the material.

(e) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

**WC-4221.3 Deviations From Tolerances.** Deviations from the tolerance requirements stipulated in WC-4221.1 and WC-4221.2 are permitted, provided the drawings are modified and reconciled with the design calculations.

**WC-4221.4 Tolerance Deviations for Containment Parts Fabricated From Pipe.** Containment parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

**WC-4221.5 Localized Thin Areas.** Localized thin areas are permitted if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in WC-3232.2.

## WC-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

**WC-4222.1 Maximum Difference in Cross-Sectional Diameters.** The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches (mm) between the maximum and minimum diameters does not exceed the lesser of

(U.S. Customary Units)

$$\frac{D + 50}{200} \quad \text{and} \quad \frac{D + 12}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \quad \text{and} \quad \frac{D + 300}{100}$$

where  $D$  is the nominal inside diameter, in. (mm), and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in WC-4232.

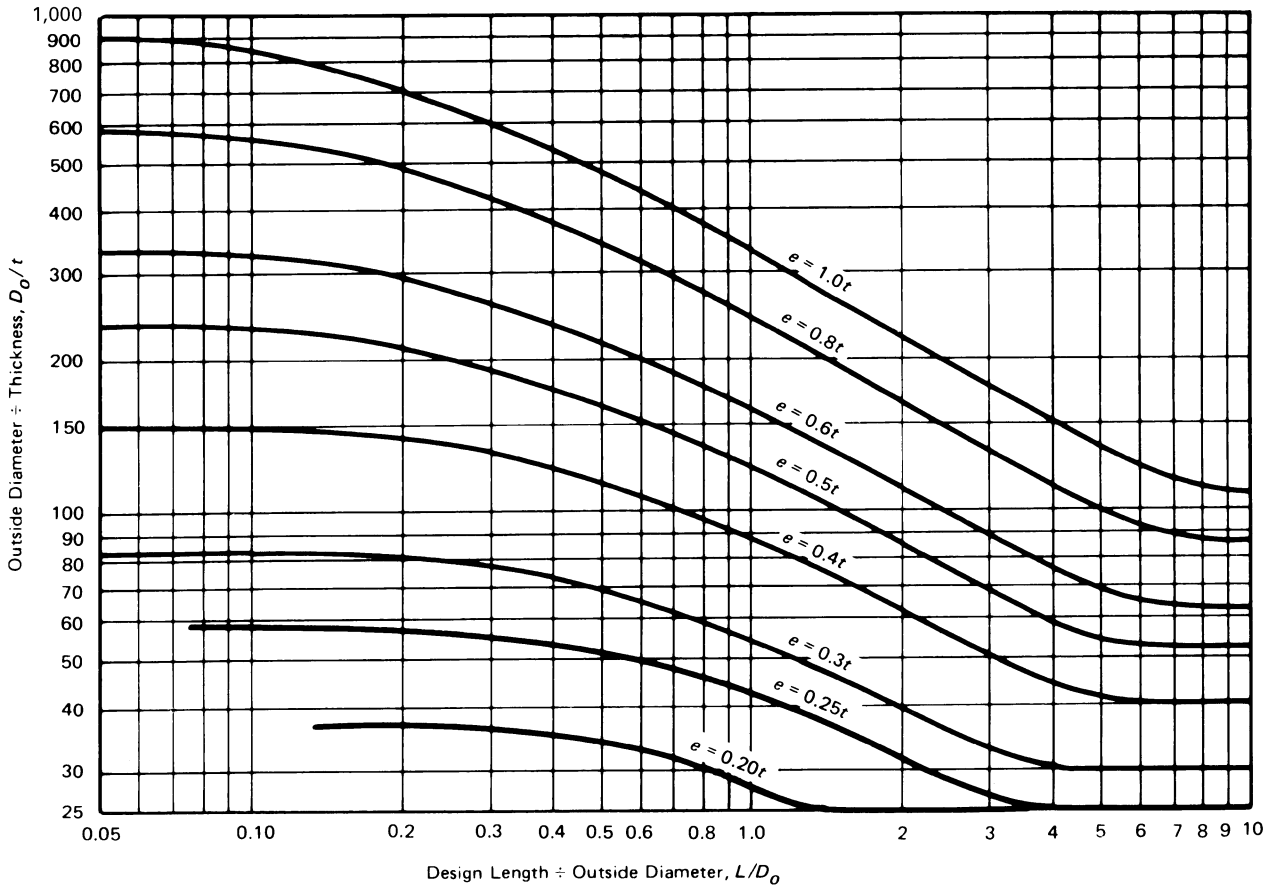
### WC-4222.2 Deviation From Specified Shape.

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than  $1\frac{1}{4}\%$  of  $D$ , nor inside the specified shape by more than  $\frac{5}{8}\%$  of  $D$ , where  $D$  is nominal inside diameter of the containment. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the containment.

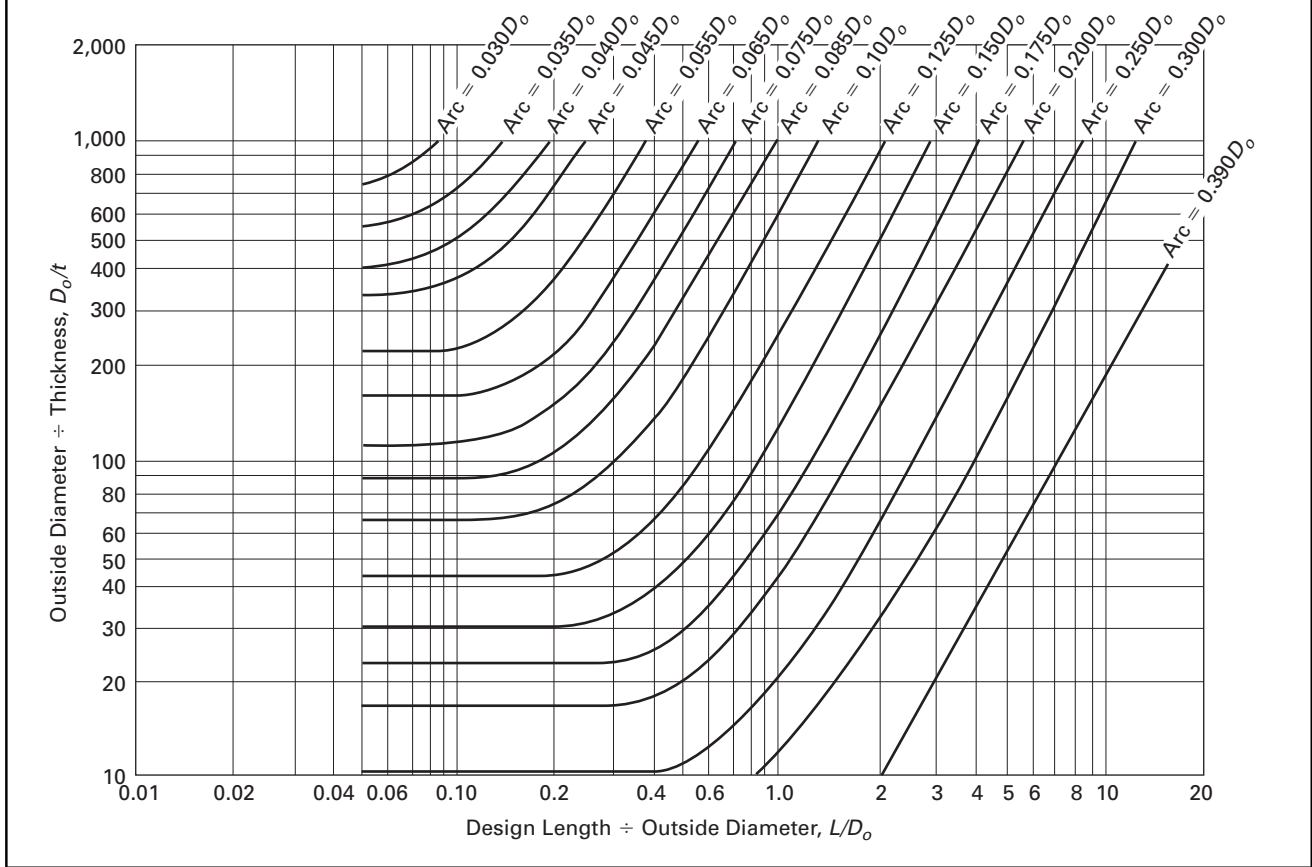
(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in WC-4221.2, using  $L$  as the outside spherical radius in inches (mm) and  $D_o$  as 2 times  $L$ .

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

**Figure WC-4221.2(a)-1**  
**Maximum Permissible Deviation  $e$  From a True Circular Form**



**Figure WC-4221.2(a)-2  
Maximum ARC Length for Determining Plus or Minus Deviation**



**WC-4230 FITTING AND ALIGNING**

**WC-4231 Fitting and Aligning Methods**

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

**WC-4231.1 Tack Welds.** Tack welds used to secure alignment shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

**WC-4232 Alignment Requirements When Components Are Welded From Two Sides**

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in [Table WC-4232\(a\)-1](#), where  $t$  is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical containments, joints within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in [Table WC-4232\(a\)-1](#) for longitudinal joints.

**WC-4232.1 Fairing of Offsets.** Any offset within the allowable tolerance provided above shall be faired to at least 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.



**Table WC-4232(a)-1  
Maximum Allowable Offset in Final Welded  
Joints**

Section Thickness, in. (mm)	Direction of Joints	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$ (13), incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$ (13 to 19), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{3}{16}$ in. (5 mm)
Over $1\frac{1}{2}$ to 2 (38 to 50), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{8}t$
Over 2 (50)	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in. (10 mm)	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ in. (19 mm)

### WC-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with WC-4232, alignment of sections shall meet the requirements of (1) and (2) below.

(1) See (-a) and (-b) below.

(-a) For circumferential joints the inside diameters shall match each other within  $\frac{1}{16}$  in. (1.5 mm). When the items are aligned concentrically, a uniform mismatch of  $\frac{1}{32}$  in. (0.8 mm) all around the joint can result, as shown in Figure WC-4233-1 sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed  $\frac{3}{32}$  in. (2.5 mm), as shown in Figure WC-4233-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variation which does not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided a gradual change in thickness from the item to adjoining items is maintained. Any welding transition is acceptable provided the wall thickness in the transition region is not less than the minimum wall thickness of the component or item and sharp reentrant angles and abrupt changes in slope in the transition region are avoided.

(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed  $\frac{3}{32}$  in. (2.5 mm), and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single-welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of WC-4232.

### WC-4260 REQUIREMENTS FOR WELD JOINTS IN CONTAINMENTS

#### WC-4262 Description and Limitations of Joint Types

The description of the joint types are as follows:

(a) *Type No. 1 Butt Joints.* Type No. 1 butt joints are those produced by double welding or by other means which produce the same quality of deposited weld metal on both inside and outside weld surfaces. Welds using backing strips which remain in place do not qualify as Type No. 1 butt joints. Type No. 1 butt joints shall have complete joint penetration and full fusion and shall meet the requirements of WC-4424 and WC-4426.

(b) *Type No. 2 Butt Joints.* Type No. 2 butt joints are single-welded butt joints having backing strips which remain in place. WC-3252.2 gives stress concentration factors to be applied to Type No. 2 joints when a fatigue analysis is required. When Type No. 2 butt joints are used, care shall be taken on aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joints for their full length. However, weld reinforcement need be supplied only on the side opposite the backing strip. The requirements of WC-4424 and WC-4426 shall be met.

(c) *Full Penetration Corner Joints.* Corner joints are those connecting two members approximately at right angles to each other in the form of an L or T and shall be made with full penetration welds (WC-3252.3). Type No. 1 corner-welded joints have full penetration welds that penetrate through the thickness of the shell [Figure WC-4265-1, sketches (a) and (b)]. Type No. 2 corner-welded joints have a full penetration weld that penetrates through the thickness of the head [Figure WC-4265-1, sketches (c), (d), and (e)].

(d) *Fillet Welded Joints.* Fillet welded joints, permitted by the rules of this subarticle, are those of approximately triangular cross section, joining two surfaces at approximately right angles to each other and having a throat dimension at least 70% of the smaller thickness of the parts being joined but not less than  $\frac{1}{4}$  in. (6 mm).

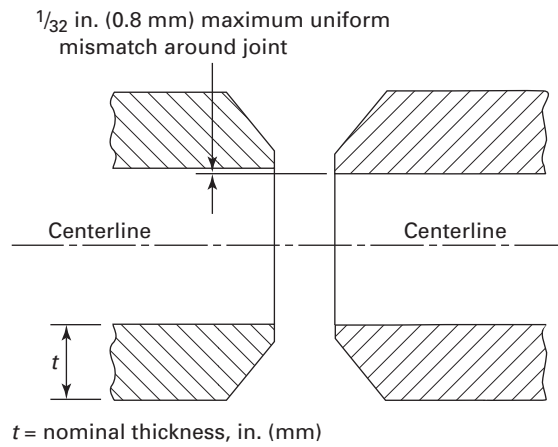
#### WC-4263 Category A Weld Joints

Category A weld joints shall be Type No. 1 butt joints.

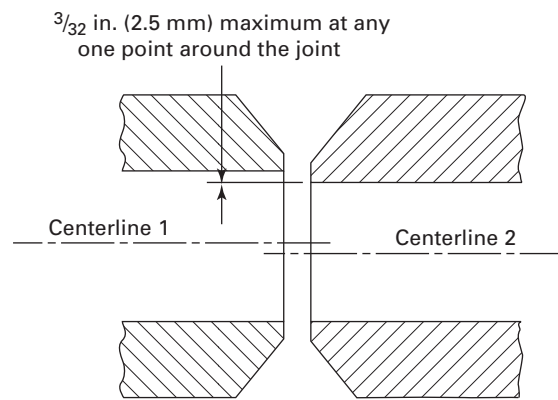
#### WC-4264 Category B Weld Joints

Category B weld joints shall be Type No. 1 or Type No. 2 butt joints. Backing strips shall be removed from Type No. 2 joints unless access conditions prevent their removal. Backing strips shall be continuous, and any splices shall be butt welded. Circumferential single-welded butt joints with one plate offset to form a backing strip are prohibited.

**Figure WC-4233-1**  
**Butt Weld Alignment and Mismatch Tolerances for Unequal I.D. and O.D. When Items Are Welded From One Side and Faying Is Not Performed**



**(a) Concentric Centerlines**



**(b) Offset Centerlines**

(17) **WC-4265 Category C Weld Joints**

Category C weld joints shall be as described in subparagraphs (a) through (d) below.

(a) *Full Penetration Butt Joints.* Category C welds shall be Type No. 1 or Type No. 2 butt joints.

(b) *Full Penetration Corner Joints.* Welds in full penetration corner joints shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Typical details for type No. 1 and No. 2 full penetration corner joints are shown in [Figure WC-4265-1](#).

(c) *Partial Penetration Closure Joints.* Partial penetration joints are acceptable for flat head closure welds (per [WC-3262](#)). Typical details are shown in [Figure WC-4265-2](#).

(d) *Flat Heads With Hubs*

(1) Hubs for butt welding to the adjacent shell, head, or other containment parts, as shown in [Figure WC-4265-3](#), for flat heads, shall not be machined from flat plate. The hubs shall be forged in such a manner as to provide in the hub the full minimum tensile strength and

elongation specified for the material in the direction parallel to the axis of the containment vessel. Proof of this shall be furnished by a tension test specimen (subsize, if necessary) taken in this direction and as close to the hubs as is practical. One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat material and the same heat treatment lot, and forged in the same manner. The minimum height of the hub shall be the lesser of  $1\frac{1}{2}$  times the thickness of the containment part to which it is welded or  $\frac{3}{4}$  in. (19 mm), but need not be greater than 2 in. (50 mm).

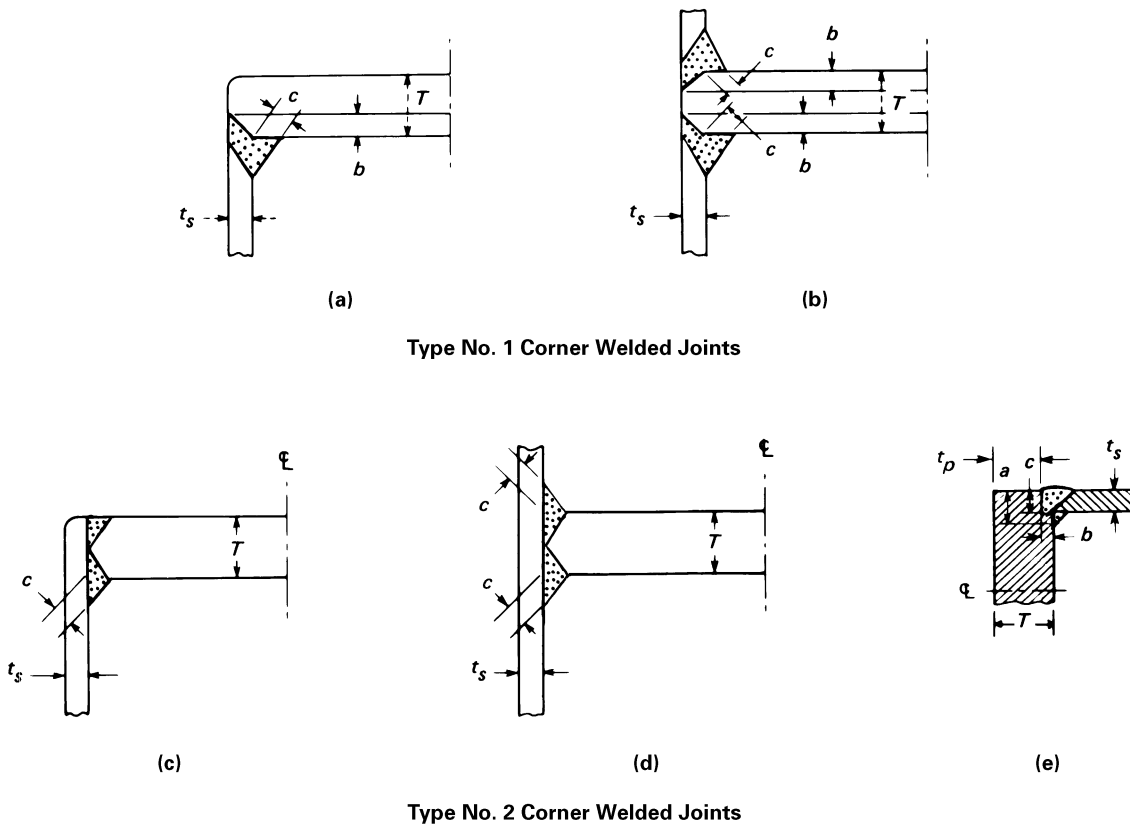
(2) Hubbed flanges shall not be machined from flat plate.

**WC-4266 Category D Weld Joints**

Category D and similar weld joints shall be welded using one of the details of (a) through (e) below.

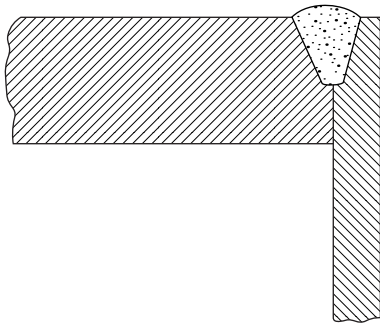
(a) *Butt-Welded Attachments.* Nozzles shall be attached by Type No. 1 butt welds through either the containment or the nozzle wall as shown in [Figure WC-4266\(a\)-1](#).

**Figure WC-4265-1**  
**Acceptable Full Penetration Weld Details for Category C Joints**

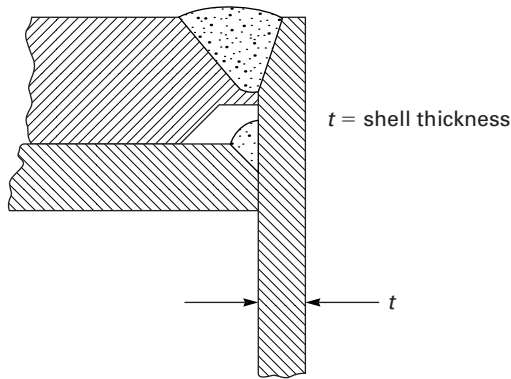


GENERAL NOTE: For definitions of nomenclature, see [WC-3252.3](#).

**Figure WC-4265-2**  
**Typical Partial Penetration Weld Detail for**  
**Category C Flat Head Closure Joints**



(a) Single Closure Weld Detail



(b) Double Closure Weld Detail

(b) *Full Penetration Corner-Welded Attachments.* Nozzles shall be attached by full penetration welds through the wall of the containment or nozzle as shown in [Figure WC-4266\(b\)-1](#). The welds shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Backing strips shall be used with welds deposited from only one side or when complete joint penetration cannot be verified by visual inspection. Backing strips, when used, shall be removed after welding.

(c) *Use of Deposited Weld Metal for Openings and Nozzles.* Weld metal may be deposited on the containment or nozzle prior to making the full penetration weld as shown in [Figure WC-4266\(c\)-1](#).

(d) *Fittings With Internal Threads.* Internally threaded fittings shall be limited to NPS 2 (DN 50). They shall meet the requirements of [WC-3252.4\(d\)](#) and be attached by full penetration groove welds as illustrated in [Figure WC-4266\(d\)-1](#) sketches (a), (b), and (c).

(e) *Attachment of Nozzles Using Partial Penetration Welds.* Partial penetration welds are limited by the restrictions of [WC-3252.4\(e\)](#). The weld size shall be such that the depth of penetration  $t_w$  will be at least  $1\frac{1}{4}t_n$ . Typical details are shown in [Figure WC-4266\(e\)-1](#).

### WC-4267 Types of Attachment Welds

Structural attachments shall be attached to containments by continuous or intermittent welds.

## WC-4300 WELDING QUALIFICATIONS

### WC-4310 GENERAL REQUIREMENTS

#### WC-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding containments or attachments thereto. Any process used shall be such that the records required by [WC-4320](#) can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

**WC-4311.1 Stud Welding Restrictions.** Stud welding is acceptable only for nonstructural and temporary attachments ([WC-4435](#)). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and  $\frac{3}{4}$  in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with [WC-4600](#), except that time at temperature need not exceed  $\frac{1}{2}$  hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

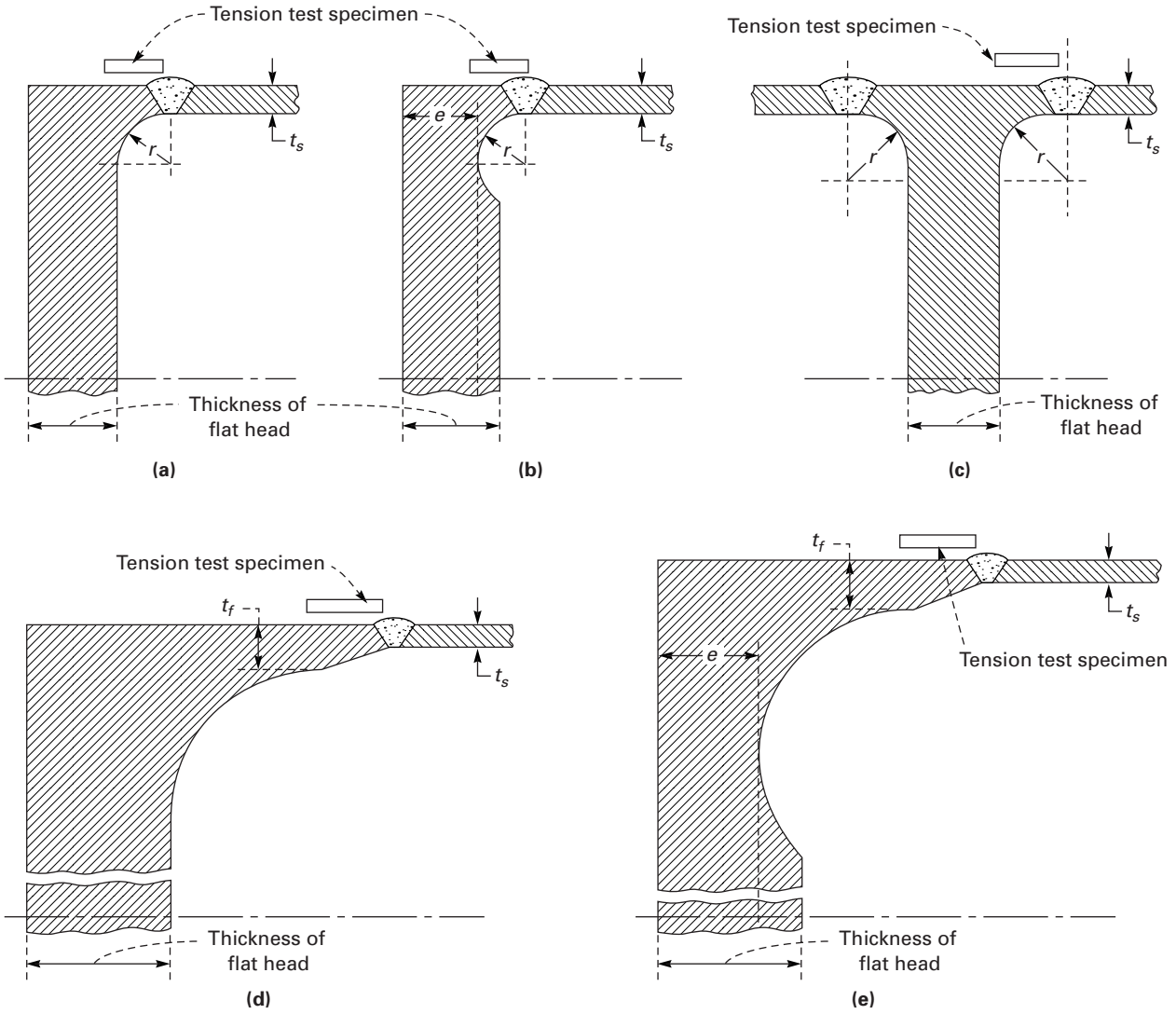
**WC-4311.2 Capacitor Discharge Welding.** Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

(a) temporary attachments are removed in accordance with the provisions of [WC-4435\(b\)](#);

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2 mm); and

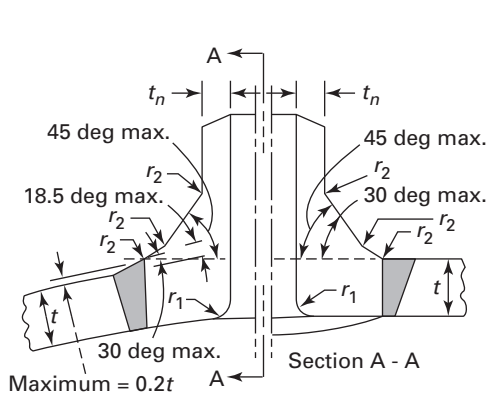
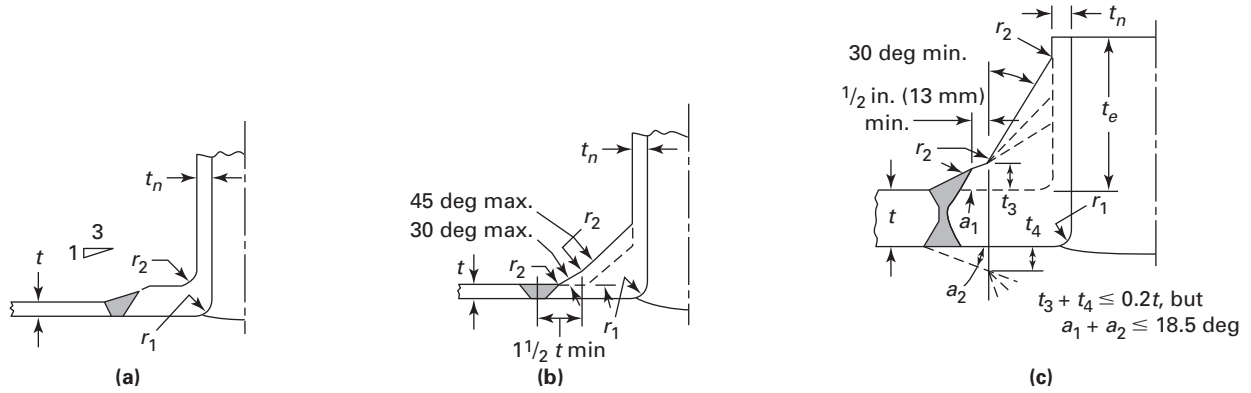
(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

**Figure WC-4265-3  
Typical Flat Heads**



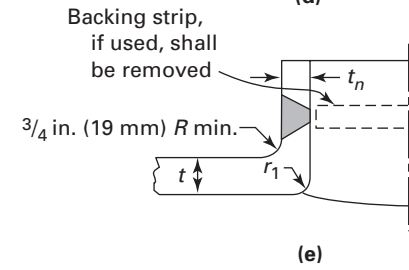
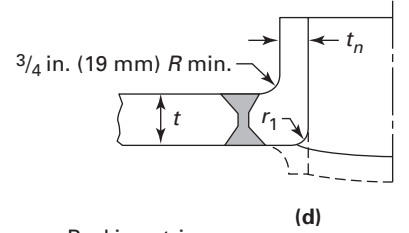
GENERAL NOTE: For definition of nomenclature, see [WC-3225](#).

**Figure WC-4266(a)-1  
Nozzles Attached by Full Penetration Butt Welds**



Sections perpendicular and parallel to the containment's cylindrical axis

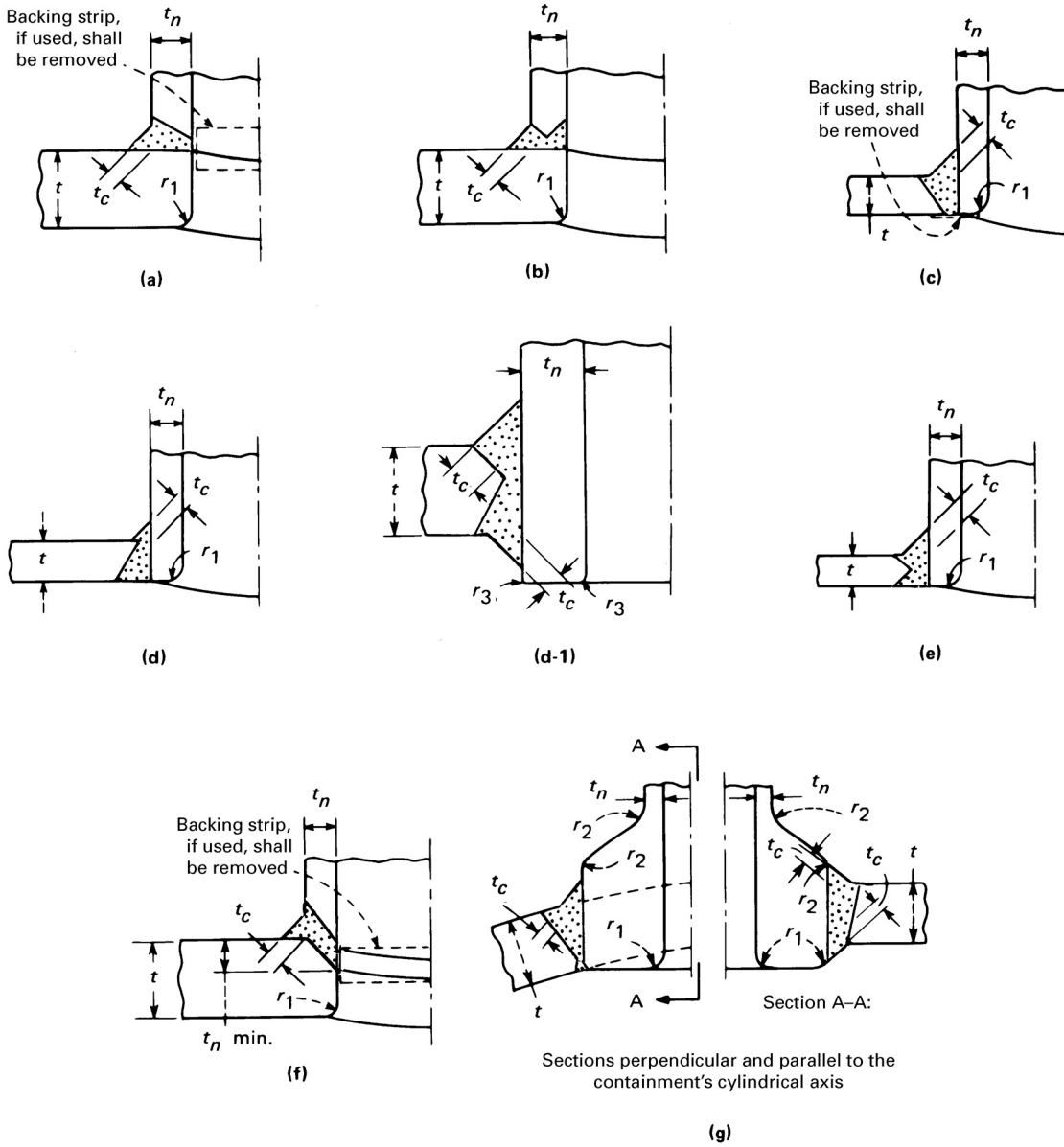
(c - 1)



GENERAL NOTE: For definitions of nomenclature, see [WC-3252.4\(a\)](#).

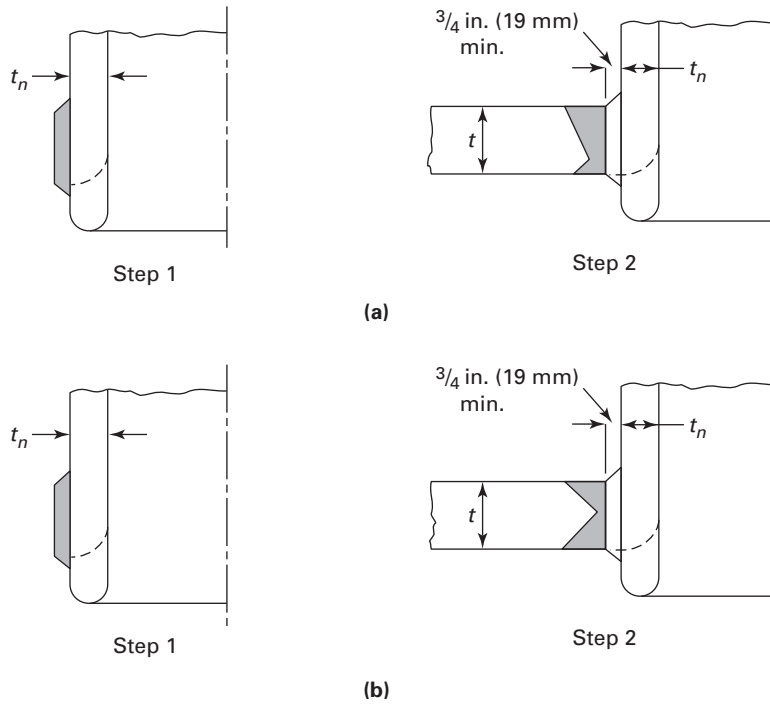


**Figure WC-4266(b)-1**  
**Full Penetration Corner-Welded Attachments**



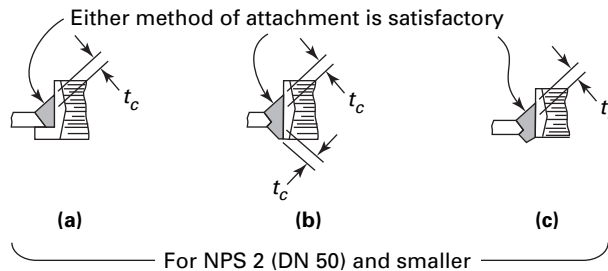
GENERAL NOTE: For definitions of nomenclature, see [WC-3252.4\(b\)](#).

**Figure WC-4266(c)-1  
Deposited Weld Metal Used as Reinforcement of Openings for Nozzles**



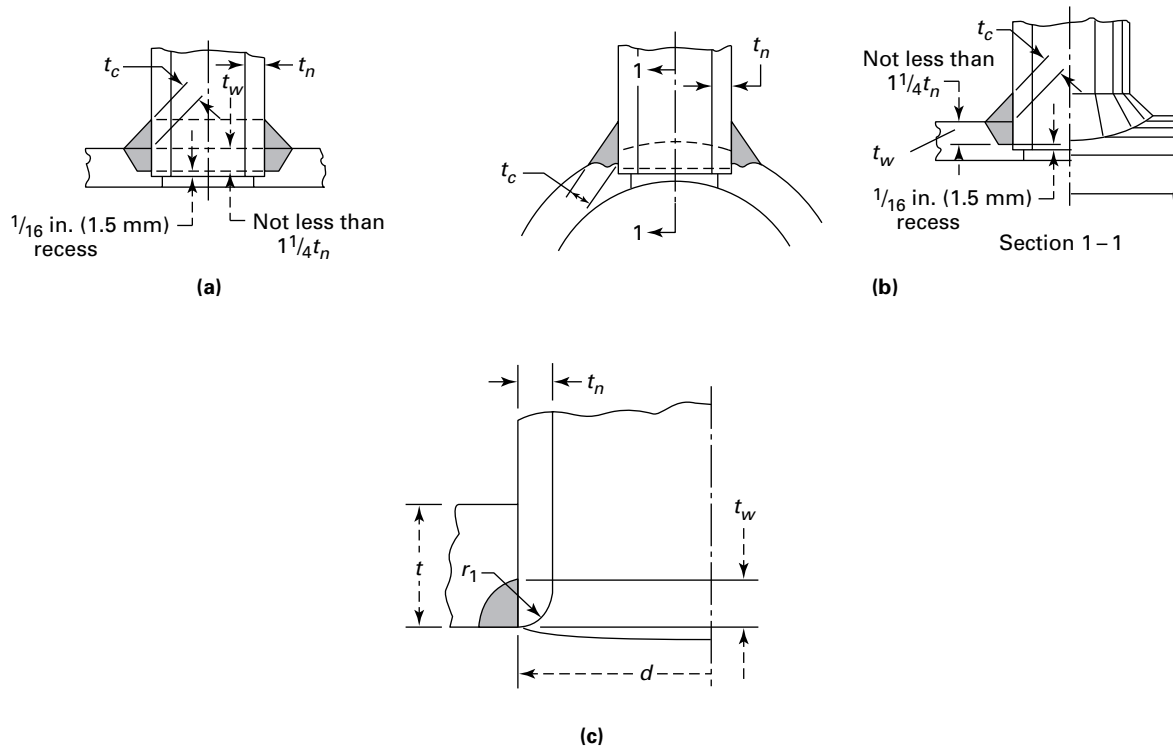
GENERAL NOTE: For definitions of nomenclature, see [WC-3252.4\(c\)](#).

**Figure WC-4266(d)-1  
Fittings With Internal Threads**



GENERAL NOTE: For definitions of nomenclature, see [WC-3252.4\(d\)](#).

**Figure WC-4266(e)-1**  
**Partial Penetration Weld Connections**



GENERAL NOTE: For definitions of nomenclature, see [WC-3252.4\(e\)](#).

### WC-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

#### WC-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization, and he shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to containments and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

### WC-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program and shall be available to the Authorized Nuclear Inspector.

#### WC-4322.1 Identification of Joints by Welder or Welding Operator.

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, weld metal cladding, and hard surfacing welds are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) Welder or welding operator identification is not required for tack welds.

### **WC-4323 Welding Prior to Qualifications**

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with WC-4320 and Section IX shall be used.

### **WC-4324 Transferring Qualifications**

The welding procedure qualifications and performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures, and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX.

### **WC-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS**

#### **WC-4331 Conformance to Section IX Requirements**

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

#### **WC-4333 Heat Treatment of Qualification Welds for Ferritic Materials**

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of WC-4600 and Section IX. The postweld heat treatment time at temperature is to be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

### **WC-4334 Preparation of Test Coupons and Specimens**

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full size impact test specimen at the  $\frac{1}{4}t$  location required by this Section, additional full size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full size test specimens. As an alternative, additional test welds can be made with each process so that full size specimens can be tested for each process.

**WC-4334.1 Coupons Representing the Weld Deposits.** Impact test specimens and testing methods shall conform to WC-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least  $\frac{1}{4}t$  and, where the thickness of the test assembly permits, not less than  $\frac{3}{8}$  in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in WC-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of  $t$  from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test assembly.

**WC-4334.2 Coupons Representing the Heat-Affected Zone.** Where impact tests of the heat-affected zone are required by WC-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of WC-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined

to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslog or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat-affected zone values with base material values [WC-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat-affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by WC-2330, drop weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of WC-2321.

### WC-4335 Impact Test Requirements

When materials are required to be impact tested per WC-2300, impact tests of the weld metal and heat-affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of WC-2332.1 and WC-4334. Retests in accordance with the provisions of WC-2350 are permitted.

#### WC-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding  $\frac{5}{8}$  in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with WC-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with WC-2310, regardless of the depth of the repair.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in WC-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection WB, NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

#### WC-4335.2 Impact Tests of Heat-Affected Zone. (17)

(a) Charpy V-notch tests of the heat-affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds  $\frac{5}{8}$  in. (16 mm) and either of the base materials require impact testing in accordance with the rules of WC-2310. Exemption of base materials by WC-2311(a)(7) does not apply to the welding procedure qualification heat-affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 materials that are postweld heat treated and are made by any process other than electroslog, electrogas, or thermit;

(2) the qualification for weld deposit cladding or hardfacing on any base material.

(3) that portion of the heat-affected zone associated with GTAW root deposits with a maximum of two layers or  $\frac{3}{16}$  in. (5 mm) thickness, whichever is less.

(b) Charpy V-notch testing shall be performed as specified in (1) through (6).

(1) Charpy V-notch test specimens representing both the heat-affected zone and the unaffected base material shall be tested. The unaffected base material shall be tested at a temperature equal to or below the LST.

(2) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of Table WC-2332.1-1 or Table WC-2332.1-2, as applicable, or additional testing shall be performed at higher temperatures until either of the above requirements are met.

(3) The heat-affected zone specimens shall be tested at the test temperature determined in (2). The average applicable toughness values of the heat-affected zone specimens shall equal or exceed the average applicable toughness values of the unaffected base material specimens, or the adjustment given in (4) through (6) shall be made. Alternatively, another test coupon may be welded and tested.

(4) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the applicable toughness values of all three specimens tested is not less than that specified in (2). The applicable average toughness values for each test meeting this requirement shall be plotted on an applicable toughness value versus temperature graph. The difference in temperature  $T_{HAZ}$  and  $T_{UBM}$  where the heat-affected zone and the unaffected base material applicable average toughness values are the same and not less than that specified in (2) shall be used to determine the adjustment temperature  $T_{ADJ}$  where:

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

$$\text{If } T_{ADJ} \leq 0, \text{ then } T_{ADJ} = 0.$$

(5) As an alternative to (4), if the applicable toughness values of the heat-affected zone specimens is no less than the values specified in Table WC-2332.1-1 or Table WC-2332.1-2, as applicable, and the average of the heat-affected zone specimens is not less than 7 ft-lb (10 J) or 5 mils (0.13 mm) below the average applicable toughness values of the unaffected base material,  $T_{ADJ}$  may be taken as 15°F (−8°C).

(6) As a second alternative to (4), if the applicable toughness values of the heat-affected zone specimens are no less than the values specified in Table WC-2332.1-1 or Table WC-2332.1-2, as applicable, the difference between the average applicable toughness values of the heat-affected zone and the unaffected base material shall be calculated and used as described in (c)(3).

(c) At least one of the following methods shall be used to compensate for the heat-affected zone toughness decrease due to the welding procedure.

(1) The LST specified in the Design Specification for all of the material to be welded in production welding procedure specifications (WPS) supported by this procedure qualification record (PQR) shall be increased by the adjustment temperature  $T_{ADJ}$ .

(2) The specified testing temperature for the production material may be reduced by  $T_{ADJ}$ .

(3) The materials to be welded may be welded using the WPS provided they exhibit toughness values that are no less than the minimum required toughness values required by WC-2300 plus the difference in the average toughness values established in (b)(6).

(d) The Charpy V-notch testing results shall be recorded on the PQR and any offsetting  $T_{ADJ}$  or increased toughness requirements on the production material on which welding is to be performed shall be noted on the PQR and WPS. More than one compensation method may be used on a par basis.

(e) A WPS qualified to the impact testing requirements of Subsection WB, NB, NC, or NE may be accepted as an alternative to the WPS impact testing requirements of this Subsection.

### **WC-4336 Qualification Requirements for Built-Up Weld Deposits**

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of WC-4331 to WC-4335, inclusive.

### **WC-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS**

#### **WC-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING**

#### **WC-4411 Identification, Storage, and Handling of Welding Materials**

Each Certificate Holder is responsible for control of the welding electrodes and other materials that are used in the fabrication and installation of components (WC-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

#### **WC-4412 Cleanliness and Protection of Welding Surfaces**

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

### **WC-4420 RULES FOR MAKING WELDED JOINTS**

#### **WC-4421 Backing Rings**

Backing rings that remain in place may be used. The materials for backing rings shall be compatible with the base metal, but spacer pins shall not be incorporated into the weld.

#### **WC-4423 Double-Welded Joints, Single-Welded Joints, and Peening**

**WC-4423.1 Double-Welded Joints.** Before applying weld metal on the second side to be welded, the root of full penetration double-welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetrations are otherwise obtained and demonstrated to be satisfactory by welding procedure qualifications.

**WC-4423.2 Single-Welded Joints.** Where single-welded joints are used, particular care shall be taken in aligning and separating the items to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

**WC-4423.3 Peening.** Controlled peening may be performed to minimize distortion. Peening shall not be used on the internal layer (root) of the weld metal nor on the final layers unless the weld is postweld heat treated.



## WC-4424 Surfaces of Welds

As-welded surfaces are permitted. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examination of the weld. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with WC-4426.1.

(c) Undercuts shall not exceed  $\frac{1}{32}$  in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of Article WC-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

## WC-4425 Welding Items of Different Diameters

When items of different diameters are welded together, there shall be a gradual transition between the two surfaces. The slope of the transition shall be such that the length–offset ratio shall not be less than 3:1, unless greater slopes are shown to be acceptable by analysis for vessels designed to WC-3200. The length of the transition may include the weld.

## WC-4426 Reinforcement of Welds

**WC-4426.1 Weld Reinforcement.** The surface of the reinforcement of all butt-welded joints may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thicknesses in the following tabulation:

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Up to 1 (25), incl.	$\frac{3}{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$\frac{1}{8}$ (3)
Over 2 to 3 (50 to 75), incl.	$\frac{5}{32}$ (4)
Over 3 to 4 (75 to 100), incl.	$\frac{7}{32}$ (5.5)
Over 4 to 5 (100 to 125), incl.	$\frac{1}{4}$ (6)
Over 5 (125)	$\frac{5}{16}$ (8)

## WC-4427 Shape and Size of Fillet Welds

(a) Fillet welds may vary from convex to concave. Except as permitted in (b) below, the shape and size of the weld shall be in accordance with the requirements of Figure WC-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld

dimension by not more than  $\frac{1}{16}$  in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. In making socket welds, a gap as shown in Figure WC-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding. For sleeve type joints without internal shoulder, the gap shall be between the butting ends of the pipe or tube.

(b) Socket welds smaller than those specified in Figure WC-4427-1 may be used provided the requirements of Article WC-3000 are met.

## WC-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

## WC-4430 WELDING OF ATTACHMENTS

### WC-4431 Materials for Attachments

Structural attachments that are not part of the containment shall be of the materials that meet the requirements of WC-2190. Structural attachments that are part of the containment shall meet the requirements of WC-2120.

### WC-4432 Welding of Structural Attachments

The rules of WC-4321 governing welding qualifications shall apply to the welding of structural attachments to containment material.

### WC-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous or intermittent welds. Figures WC-4433-1 and WC-4433-2 illustrate some of the typical details for attaching structural attachments to a component using full penetration welds.

### WC-4434 Welding of Internal Structural Supports to Clad Containments

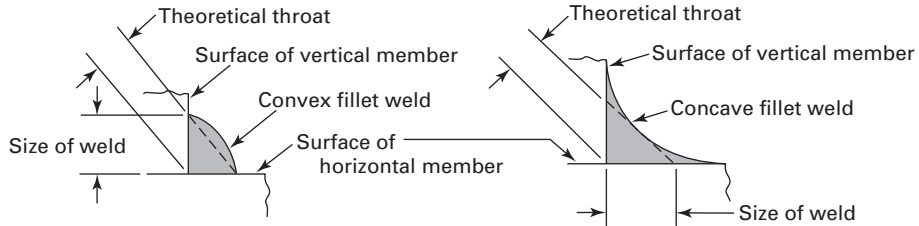
Internal structural supports on clad containments shall be welded to the base metal and not to the cladding except for weld overlay cladding.

### WC-4435 Welding of Nonstructural and Temporary Attachments and Their Removal

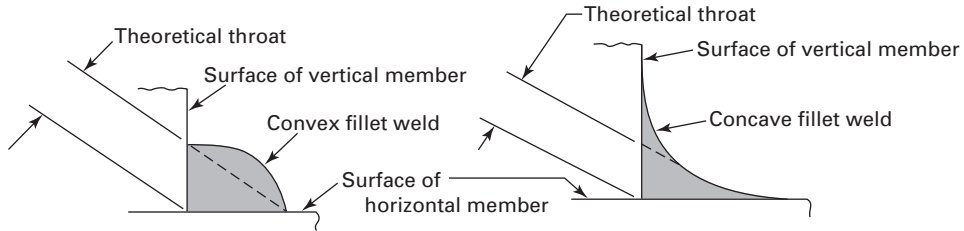
(a) Nonstructural attachments welded to the containment need not comply with Article WC-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

(1) The welding procedure and the welders have been qualified in accordance with WC-4321.

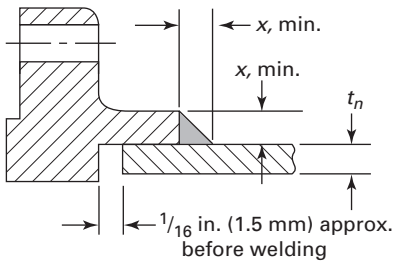
**Figure WC-4427-1  
Fillet and Socket Weld Details and Dimensions**



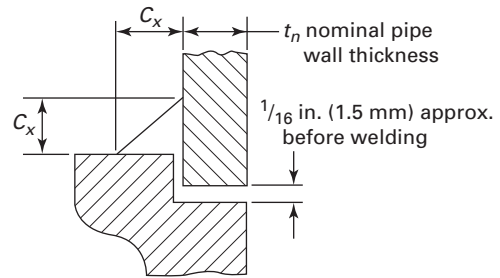
**(a) Equal Leg Fillet Weld [Note (1)]**



**(b) Unequal Leg Fillet Weld [Note (2)]**



**(c-1) Socket Welding Flange [Note (3)]**



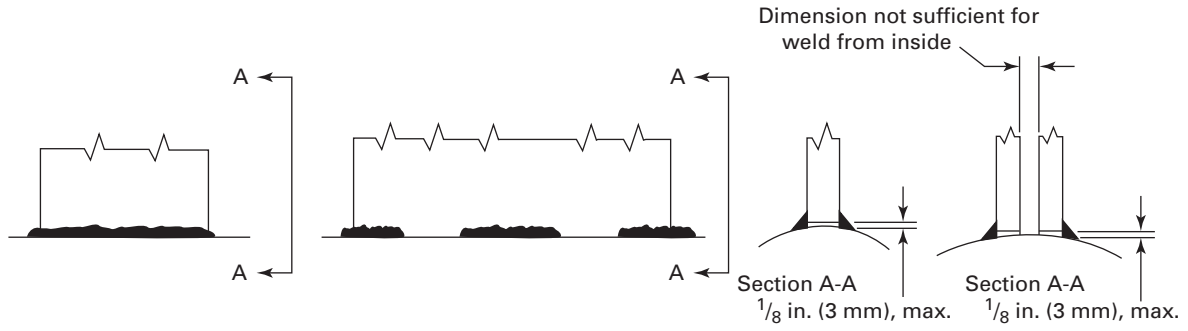
**(c-2) Socket Welding Fittings [Note (4)]**

**(c) Minimum Welding Dimensions for Slip-On and Socket Welding Flanges and Socket Welding Fittings**

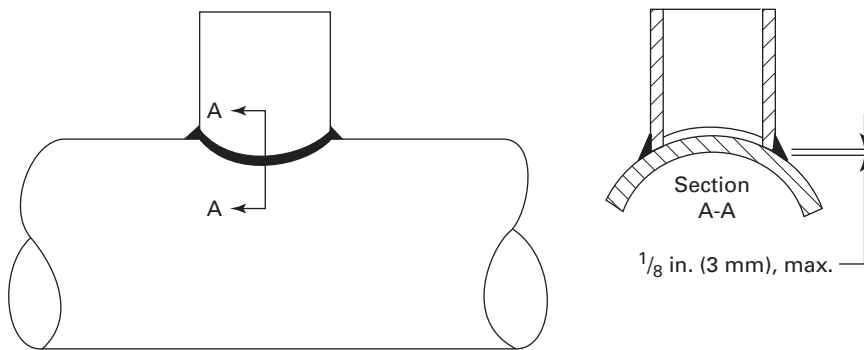
**NOTES:**

- (1) The size of an equal leg fillet weld is the leg length of the largest right isosceles triangle. Theoretical throat =  $0.7 \times$  size of weld.
- (2) The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross section.
- (3)  $x, \text{ min.} = 1.4t_n$  or the thickness of the hub, whichever is smaller, but not less than  $\frac{1}{8}$  in. (3 mm)
- (4)  $C_x, \text{ min.} = 1.09t_n$  where  $t_n =$  nominal pipe wall thickness

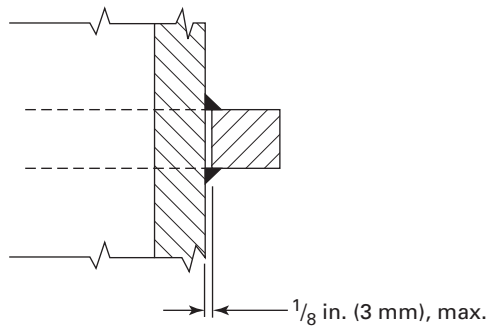
**Figure WC-4433-1  
Typical Types of Attachment Welds**



**(a) Attachment of Lugs, Shoes, Pipe Saddles, and Brackets**



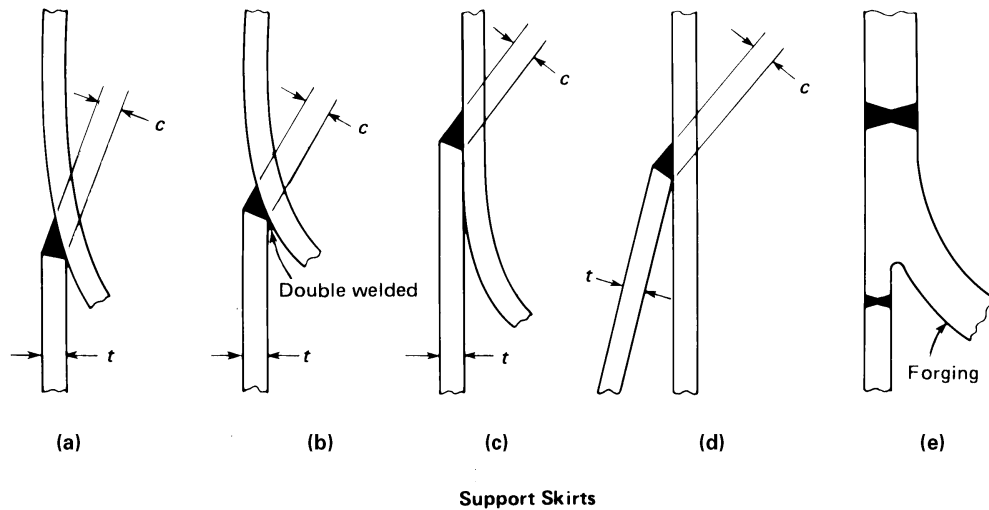
**(b) Attachment of Trunnions**



**(c) Attachment of Rings**

GENERAL NOTE: The welds may be partial penetration or fillet welds.

**Figure WC-4433-2  
Typical Attachments**



**GENERAL NOTES:**

(a)  $a \geq t/4$ ;  $b \geq t/2$ ;  $c \geq t$

$t$  = thickness of attached member

$c$  = minimum thickness of weld metal from the root to the face of the weld

(b) All welds continuous.

(2) The material is identified and is compatible with the material to which it is attached.

(3) The welding material is identified and is compatible with the materials joined.

(4) The welds are postweld heat treated when required by WC-4620.

(b) Removal of nonstructural attachments, when temporary, shall be accomplished as follows:

(1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.

(2) The temporary attachment is completely removed in accordance with the procedures of WC-4211.

(3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of WC-5120 and meets the acceptance standards of WC-5340 or WC-5350, whichever is applicable.

(4) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

## WC-4450 REPAIR OF WELD METAL DEFECTS

### WC-4451 General Requirements

Defects in weld metal detected by the examinations required by Article WC-5000 or by the tests of Article WC-6000 shall be eliminated and repaired when necessary or the indication reduced to an acceptable limit.

### WC-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided the requirements of (a), (b), and (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by Article WC-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with WC-5100 after blending and meets the acceptance standards of WC-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

**WC-4453 Requirements for Making Repairs of Welds**

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

**WC-4453.1 Defect Removal.** Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with [WC-5100](#) and meet the acceptance standards of [WC-5340](#) or [WC-5350](#). This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

**WC-4453.2 Requirements for Welding Materials, Procedures, and Welders.** The weld repair shall be made using welding materials, welders, and welding procedures qualified in accordance with [WC-4125](#) and [WC-4300](#).

**WC-4453.3 Blending of Repaired Areas.** After repair the surface shall be blended uniformly into the surrounding surface.

**WC-4453.4 Examination of Repair Welds.**

(a) The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(1)  $\frac{1}{3}t$  for  $t \leq \frac{3}{4}$  in. (19 mm)

(2)  $\frac{1}{4}$  in. (6 mm) for  $\frac{3}{4}$  in. (19 mm)  $< t \leq 2\frac{1}{2}$  in. (64 mm)

(3) the lesser of  $\frac{3}{8}$  in. (10 mm) or  $10\%t$  for  $t > 2\frac{1}{2}$  in. (64 mm) where  $t$  equals the thickness of the weld.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a) above, but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted, provided that:

(1) the weld has been previously radiographed and met the applicable acceptance standards;

(2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article 4 to the acceptance standards of [WC-5330](#);

(3) the substitution is limited to Category A and B welds in containments and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

**WC-4453.5 Heat Treatment of Repaired Areas.** The area shall be heat treated in accordance with [WC-4620](#).

**WC-4500 BRAZING****WC-4510 RULES FOR BRAZING****WC-4511 Where Brazing May Be Used**

Brazing is permitted for nonstructural attachments only.

**WC-4512 Brazing Material**

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in [WC-2150](#) and to the requirements of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (425°C) and at least 500°F (280°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

**WC-4520 BRAZING QUALIFICATION REQUIREMENTS****WC-4521 Brazing Procedure and Performance Qualification**

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except as noted below.

**WC-4523 Reheated Joints**

In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (170°C) of the solidus temperature of the filler metal.

**WC-4524 Maximum Temperature Limits**

The Design Temperature shall not exceed the upper temperature shown in the third column of [Table WC-4524-1](#). For Design Temperatures below the temperature shown in the second column of [Table WC-4524-1](#), no further testing beyond that required by Section IX is required. For Design Temperatures in the range shown in the third column of [Table WC-4524-1](#), tests in addition to those required by Section IX are required. These tests shall be considered a part of the procedure qualification. For such Design Temperatures, two

tension tests on production type joints are required, one at the Design Temperature and one at  $1.05T$  [where  $T$  is the Design Temperature in °F (°C)]. Neither of these production-type joints shall fail in the braze metal.

**WC-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED**

Parts to be joined by brazing shall be fitted, and retained in position during the brazing operation within the tolerances specified in the brazing procedure specification. Brazed joints shall be assembled in a sequence which will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.

**WC-4540 EXAMINATION OF BRAZED JOINTS**

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with [WC-5275](#).

**WC-4600 HEAT TREATMENT**

**WC-4610 WELDING PREHEAT REQUIREMENTS**

**WC-4611 When Preheat Is Necessary**

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Section III Appendices, Nonmandatory Appendix D as a general guide for the materials listed by P-Number of Section IX. It is cautioned that the preheating suggested in Section III Appendices, Nonmandatory Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The welding procedure specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

**WC-4612 Preheating Methods**

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

**WC-4613 Interpass Temperature**

Consideration must be given to the limitations of interpass temperatures for quenched and tempered materials to avoid detrimental effects on the mechanical properties.

**WC-4620 POSTWELD HEAT TREATMENT**

**WC-4621 Heating and Cooling Methods**

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

**WC-4622 PWHT Time and Temperature Requirements**

**WC-4622.1 General Requirements.** Except as otherwise permitted in [WC-4622.7](#), all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature ranges for the minimum holding time specified in [Table WC-4622.1-1](#) except as otherwise permitted in [WC-4622.4\(c\)](#). P-Number groups in [Table WC-4622.1-1](#) are in accordance with Section IX, QW-420. Except as provided in [WC-4624.3](#), PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this (17)

**Table WC-4524-1  
Maximum Design Temperatures for Brazing Filler Metal, °F (°C)**

Filler Metal Classification	Temperature Below Which Section IX Tests Only Are Required	Temperature Range Requiring Section IX Tests and Additional Tests
BCuP	300 (150)	300-350 (150-175)
B <sub>Ag</sub>	400 (205)	400-500 (205-260)
BCuZn	400 (205)	400-500 (205-260)
BCu	400 (205)	400-650 (205-345)
BAISi	300 (150)	300-350 (150-175)
BNi	800 (425)	...

GENERAL NOTE: Temperatures are based on AWS recommendations.



time in the total time at temperature specified to be applied to the test specimens. In addition, the requirements of the following subparagraphs shall apply.

**WC-4622.2 Time-Temperature Recordings.** Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the weld, part, or component. A summary of the time-temperature recording may be provided for permanent records in accordance with [WA-4134](#).

**WC-4622.3 Definition of Nominal Thickness Governing PWHT.** Nominal thickness in [Table WC-4622.7\(b\)-1](#) is the thickness of the weld, the containment material for structural attachment welds or the thinner of the containment materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed  $\frac{1}{8}$  in. (3 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

**WC-4622.4 Holding Times at Temperature.**

(a) The holding time at temperature as specified in [Table WC-4622.1-1](#) shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat-treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of [Table WC-4622.1-1](#) may be used, provided that specimens so heat treated are tested in accordance with [WC-2200](#), [WC-2400](#), and [WC-4300](#).

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in [Table WC-4622.1-1](#), it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with [Table WC-4622.4\(c\)-1](#) and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in [Table WC-4622.4\(c\)-1](#) are to be postweld heat treated at the lower minimum temperatures, the impact test specimens for the welding procedure qualification required by [WC-4300](#) shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in [Table WC-4622.1-1](#) and at the lower temperature and increased minimum holding time permitted by [Table WC-4622.4\(c\)-1](#), are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from [Table WC-4622.1-1](#) and the alternative requirements from [Table WC-4622.4\(c\)-1](#).

(2) Except for P-No. 1 materials, when welds in the materials listed in [Table WC-4622.4\(c\)-1](#) are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by [WC-2400](#) shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in [Table WC-4622.1-1](#) and at the lower minimum temperatures and increased minimum holding time permitted by [Table WC-4622.4\(c\)-1](#) are also certified for any temperature in between.

(3) Base materials certified in accordance with [WC-2200](#) may be postweld heat treated at these lower minimum temperatures and increased minimum holding

**Table WC-4622.1-1  
Mandatory Requirements for Postweld Heat Treatment of Welds**

P-No. (Sec. IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		$\frac{1}{2}$ in. (13 mm) or less	Over $\frac{1}{2}$ in. to 2 in. (13 mm to 50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
1, 3	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45 and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in [WC-4622.7](#).

NOTE:

(1) All temperatures are metal temperatures.

**Table WC-4622.4(c)-1  
Alternative Holding Temperatures and Times**

Material P-Numbers	Alternative Minimum	
	Holding Temperatures, °F (°C)	Holding Times
1, 3	1,050 (565)	2 hr/in. (4 min/mm) thick
1, 3	1,000 (540)	4 hr/in. (8 min/mm) thick

GENERAL NOTE: All other requirements of WC-4622 shall apply.

times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

**WC-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.** When containment materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table WC-4622.1-1 for the material requiring the higher PWHT temperature range.

**WC-4622.6 PWHT Requirements for Noncontainment Parts.** When parts not performing a containment function are welded to containment materials, the postweld heat treatment temperature range of the containment materials shall control.

**WC-4622.7 Exemptions to Mandatory Requirements.** Postweld heat treatment in accordance with this subarticle is not required for (a) through (g) below:

- (a) nonferrous materials;
- (b) welds exempted in Table WC-4622.7(b)-1;
- (c) welds subjected to temperatures above the PWHT temperature range specified in Table WC-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperature;
- (d) welds connecting nozzles to containments provided the requirements in WC-4622.8 are met;
- (e) weld repairs to P-No. 1 or P-No. 3 materials in containments, provided the requirements of WC-4622.9 or WC-4622.10 are met;
- (f) weld repairs to cladding after final postweld heat treatment provided the requirements of WC-4622.11 are met;
- (g) weld repairs to dissimilar metal welds after final postweld heat treatment provided the requirements of WC-4622.12 are met.

**WC-4622.8 Requirements for Exempting PWHT of Nozzles to Containment Welds.** Welds connecting nozzles of P-No. 1 materials to containments of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in

Table WC-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) are met for partial penetration and (b) are met for full penetration welds.

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal after:

(1) the ferritic materials to be joined are buttered or buildup with A-No. 8 or non-air-hardening nickel-chromium-iron weld metal having a minimum thickness of  $\frac{1}{4}$  in. (6 mm); and

(2) the heat-affected zones of the buttered or buildup ferritic materials are postweld heat treated in accordance with WC-4620, without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal, provided that:

(1) the containment is built up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of  $\frac{1}{4}$  in. (6 mm);

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with WC-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the containment thickness;

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle to the containment does not exceed  $1\frac{1}{2}$  in. (38 mm), and the maximum reported carbon content of the nozzle connection does not exceed 0.30%;

(6) a 200°F (95°C) minimum preheat is maintained during welding whenever the nominal thickness of the weld exceeds:

(-a)  $1\frac{1}{4}$  in. (32 mm) and the maximum reported carbon content of the material of the nozzle is 0.30% or less; or

(-b)  $\frac{3}{4}$  in. (19 mm) and the maximum reported carbon content of material of the nozzle connection exceeds 0.30%.

**WC-4622.9 Weld Repair to Containments.** Limited weld repairs to containments of P-No. 1 and P-No. 3 materials and A-No. 1, A-No. 2, A-No. 10, or A-No. 11 weld filler metal (Section IX, Table QW-442) may be made without PWHT or after the final PWHT, provided the requirements of the following subparagraphs are met:

(a) *Examination of Area to Be Repaired.* Before a repair is made, the area shall be examined by magnetic particle or liquid penetrant method in accordance with WC-5100 and shall meet the acceptance standards of WC-5340 or WC-5350, as appropriate.

(b) *Maximum Extent of Repairs.* A repair shall not exceed 10 in.<sup>2</sup> (6 500 mm<sup>2</sup>) in surface area and shall not be greater in depth than 50% of the base metal or weld thickness or  $\frac{1}{2}$  in. (13 mm), whichever is less.

**Table WC-4622.7(b)-1  
Exemptions to Mandatory PWHT**

P-No. (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness, in. (mm) (WC-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)
1	All welds, where the materials being joined are 1½ in. (38 mm) and less	1¼ (32) and less	0.30 and less	...
		Over 1¼ to 1½ (32 to 38)	0.30 and less	200 (95)
		¾ (19) or less	Over 0.30	...
		Over ¾ to 1½ (19 to 38)	Over 0.30	200 (95)
	All welds in material over 1½ in. (38 mm)	¾ (19) or less	...	200 (95)
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. (38 mm) or less	...	0.30	100 (38)
	Over 1½ in. to 3 in. (38 mm to 75 mm)	...	0.30	200 (95) [Note (4)]
	Over 3 in. (75 mm)	...	0.30	250 (120) [Note (5)]
3	For containment repair without required PWHT, see WC-4622.9 or WC-4622.10	...	...	350 (175)
3 except Gr. 3	All welds, except repair welds in containments, provided weld procedure qualification is made using equal or greater thickness base material than production weld [Note (6)]	5⁄8 (16) or less	0.25 or less	200 (95)
	Attachment welds joining containment to noncontainment material	1⁄2 (13) or less	0.25 or less	200 (95)

GENERAL NOTE: The exemptions noted in this Table do not apply to electron beam welds in ferritic materials over 1⁄8 in. (3 mm) in thickness.

NOTES:

- (1) Where the thickness of material is identified in the column Type of Weld, it is the thickness of the base material at the welded joint.
- (2) Carbon level of the pressure-retaining materials being joined.
- (3) The maximum resulting hardness of the heat-affected zone, in the procedure qualification test plate shall not exceed 35 Rc.
- (4) Intermediate postweld soak at not less than 200°F (95°C) for 2 hr minimum.
- (5) Intermediate postweld soak at not less than 300°F (150°C) for 2 hr minimum.
- (6) Weld Procedure Qualification coupon need not exceed 1.5 in. (38 mm) in thickness.

*(c) Repair Welding Procedure*

(1) The repairs shall be made using one or more procedures and welders qualified in accordance with Section IX and the requirements of this Article using the shielded metal-arc process and low hydrogen covered electrodes.

(2) The largest electrode diameter shall be 5⁄32 in. (4 mm), and the bead width shall not exceed four times the electrode diameter.

(3) The repair weld shall be made with a minimum of two layers of weld metal. The last layer shall be limited or ground off so that the weld surface does not extend above the base metal a greater distance than that allowed for reinforcement of butt welds.

(4) A preheat and interpass temperature of 300°F (150°C) minimum shall be used.

(d) *Examination of Repair Welds.* Following the repair and when the area has reached ambient temperature, the area shall again be examined by magnetic particle methods and accepted in accordance with (a) above.

**WC-4622.10 Temper Bead Technique.** Limited weld repairs to P-No. 1 and P-No. 3 material, and A-Nos. 1, 2, 10, or 11 weld filler metal (Section IX, Table QW-442),

may be made without PWHT or after the final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met:

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with Article WC-5000.

(b) *Maximum Extent of Repair.* The maximum area of an individual repair based on the finished surface shall be 100 in.<sup>2</sup> (65 000 mm<sup>2</sup>) and the depth of repair shall not be greater than one-third of the base material thickness.

(c) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Subsection and shall include the requirements of (1) through (8) below.

(1) The area to be repaired shall be suitably prepared for welding in accordance with a written procedure.

(2) The weld metal shall be deposited by the manual shielded metal arc process using low hydrogen type electrode. The maximum bead width shall be four times the electrode core diameter.

(3) Welding electrodes shall meet the requirements for supplemental designators “R” indicating a moisture-resistant coating and “H4” indicating that they are low in diffusible hydrogen as defined in the applicable specifications in Section II, Part C. Welding electrodes shall also be supplied in unopened hermetically sealed containers.

(4) After a hermetically sealed container is opened, the electrodes shall be stored in holding ovens at 225°F to 350°F (105°C to 175°C). When electrodes are removed from elevated storage, they may be exposed to the atmosphere for a maximum of 8 hr.

(5) Electrodes, which are exposed to the atmosphere for more than 8 hr, shall be discarded or baked to remove any absorbed moisture for the time and temperature recommended by the electrode manufacturer. After baking and before the electrodes are allowed to cool below 225°F (105°C), they shall be transferred immediately into holding ovens at 225°F to 350°F (105°C to 175°C). When the once-baked electrodes are removed from elevated storage, they may be exposed to the atmosphere for an additional 8 hr after which they shall be discarded.

(6) The weld area plus a band around the repair area of at least  $1\frac{1}{2}$  times the containment thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding. The maximum interpass temperature shall be 450°F (230°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with WC-4435(b).

(7) The cavity shall be buttered, using a  $\frac{3}{32}$  in. (2.5 mm) diameter electrode as shown in Figure WC-4622.10(c)(7)-1. The weld bead crown surface shall be removed by grinding or machining before depositing the second layer [see Figure WC-4622.10(c)(7)-1, Step 2]. The second layer shall be deposited with a  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers shall be deposited with a welding electrode no larger than  $\frac{5}{32}$  in. (4 mm) diameter. Bead deposition shall be performed in a manner shown in Figure WC-4622.10(c)(7)-1, Step 3. The completed weld shall have at least one layer of weld reinforcement deposited and then this reinforcement shall be removed by mechanical means, making the finished surface of the repair substantially flush with the surface of the vessel surrounding the repair [Figure WC-4622.10(c)(7)-2]. The technique described in this paragraph shall be performed in the procedure qualification test.

(8) The weld area shall be maintained at a temperature of 450°F to 550°F (230°C to 290°C) for a minimum period of 2 hr after completion of the weld repair in P-No. 1 materials. For P-No. 3 materials, the holding time shall be a minimum of 4 hr.

(d) *Examination of Repair Welds.* The second (temper bead) layer shall be examined by the magnetic particle or liquid penetrant method. The completed weld shall have the weld reinforcement, including the final layer,

removed substantially flush with the surface prior to performing the required nondestructive examination. The nondestructive examination shall be performed after the completed weld has been at ambient temperature for a minimum period of 48 hr to detect the presence of possible delayed cracking of the weldment. The nondestructive examination of the repair welded and preheated region shall be in accordance with WC-4453.4. In addition, all repairs shall be ultrasonically examined. All nondestructive examination shall be in accordance with Article WC-5000.

(e) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with WC-4130, exclusive of the size requirements.

(f) *Welding Procedure Qualification Test Plate.* The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair, but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repair section of the component, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (150 mm). The qualification test plate shall be prepared in accordance with Figure WC-4622.10(f)-1.

(g) This test assembly may be used to qualify procedures for weld buildup repairs of pressure-retaining materials. In this case, the depth of the cavity shall not be less than the thickness of the weld buildup or 1 in. (25 mm), whichever is greater, and the area of the weld buildup to be applied or  $54 \text{ in.}^2$  ( $35\,000 \text{ mm}^2$ ), whichever is less.

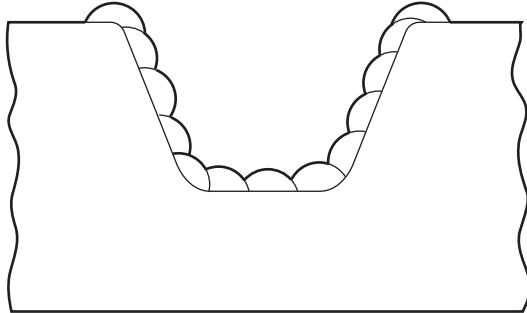
(h) In all cases, the test assembly and cavity shall be of sufficient size to permit removal of the required test specimens.

(i) *Performance Qualifications.* If the repair weld is to be performed where physical obstructions impair the welder’s ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

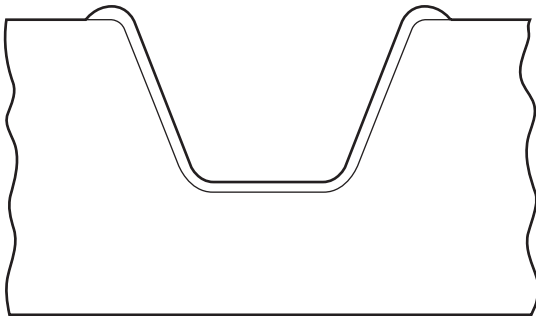
**WC-4622.11 Repair Welds to Cladding After Final Postweld Heat Treatment.** Nonpostweld heat-treated weld repairs may be made to P-No. 8 or P-No. 43 cladding of P-No. 1 and P-No. 3 material after final PWHT, provided it is impossible or impractical to postweld heat treat the area after repair, and provided the requirements of the following subparagraphs are met:

(a) *Maximum Extent of Repair.* This procedure may be used with the base material exposed to a depth not greater than  $\frac{1}{4}$  in. (6 mm) or 10% of the base material

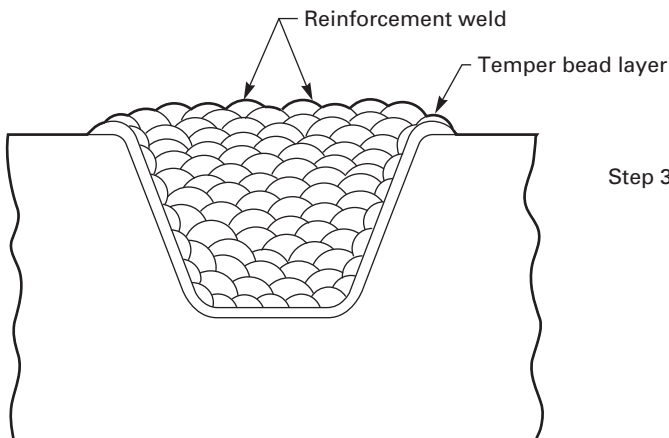
**Figure WC-4622.10(c)(7)-1  
Temper Bead Weld Repair and Weld Temper Bead Reinforcement**



Step 1: Butter cavity with one layer of weld metal using  $\frac{3}{32}$  in. (2.5 mm) diameter coated electrode.



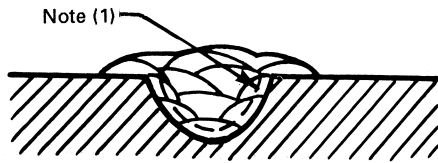
Step 2: Remove the weld bead crown of the first layer of grinding.



Step 3: The second layer shall be deposited with a  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers shall be deposited with welding electrodes no larger than  $\frac{5}{32}$  in. (4 mm) maximum diameter. Bead deposition shall be performed in the manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in points as well as its removal to ensure that the heat-affected zone of the base metal and the deposited weld metal is tempered and the resulting surface is substantially flush.



**Figure WC-4622.10(c)(7)-2  
Temper Bead Reinforcement**



**NOTE:**

(1) Apply temper bead reinforcement weld metal to a level above the surface and then remove it substantially flush to the surface as required by WC-4622.10(c)(7).

thickness, whichever is less, nor to an individual area greater than 100 in.<sup>2</sup> (65 000 mm<sup>2</sup>). Areas with greater base material exposure depth shall be repaired in accordance with WC-4622.10 to within this limit before implementing the cladding repair.

(b) *Repair Welding Procedure.* The welding procedure shall be in accordance with Section IX and this Article, and shall include the requirements of (1) through (7) below.

(1) The repairs shall be made using A-No. 8 weld metal (Section IX, Table QW-442) for P-No. 8 cladding or F-No. 43 weld metal (Section IX, Table QW-432) for either P-No. 8 or P-No. 43 cladding.

(2) The manual shielded metal arc process shall be used for welding with a bead width not to exceed four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (105°C) and 350°F (175°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(4) During the repair, the electrodes may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (105°C) and 350°F (175°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(5) The weld area plus a band around the clad repair of 1½ times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding. The maximum interpass temperature shall be 450°F (230°C). Thermocouples and recording instruments shall be used to monitor the process temperatures. Their removal shall be in accordance with WC-4435.

(6) All areas of the base material on which weld metal is to be deposited shall be covered with a single layer of weld deposit using 3/32 in. (2.5 mm) diameter electrode, followed by a minimum of one layer of weld deposit using 1/8 in. (3 mm) diameter electrode. Subsequent layers may be deposited with electrode no larger than 5/32 in. (4 mm). The weld bead crown surface of the first layer shall be removed by grinding.

(7) After completion of welding, the weld area shall be maintained at a temperature of 450°F to 550°F (230°C to 290°C) for a period of 2 hr for P-No. 1 material and 4 hr for P-No. 3 material.

(c) *Examination of Repair Welds.* The weld repair as well as the preheated band shall be examined by the liquid penetrant method. All nondestructive examination shall be in accordance with Article WC-5000.

(d) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with WC-4130, exclusive of the size requirements.

(e) *Welding Procedure Qualification Test Plate*

(1) The test assembly material for the welding procedure qualification test shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature of that applied to the material being repaired. If the repair involves two different P-Number or Group Number materials, the test assembly shall duplicate the combination.

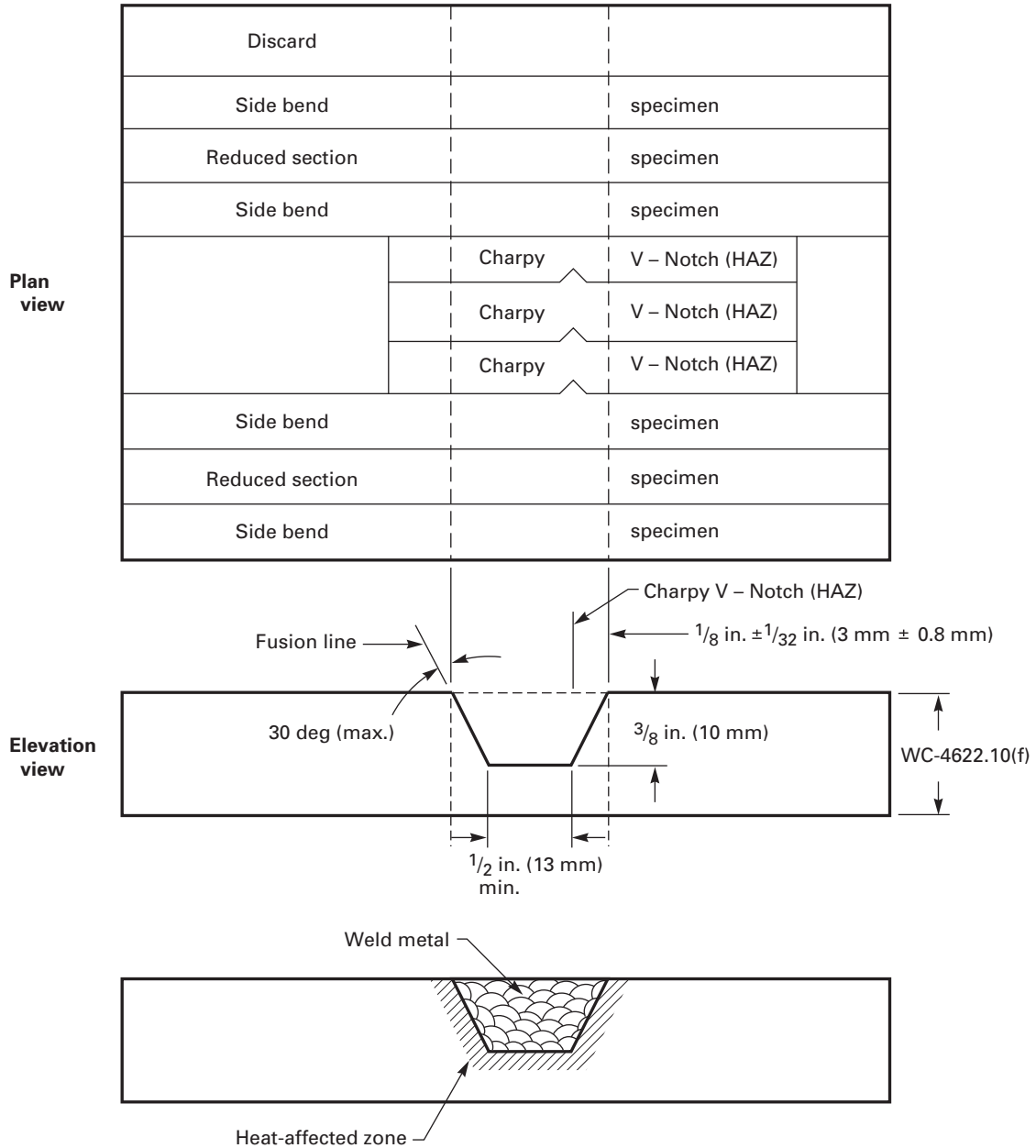
(2) The test assembly base material shall be at least 12 in. (300 mm) by 12 in. (300 mm), 2 in. (50 mm) min. thickness, with a clad surface area of at least 8 in. (200 mm) by 8 in. (200 mm), in the area from which the bend test specimens will be removed.

(3) The qualification test plate assembly shall be prepared and tested in accordance with the requirements of Section IX. The guided bend test acceptance standards described in Section IX for cladding shall also be applicable to the HAZ of the base material.

(f) *Performance Qualifications.* If the repair weld is to be performed where physical obstructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.



**Figure WC-4622.10(f)-1  
Qualification Test Plate**



**WC-4622.12 Temper Bead Weld Repair to Dissimilar Metal Welds or Buttering.** Whenever PWHT is impractical or impossible, limited weld repairs to dissimilar metal welds of P-No. 1 and P-No. 3 material or weld filler metal A-No. 8 (Section IX, Table QW-442) or F-No. 43 (Section IX, Table QW-432) may be made without PWHT or after the final PWHT provided the requirements of the following subparagraphs are met:

(a) *Examination of Area to Be Repaired.* Before repair, the area shall be examined by either the magnetic particle or liquid penetrant method in accordance with [Article WC-5000](#).

(b) *Maximum Extent of Repair.* Repairs made to this paragraph are limited to those along the fusion line of a nonferritic weld to ferritic base material where  $\frac{1}{8}$  in. (3 mm) or less of nonferritic weld deposit exists above the original fusion line after defect removal. If the defect penetrates into the ferritic base material, repair of the base material may be performed in accordance with [WC-4622.12](#) provided the depth of repair in the base material does not exceed  $\frac{3}{8}$  in. (10 mm). The repairs to a completed joint shall not exceed one-half the joint thickness. The surface of the completed repair shall not exceed 100 in.<sup>2</sup> (65 000 mm<sup>2</sup>).

(c) *Repair Welding Procedure.* The welding procedure and welder qualification shall meet all of the requirements of Section IX and the additional requirements of this Article. In addition, the Welding Procedure Specification shall include the following requirements:

(1) The area to be repaired shall be suitably prepared for welding in accordance with the written procedure to be used for the repair.

(2) The weld metal shall be deposited by the shielded metal arc welding process (SMAW) using A-No. 8 weld metal (Section IX, Table QW-442) for P-No. 8 to P-No. 1 or P-No. 3 weld joints or F-No. 43 weld metal (Section IX, Table QW-432) for either P-No. 8 or P-No. 43 to P-No. 1 or P-No. 3 weld joints. The maximum bead width shall be four times the electrode core diameter.

(3) All covered electrodes used for qualification test and repair welding shall be from unopened, hermetically sealed packages or heated ovens maintained between 225°F (105°C) and 350°F (175°C). Electrodes withdrawn from hermetically sealed containers or ovens for longer than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(4) During the repair, the electrode may be maintained in heated ovens in the repair area. The oven temperature shall be maintained between 225°F (105°C) and 350°F (175°C). Electrodes exposed to the atmosphere for more than 8 hr shall be discarded, or baked once at the time and temperature recommended by the electrode

manufacturer and placed immediately back into the holding ovens. Electrodes exposed to the atmosphere for more than 8 hr after once being baked shall be discarded.

(5) The weld area plus a band around the weld repair of  $1\frac{1}{2}$  times the component thickness or 5 in. (125 mm), whichever is less, shall be preheated and maintained at a minimum temperature of 350°F (175°C) during welding. The maximum interpass temperature shall be 450°F (230°C). Thermocouples and recording instruments shall be used to monitor the metal temperature during welding. Their removal shall be in accordance with [WC-4435](#).

(6) All areas of the ferritic base material, exposed or not, on which weld metal is to be deposited, shall be covered with a single layer of weld deposit using  $\frac{3}{32}$  in. (2.5 mm) diameter electrode. The weld bead crown surface shall be removed by grinding before depositing the second layer. The second layer shall be deposited with  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layers may be deposited with  $\frac{5}{32}$  in. (4 mm) maximum diameter electrode. The techniques described in this paragraph shall be duplicated in the procedure qualification. [see [Figure WC-4622.12\(c\)\(6\)-1](#)].

(7) After at least  $\frac{3}{16}$  in. (5 mm) of weld metal has been deposited, the preheated area as defined in (5) above shall be maintained in the range of 450°F to 550°F (230°C to 290°C) for 4 hr as a minimum.

(8) Subsequent to the above heat treatment, the balance of the welding may be performed at a minimum preheat temperature of 100°F (38°C) and at a maximum interpass temperature of 350°F (175°C).

(d) *Examination of Repair Areas*

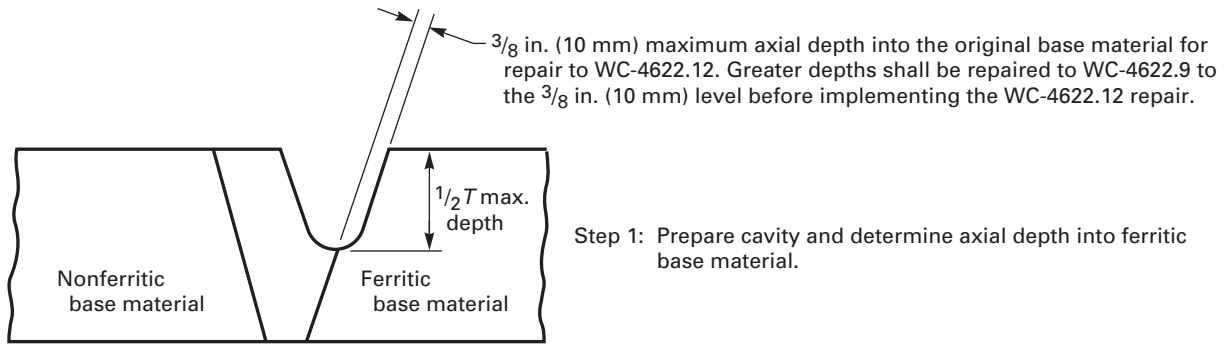
(1) After the heat treatment specified in (c)(7) above has been completed, the repaired area shall be examined by the liquid penetrant method.

(2) The repaired area and the preheated band as defined in (c)(5) above shall be examined by the liquid penetrant method after the completed weld has been at ambient temperature for a minimum of 48 hr. The repaired region shall be examined by the radiographic method and, if practical, by the ultrasonic method.

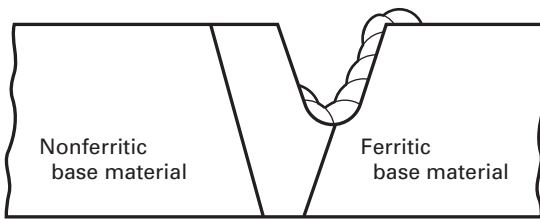
(3) For repairs to partial penetration welds, the radiographic and ultrasonic examinations specified in (2) above need not be performed, if meaningful results cannot be obtained. For these cases, liquid penetrant examination only shall be performed. For weld repair depths approximately  $\frac{3}{16}$  in. (5 mm), liquid penetrant examination shall be performed at the time specified in (2) above. For weld repair depths greater than  $\frac{3}{16}$  in. (5 mm), liquid penetrant examination shall be performed after approximately  $\frac{3}{16}$  in. (5 mm) thickness has been deposited and the post heat specified in (c)(7) above has been completed. Additional incremental deposit thicknesses shall be liquid penetrant examined in accordance with [WC-5245](#). The final weld surface shall be liquid penetrant examined at the time specified in (2) above.

(4) All nondestructive examination shall be in accordance with [Article WC-5000](#).

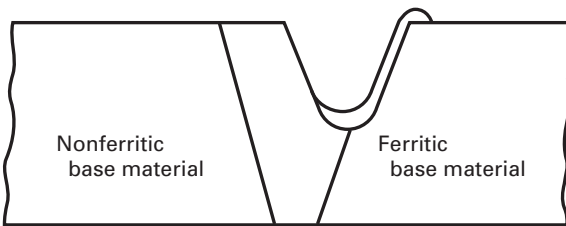
**Figure WC-4622.12(c)(6)-1**  
**Temper Bead Weld Repair and Weld Temper Bead Reinforcement of Dissimilar Metal Welds or Buttering**



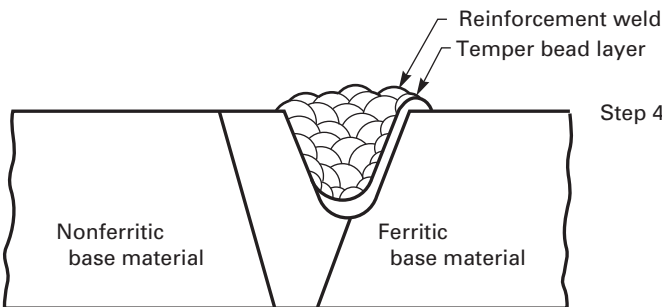
Step 1: Prepare cavity and determine axial depth into ferritic base material.



Step 2: Butter cavity with one layer of weld metal using  $\frac{3}{32}$  in. (2.5 mm) diameter coated electrode.



Step 3: Remove the weld bead crown of the first layer by grinding.



Step 4: The second layer shall be deposited with a  $\frac{1}{8}$  in. (3 mm) diameter electrode. Subsequent layer shall be deposited with welding electrodes no larger than  $\frac{5}{32}$  in. (4 mm) diameter. Bead deposition shall be performed in the manner as shown. Particular care shall be taken in the application of the temper bead reinforcement weld at the tie-in point with the ferritic material as well as its removal to ensure that the base metal and the deposited weld metal are tempered and the resulting surface is substantially flush.

(e) *Documentation of Weld Repairs.* Documentation of weld repairs shall be in accordance with [WC-4130](#), exclusive of the size requirements.

(f) *Welding Procedure Qualification Test Plate.* The test assembly materials for the welding procedure qualification shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature applied to the materials being repaired. The depth of cavity in the test assembly shall be a minimum of one-half the depth of actual repair but not less than 1 in. (25 mm). The test assembly thickness shall be a minimum of twice the depth of cavity in the test assembly. The test assembly shall be large enough to permit removal of the required test specimens. In order to simulate the restraint that the weld metal will experience in the repaired section of the containment, the test assembly dimensions surrounding the cavity shall be equal to the test assembly thickness, but not less than 6 in. (150 mm). The qualification test plate shall be prepared in accordance with [Figure WC-4622.10\(f\)-1](#).

(g) *Performance Qualifications.* If the repair weld is to be performed where physical constructions impair the welder's ability to perform, the welder shall also demonstrate the ability to deposit sound weld metal in the positions required, using the same parameters and simulated physical obstructions as are involved in the repair.

#### **WC-4623 PWHT Heating and Cooling Rate Requirements**

Above 800°F (425°C), the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches (millimeters) of the material being heat treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.5 m) interval of weld length.

#### **WC-4624 Methods of Postweld Heat Treatment**

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

**WC-4624.1 Furnace Heating — One Heat.** Heating the component or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the item is prohibited.

**WC-4624.2 Furnace Heating — More Than One Heat.** The component or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of [WC-4624.1](#) apply and that overlap of the heated sections of the item is at least 5 ft (1.5 m). When this procedure is used, the portion of the

item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

**WC-4624.3 Local Heating.** Welds may be locally postweld heat treated when it is not practical to heat treat the entire item. Local postweld heat treatment shall consist of heating a circumferential band around the item at temperatures within the ranges specified in this subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

**WC-4624.4 Heating Components Internally.** The item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the item. Previous to this operation, the item should be fully enclosed with insulating material.

#### **WC-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT**

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

#### **WC-4700 MECHANICAL JOINTS**

##### **WC-4710 BOLTING AND THREADING**

##### **WC-4711 Thread Engagement**

The threads of all bolts or studs shall be engaged in accordance with the design.

##### **WC-4712 Thread Lubricants**

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

##### **WC-4713 Removal of Thread Lubricants**

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

**WC-4720 BOLTING FLANGED JOINTS**

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the

design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

## ARTICLE WC-5000 EXAMINATION

### WC-5100 GENERAL REQUIREMENTS FOR EXAMINATION

### WC-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

#### WC-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be performed in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2, and the image quality indicators (IQIs) of Table WC-5111-1 shall be used in lieu of those shown in Section V, Article 2, Table T-276. The requirements for the retention of electronic and digital radiographic images are the same as that for radiographic film. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; and liquid penetrant examination shall be in accordance with Section V, Article 6. The examinations required by this Article, or by reference to this Article, shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

#### WC-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radiosopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

### WC-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

### WC-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by WC-5200 shall be performed at the times stipulated in (a) through (g) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate<sup>12</sup> or final postweld heat treatment, when required, except radiographic examination of welds in containments fabricated of P-No. 1 or P-No. 3 materials may be performed prior to an intermediate or final postweld heat treatment, provided the welds are ultrasonically examined after an intermediate or final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. The magnetic particle or liquid penetrant examination of welds at progressive stages of welding, as required in WC-5245, may be performed before PWHT.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material, or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall, shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations may be performed before PWHT.

(e) Weld metal cladding shall be examined after either an intermediate<sup>12</sup> or final postweld heat treatment, except the examination of weld metal cladding on P-Nos. 1 and 3 materials may be performed before or after the intermediate<sup>12</sup> or final postweld heat treatment.



**Table WC-5111-1**  
**Thickness, IQI Designations, Essential Holes, and Wire Diameters**

U.S. Customary Units								
Single Wall Material Thickness Range, in.	IQI(s) — Hole or Wire Type [Note (1)]							
	Source Side				Radiograph Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to 0.25 incl.	5	0.040	4 T	0.006	5	0.040	4 T	0.006
Over $\frac{1}{4}$ – $\frac{3}{8}$	7	0.040	4 T	0.006	7	0.040	4 T	0.006
Over $\frac{3}{8}$ – $\frac{1}{2}$	10	0.040	4 T	0.010	10	0.040	4 T	0.010
Over $\frac{1}{2}$ – $\frac{5}{8}$	12	0.050	4 T	0.013	12	0.050	4 T	0.013
Over $\frac{5}{8}$ – $\frac{3}{4}$	15	0.060	4 T	0.016	12	0.050	4 T	0.013
Over $\frac{3}{4}$ –1	20	0.040	2 T	0.016	17	0.035	2 T	0.013
Over 1–1 $\frac{1}{4}$	25	0.050	2 T	0.020	17	0.035	2 T	0.013
Over 1 $\frac{1}{4}$ –1 $\frac{1}{2}$	30	0.060	2 T	0.025	20	0.040	2 T	0.016
Over 1 $\frac{1}{2}$ –2	35	0.070	2 T	0.032	25	0.050	2 T	0.020
Over 2–2 $\frac{1}{2}$	40	0.080	2 T	0.040	30	0.060	2 T	0.025
Over 2 $\frac{1}{2}$ –3	45	0.090	2 T	0.040	35	0.070	2 T	0.032
Over 3–4	50	0.100	2 T	0.050	40	0.080	2 T	0.040
Over 4–6	60	0.120	2 T	0.063	45	0.090	2 T	0.040
Over 6–8	80	0.160	2 T	0.100	50	0.100	2 T	0.050
Over 8–10	100	0.200	2 T	0.126	60	0.120	2 T	0.063
Over 10–12	120	0.240	2 T	0.160	80	0.160	2 T	0.100
Over 12–16	160	0.320	2 T	0.250	100	0.200	2 T	0.126
Over 16–20	200	0.400	2 T	0.320	120	0.240	2 T	0.160
SI Units								
Single Wall Material Thickness Range, mm	IQI(s) — Hole or Wire Type [Note (1)]							
	Source Side				Radiograph Side			
	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI	Designation	Hole Size	Essential Hole	Required Wire Diameter — IQI
Up to 6 incl.	5	1.02	4 T	0.15	5	1.02	4 T	0.15
Over 6–10	7	1.02	4 T	0.15	7	1.02	4 T	0.15
Over 10–13	10	1.02	4 T	0.25	10	1.02	4 T	0.25
Over 13–16	12	1.27	4 T	0.33	12	1.27	4 T	0.33
Over 16–19	15	1.52	4 T	0.41	12	1.27	4 T	0.33
Over 19–25	20	1.02	2 T	0.41	17	0.89	2 T	0.33
Over 25–32	25	1.27	2 T	0.51	17	0.89	2 T	0.33
Over 32–38	30	1.52	2 T	0.64	20	1.02	2 T	0.41
Over 38–50	35	1.78	2 T	0.81	25	1.27	2 T	0.51
Over 50–64	40	2.03	2 T	1.02	30	1.52	2 T	0.64
Over 64–75	45	2.29	2 T	1.02	35	1.78	2 T	0.81
Over 75–100	50	2.54	2 T	1.27	40	2.03	2 T	1.02
Over 100–150	60	3.05	2 T	1.60	45	2.29	2 T	1.02
Over 150–200	80	4.06	2 T	2.54	50	2.54	2 T	1.27
Over 200–250	100	5.08	2 T	3.20	60	3.05	2 T	1.60
Over 250–300	120	6.10	2 T	4.06	80	4.06	2 T	2.54
Over 300–400	160	8.13	2 T	6.35	100	5.08	2 T	3.20
Over 400–500	200	10.16	2 T	8.13	120	6.10	2 T	4.06

NOTE:

(1) Hole (plaque) type IQIs may be used on flat plates and on objects with geometries such that the IQI hole image is not distorted.

(f) All of the joints in austenitic stainless steel and non-ferrous material shall be examined by the liquid penetrant method after an intermediate or final postweld heat treatment, if any, is performed.

(g) Ultrasonic examination of electrosag welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

### **WC-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES**

All full penetration weld edge preparation surfaces for joint Categories A, B, C, D, and similar joints in material 2 in. (50 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of  $\frac{3}{8}$  in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than  $\frac{3}{16}$  in. (5 mm) long;

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm);

(3) four or more indications, in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Category A, B, C, D, or similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

### **WC-5140 EXAMINATION OF ADJACENT BASE MATERIAL**

When performing the surface examinations of weld joint Categories A, B, C, and D as required by WC-5200, the external and accessible internal weld surfaces and adjacent base material for at least  $\frac{1}{2}$  in. (13 mm) on each side of the weld shall be included in the examination. Acceptance standards for the weld shall be as stated in this Article, while the acceptance standards for base material shall be as stated in WC-2500.

### **WC-5200 REQUIRED EXAMINATION OF WELDS**

#### **WC-5210 CATEGORY A LONGITUDINAL WELDED JOINTS**

Category A longitudinal welded joints shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

#### **WC-5220 CATEGORY B CIRCUMFERENTIAL WELDED JOINTS**

Category B welded joints shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

#### **WC-5230 CATEGORY C WELDED JOINTS**

##### **WC-5231 General Requirements**

Except for welds that meet the requirements of WC-3262 all Category C welded joints shall meet the following requirements:

(a) Category C Type No. 1 or Type No. 2 full penetration butt-welded joints shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

(b) Category C Type No. 1 or Type No. 2 full penetration corner-welded joints shall be ultrasonically or radiographically examined and either liquid penetrant or magnetic particle examined.

(c) Category C Type No. 2 full penetration corner-welded joints similar to Figure WC-4265-1 sketches (c), (d), and (f) also require the fusion zone and the parent metal beneath the attachment surface to be ultrasonically examined after welding to verify freedom from lack of fusion and laminar defects.

(d) Category C partial penetration and fillet welded joints shall be examined by either the magnetic particle or liquid penetrant method on all accessible surfaces.

#### **WC-5240 CATEGORY D WELDED JOINTS**

##### **WC-5241 General Requirements**

All Category D welded joints shall be examined as stated in the following paragraphs.

##### **WC-5242 Full Penetration Butt-Welded Nozzles**

Nozzles attached by full penetration butt-welded joints as shown in Figure WC-4266(a)-1 shall be examined by the radiographic and either the liquid penetrant or magnetic particle method.

##### **WC-5243 Corner-Welded Nozzles**

Full penetration corner-welded nozzles in containments as shown in Figure WC-4266(b)-1 shall be examined by either the ultrasonic or the radiographic method, and either the liquid penetrant or magnetic particle method. If radiographed, the weld fusion zone and

the parent metal beneath the attachment surface for details shown in [Figure WC-4266\(b\)-1](#) sketches (c), (d), (d-1), (e), and (g) and beneath the weld surface in sketches (a) and (b) shall be ultrasonically examined after welding to assure freedom from lack of fusion and laminar defects.

#### **WC-5244 Weld Metal Buildup at Openings for Nozzles**

When weld metal buildup is made to a surface as shown in Step 1 of [Figure WC-4266\(c\)-1](#), the weld metal buildup and the parent metal beneath the weld metal buildup shall be ultrasonically examined. The parent material beneath the weld metal buildup shall be ultrasonically examined to detect laminar defects after weld metal buildup. Nozzles may then be attached by a full penetration weld as shown in Step 2 of [Figure WC-4266\(c\)-1](#). The full penetration butt-welded joint shall be examined by either the ultrasonic or radiographic method, and either the liquid penetrant or magnetic particle method and the weld metal buildup shall be examined by either the magnetic particle or liquid-penetrant method.

#### **WC-5245 Other Welded Joints**

Other welded joints, as shown in [Figures WC-4266\(d\)-1](#) and [WC-4266\(e\)-1](#), shall be examined progressively using either the magnetic particle or liquid penetrant methods. The increments of examination shall be the lesser of one-half of the maximum welded joint dimension measured parallel to the center line of the connection or  $\frac{1}{2}$  in. (13 mm). The surface of the finished welded joint shall also be examined by either method.

#### **WC-5250 EXAMINATION OF CONTAINMENT CLOSURE WELDS**

Containment closure welds meeting the requirements of [WC-3262](#) shall be examined in accordance with (a) below:

(a) Full and partial penetration welds shall be examined in accordance with the requirements of [Table WC-3262-1](#). Acceptance criteria shall be in accordance with [WC-5340](#) or [WC-5350](#).

#### **WC-5260 FILLET, PARTIAL PENETRATION, SOCKET, AND ATTACHMENT WELDED JOINTS**

#### **WC-5261 Fillet, Partial Penetration, and Socket Welded Joints**

Fillet and partial penetration welded joints, except for nonstructural attachments and socket welds shall be examined by the magnetic particle or liquid penetrant method.

#### **WC-5262 Structural Attachment Welded Joints**

Structural attachment welded joints made to containment material shall be examined by either the magnetic particle or liquid penetrant method.

#### **WC-5270 SPECIAL WELDS AND BRAZED JOINTS**

#### **WC-5272 Weld Metal Cladding**

Weld metal cladding shall be examined by the liquid penetrant method.

#### **WC-5273 Hard Surfacing**

Hard surfacing weld metal shall be examined by the liquid penetrant method in accordance with [WC-2546](#), and the acceptance standards applicable to materials less than  $\frac{5}{8}$  in. (16 mm) thick shall apply.

#### **WC-5275 Brazed Joints**

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints which cannot be directly examined.

#### **WC-5277 Electron Beam Welds**

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electron beam welding process shall be ultrasonically examined.

#### **WC-5279 Special Exceptions**

Except for those closure welds addressed in [WC-5250](#), when the joint detail, or environmental conditions (e.g., background radiation), does not permit radiographic examination to be performed in accordance with this Article, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Article. The nondestructive examination shall be in accordance with [WC-5110](#) and meet the acceptance standards of [WC-5300](#).

**WC-5300 ACCEPTANCE STANDARDS****WC-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS**

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration;

(b) any indication characterized as incomplete penetration or incomplete fusion, except that such indications in welds between P-8 metals that were made using GTAW or SMAW in which the deposit analysis is A-8 or A-9 are acceptable provided they do not exceed the length in (c).

(c) any other elongated indication which has a length greater than:

(1)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(2)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. to  $2\frac{1}{4}$  in. (19 mm to 57 mm), inclusive

(3)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm)

where  $t$  is the thickness of the thinner portion of the weld;

(d) internal root weld conditions are acceptable when the density change or image brightness difference as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable, as provided in (c) above;

(e) any group of aligned indications having an aggregate length greater than  $t$  in a length of  $12t$ , unless the minimum distance between successive indications exceeds  $6L$ , in which case the aggregate length is unlimited,  $L$  being the length of the largest indication;

(f) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

**WC-5330 ULTRASONIC ACCEPTANCE STANDARDS**

All imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

(1)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(2)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. to  $2\frac{1}{4}$  in. (19 mm to 57 mm), inclusive

(3)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm)

where  $t$  is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld,  $t$  is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

**WC-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS****WC-5341 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

**WC-5342 Acceptance Standards**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks and linear indications;

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm);

(3) four or more rounded indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

**WC-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS****WC-5351 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications which are nonrelevant.

(b) Any indication which is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are indications which result from imperfections. Linear indications are indications in which the length is more than 3 times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than 3 times the width.

### **WC-5352 Acceptance Standards**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm);

(3) four or more rounded indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated.

### **WC-5360 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS**

Braze metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow visible line of brazing alloy at the end of the joint.

### **WC-5400 FINAL EXAMINATION OF CONTAINMENTS**

#### **WC-5410 EXAMINATION AFTER PRESSURE TEST**

After the hydrostatic or pneumatic pressure test of a containment, all weld joints and heat-affected zones of Categories A, B, C, and D, used to join ferritic material and repair welds in ferritic material that exceed in depth either  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness, whichever is less, shall be examined when physically accessible by the magnetic particle or liquid penetrant method.

## **WC-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL**

### **WC-5510 GENERAL REQUIREMENTS**

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by WC-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of WC-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

### **WC-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION**

#### **WC-5521 Qualification Procedure**

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.<sup>13, 14</sup> The ACCP Level II and III provisions for qualification and certification and the ASNT administered Level II certification provision for qualification and certification of NDE Personnel shall not be used for Section III. The Employer's<sup>15</sup> written practice, required by paragraph 5 of SNT-TC-1A, shall identify the requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered as minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by Employer,<sup>15</sup> ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may



be less than that recommended in Table 6.3.1 A of SNT-TC-1A. The time of training and experience shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times for visual examination personnel identified in Table 6.3.1 A of SNT-TC-1A for Level II certification may be reduced from 16 hr to 8 hr.

(4) For the near-vision acuity examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions, and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more

operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

### **WC-5522 Certification of Personnel**

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [WC-5521(a)(1)(-a)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

### **WC-5523 Verification of Nondestructive Examination Personnel Certification**

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations and qualified by them in accordance with WA-3820 and subcontractors who provide nondestructive examination services to them.

### **WC-5530 RECORDS**

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.



# ARTICLE WC-6000 TESTING

## WC-6100 GENERAL REQUIREMENTS

### WC-6110 SCOPE

(a) This Article contains the testing requirements for storage containments constructed in accordance with this Subsection.

(b) The terms test and testing as used in this Article include hydrostatic testing (WC-6200), pneumatic testing (WC-6300), and leak testing (WC-6700).

### WC-6120 TESTING OF CONTAINMENTS

Except for closure welds meeting the requirements of WC-3262 all storage containments shall be hydrostatically (WC-6200), or pneumatically (WC-6300) pressure tested, except as permitted by WC-6710. Closure welds made after containments are loaded and meeting the requirements of WC-3262 shall be tested as required by WC-6720.

### WC-6121 Pneumatic Testing

A pneumatic test in accordance with WC-6300 may be substituted for the hydrostatic test when permitted by the Design Specification.

**WC-6121.1 Pneumatic Test Limitations.** A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

**WC-6121.2 Precautions to Be Employed in Pneumatic Testing.** Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

### WC-6122 Witnessing of Tests

All testing required by this Article shall be performed in the presence of the Inspector.

### WC-6123 Time of Testing

**WC-6123.1 Containments.** Completed containments shall have all the testing required by this Article completed prior to initial service.

**WC-6123.2 Material Pressure Test.** The containment test may be used in lieu of any pressure test required by the material specification for material used in the containment provided

(a) nondestructive examinations, if required by the material specification, can be performed subsequent to the containment test;

(b) the material can be repaired by welding in accordance with the rules of WC-4130.

(c) postweld heat treatment, when required after repairs, can be performed in accordance with WC-4620.

### WC-6124 Machining After Testing

An additional amount of material, not to exceed 10% of the wall thickness or  $\frac{3}{8}$  in. (10 mm), whichever is less, is permitted on the completed item after testing where critical dimensions and tolerances is required.

## WC-6130 PREPARATION FOR TESTING

### WC-6131 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

### WC-6132 Addition of Temporary Supports

Containments designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid when hydrostatic testing is performed.

### WC-6133 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

### WC-6134 Isolation of Equipment Not Subjected to Testing

Equipment that is not to be subjected to the pressure test shall be either disconnected from the containment or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for the proposed test pressure.

### WC-6135 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

**WC-6136 Precautions Against Test Medium Expansion**

If a test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

**WC-6137 Check of Test Equipment Before Applying Pressure**

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

**WC-6200 HYDROSTATIC TESTS****WC-6210 HYDROSTATIC TEST PROCEDURE****WC-6211 Venting During Fill Operation**

The containment in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

**WC-6212 Test Medium and Test Temperature**

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture (Section III Appendices, Nonmandatory Appendix G). The test pressure shall not be applied until the containment and the pressurizing fluid are at approximately the same temperature.

**WC-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS****WC-6221 Minimum Hydrostatic Test Pressure**

The containment shall be hydrostatically tested at not less than 1.25 times Design Pressure.

**WC-6222 Maximum Permissible Test Pressure**

The stress limits specified in [WC-3218](#) shall be used in determining the maximum permissible test pressure. In multichamber containments, pressure may be simultaneously applied to the appropriate adjacent chamber to satisfy these stress limits.

**WC-6223 Hydrostatic Test Pressure Holding Time**

The hydrostatic test pressure shall be maintained a minimum of 10 minutes prior to initiation of the examination for leakage required by [WC-6224](#).

**WC-6224 Examination for Leakage After Application of Pressure**

Following the application of the hydrostatic test pressure for the required time ([WC-6223](#)), all joints, connections, and regions of high stress, such as regions around openings and thickness transition sections, shall be examined for leakage. This examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain test pressure for the required amount of time. Other leaks, such as those from permanent seals, seats, and gasketed joints in containments, may be permitted when specifically allowed by the Design Specification. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the containment to avoid masking leaks from other joints.

**WC-6300 PNEUMATIC TESTS****WC-6310 PNEUMATIC TESTING PROCEDURES****WC-6311 General Requirements**

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of [WC-6100](#) and this Article.

**WC-6312 Test Medium and Test Temperature**

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with [WC-6212\(b\)](#).

**WC-6313 Procedure for Applying Pressure**

The pressure in the system shall gradually be increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

**WC-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS****WC-6321 Minimum Required Pneumatic Test Pressure**

The containment shall be pneumatically tested at not less than 1.25 times Design Pressure.

**WC-6322 Maximum Permissible Test Pressure**

The maximum test pressure shall be limited as defined in [WC-6222](#).

**WC-6323 Test Pressure Holding Time**

The test pressure of [WC-6321](#) shall be maintained for a minimum total time of 10 minutes.

**WC-6324 Examination for Leakage After Application of Pressure**

Following the application of pressure for the time specified in [WC-6323](#), the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure and held for a sufficient time to permit examination as defined in accordance with [WC-6224](#).

**WC-6400 TEST GAGES****WC-6410****WC-6411 Types of Gages to Be Used and Their Location**

Test gages used in testing shall be indicating pressure gages and shall be connected directly to the item being tested. If the indicating gage is not readily visible to the operator controlling the test, an additional indicating gage shall be provided where it will be visible to the operator for the duration of the test.

**WC-6412 Range of Indicating Gages**

(a) Analog type indicating gages used in testing shall be graduated over a range not less than  $1\frac{1}{2}$  times nor more than 4 times the test pressure.

(b) Digital type gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

**WC-6413 Calibration of Pressure Test Gages**

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests using the same pressure test gage or gages which is conducted at the same site within a period not exceeding 2 weeks.

**WC-6600 SPECIAL TEST PRESSURE SITUATIONS****WC-6610 CONTAINMENTS DESIGNED FOR EXTERNAL PRESSURE**

Containments designed for external pressure only shall be subjected to an internal test pressure at 1.25 times the Design External Pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more than 6%.

**WC-6620 PRESSURE TESTING OF COMBINATION UNITS****WC-6621 Pressure Chambers Designed to Operate Independently**

Pressure chambers of combination units that have been designed to operate independently shall be tested as separate containments; that is, each chamber shall be tested without pressure in the adjacent chamber.

**WC-6622 Common Elements Designed for a Maximum Differential Pressure**

(a) When chambers of combination units have their common elements designed for the maximum differential pressure and the differential pressure is less than the higher of the Design Pressure of the adjacent chambers, the common elements shall be subjected to a test pressure of at least  $1\frac{1}{4}$  times the maximum differential pressure.

(b) Following the test of the common elements, as required by (a) above and their inspection, the adjacent chambers shall be tested. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

**WC-6700 LEAK TESTING****WC-6710 HELIUM LEAK TESTING**

(a) Helium leak testing of containment welds, other than closure welds of [WC-3262](#), may be substituted for pressure testing if the primary membrane stress due to a hydrostatic ([WC-6200](#)) or pneumatic ([WC-6300](#)) test does not exceed the smaller of the one-third of the minimum specified minimum yield strength or one-fifth of the minimum specified tensile strength of the containment material and when specified in the Design Specification.

(b) Helium leak testing shall be conducted in accordance with Section V, Article 10, and ANSI N14.5, Leakage Tests on Packages for Shipment.<sup>16</sup> Personnel performing leak testing shall be qualified in accordance with [Article WC-5000](#).

(c) The allowable volumetric leakage rate shall be defined in the Design Specification. An acceptable method to determine the maximum, permissible volumetric leakage rate can be found in ANSI N14.5.

(d) If a single leak-rate test is conducted, the conversion methods in ANSI N14.5 shall be used to determine if the leakage rates specified in the Design Specification have been met.

## **WC-6720 CONTAINMENT CLOSURES**

(a) Closure welds identified in the Design Specification as meeting the requirements of [WC-3262](#), and mechanical closures and seals shall be helium leak tested.

(b) Helium leak testing shall be conducted in accordance with Section V, Article 10, and ANSI N14.5. Personnel performing helium leak-rate testing shall be qualified in accordance with [Article WC-5000](#).

(c) The allowable volumetric leakage rate shall be defined in the Design Specification. An acceptable method to determine the maximum, permissible volumetric leakage rate can be found in ANSI N14.5.

(d) If a single leak-rate test is conducted, the conversion methods in ANSI N14.5 shall be used to determine if the leakage rates specified in the Design Specification have been met.

# **ARTICLE WC-8000 NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORTS**

## **WC-8100 GENERAL REQUIREMENTS**

The requirements for nameplates, stamping with the Certification Mark, and reports are contained in [Article WA-8000](#).

# SUBSECTION WD

# CLASS ISS INTERNAL SUPPORT STRUCTURES

(17)


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## ARTICLE WD-1000 INTRODUCTION

### WD-1100 SCOPE AND GENERAL REQUIREMENTS

#### WD-1110 SCOPE

(a) Subsection WD contains rules for the material, design, fabrication, examination, marking, stamping, and preparation of reports by the Certificate Holder for Class ISS internal support structures for spent nuclear fuel and high-level radioactive material. These internal support structures<sup>22</sup> are for use in transportation (Class TC) or storage (Class SC) containments.

(b) The rules of Subsection WD cover the requirements for strength integrity of items, the failure or excessive deformation of which would cause loss of geometric configuration of the containment contents. Geometric configuration is defined as maintaining geometry of the contents as required by the Design Specification to maintain the relative physical location of the contents (e.g., criticality control and/or damage from physical contact). Acceptable deformations shall be defined by the Design Specification. Deformations may be demonstrated to be acceptable by the use of analytical methods or testing. The rules address load stresses but do not address deterioration that may occur in service as a result of corrosion, erosion, radiation effects, or instability of internal support structure material. These shall be addressed in the Design Specification by requiring appropriate prevention or mitigation measures to be included in the design (WA-1130).

(c) The rules of Subsection WD do not address pressure-retaining or containment boundary components.

(d) The rules of Subsection WD do not apply to internal structures of containment systems where geometric configuration is not required unless required by the Design Specification.

### WD-1120 LIMITS OF RULES FOR CLASS ISS INTERNAL SUPPORT STRUCTURES

(a) Subsection WD does not contain rules to cover all details of construction of internal support structures. Where complete details are not provided in this Subsection, it is intended that the N3 Certificate Holder, subject to review by the Inspector (Article WA-5000), shall provide the details of construction that will be consistent with the rules provided in this Subsection.

(b) Items that facilitate containment operations (e.g., vent and drain tubes, neutron moderator materials, and shielding) are not included as part of the internal support structure unless they are relied on to supplement the structural integrity of the internal support structure.

### WD-1130 BOUNDARIES OF JURISDICTION

#### WD-1131 Boundaries Between the Internal Support Structure and Containment

The jurisdictional boundary between the internal support structure and containment shall be as defined in (a) through (d) below.

(a) The jurisdictional boundary between an internal support structure and the containment shall be the inner surface of the containment.

(b) The first connecting weld of an internal support structure to the containment shall be considered part of the containment unless the weld is more than  $2t$  from the boundary of the containment, where  $t$  is the nominal thickness of the containment material.

(c) Beyond the first connecting weld to the containment, or beyond  $2t$  from the boundary of the containment, the attachment or other welds shall be considered part of the internal support structure, unless otherwise specified in the Design Specification.

(d) Mechanical fasteners used to connect an internal support structure to the containment shall meet the requirements of the containment. The effects of holes into the containment material shall be addressed by the appropriate containment rules.



Figure WD-1131-1 is provided as an aid in defining the boundary and construction requirements of this Subsection.

### WD-1132 Boundaries Between the Internal Support Structure and Nonstructural Items

The jurisdictional boundary between the internal support structure and nonstructural items (e.g., criticality poisons, vent and drain piping) shall be as defined in (a) and (b) below.

(a) Welds used to connect a nonstructural item to the internal support structure shall be considered part of the internal support structure.

(b) Mechanical fasteners used to connect a nonstructural item to the internal support structure shall be considered part of the internal support structure.

### WD-1132.1 Attachments.

(a) An attachment is an element in contact with or connected to the inside or outside surface of the internal support structure.

(b) Attachments may have either a structural or nonstructural function.

(1) Attachments with a structural function (structural attachments)

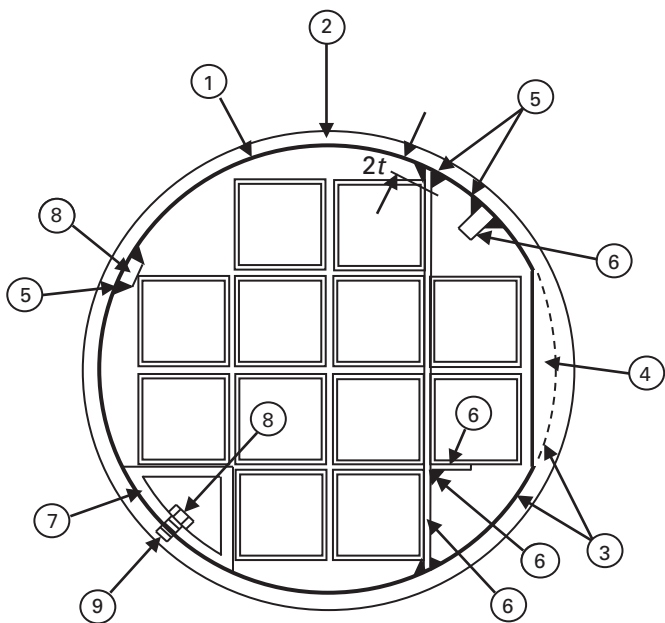
(-a) perform a geometry control function

(-b) are in the internal support structure load path

(-c) may be permanent or temporary

(2) Nonstructural attachments include items such as nameplates, insulation supports, drain tubes, locating lugs, and lifting lugs that are not in the structural load path during operations involving spent nuclear fuel or high-level radioactive material.

**Figure WD-1131-1**  
**Jurisdictional Boundary Between the Internal Support Structure and the Containment**



- ① Jurisdictional boundary (heavy line).
- ② Containment shall conform to Subsection WB or WC requirements as appropriate.
- ③ Boundary of the containment.
- ④ Weld buildup shall conform to Subsection WB or WC requirements as appropriate.
- ⑤ At or within  $2t$  from the boundary of the containment, the first connecting weld shall conform to Subsection WB or WC requirements as appropriate.
- ⑥ Beyond  $2t$  from the boundary of the containment or beyond the first connecting weld, the attachment or weld shall conform to Subsection WD requirements.
- ⑦ Attachment connection shall conform to Subsection WD requirements.
- ⑧ At or within  $2t$  from the boundary of the containment, the interaction effects of the attachment shall conform to Subsection WB or WC requirements as appropriate.
- ⑨ Drilled or threaded holes through the boundary of the containment and into the containment shall conform to Subsection WB or WC requirements as appropriate.

#### GENERAL NOTES:

(a) The sketch is intended to show jurisdictional concepts and should not be considered as recommended configurations.

(b) If the attachment is an internal structure [WD-1110(d)], material, design, and connections, as appropriate, are outside Code jurisdiction except when the N3 Certificate Holder stipulates in the Design Specification that it shall conform to Subsection WD.

## ARTICLE WD-2000 MATERIAL

### WD-2100 GENERAL REQUIREMENTS FOR MATERIAL

#### WD-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term Material Organization is defined in Article NCA-9000.

(b) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate*: the thickness is the dimension of the short transverse direction

(2) *forgings*: the thickness is the dimension defined as follows:

(-a) *hollow forgings*: the nominal thickness is measured between the inside and outside surfaces (radial thickness)

(-b) *disk forgings* (axial length less than the outside diameter): the nominal thickness is the axial length

(-c) *flat ring forgings* (axial length less than the radial thickness): for axial length  $\leq 2$  in. (50 mm), the axial length is the nominal thickness; for axial length  $> 2$  in. (50 mm), the radial thickness is the nominal thickness

(-d) *rectangular solid forgings*: the least rectangular dimension is the nominal thickness

### WD-2120 MATERIAL FOR INTERNAL SUPPORT STRUCTURES

#### WD-2121 Permitted Material Specifications

(a) Internal support structural material, and material welded thereto, and bolting materials, with the exception of welding material (WD-2400), hard surfacing material (Section IX, QW-251.4), or cladding, which is 10% or less of the thickness of the base material (WD-3122), shall conform to the requirements of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, including all applicable notes in the table, and to all of the special requirements of this Article that apply to the product form in which the material is used.

(b) The Certificate Holder shall certify that the material used for the internal support structures shall not adversely affect the integrity of the applicable containment.

(c) Welding material used in manufacture of items shall comply with an SFA Specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also

comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

#### WD-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (NCA-4256). Where the special requirements include an examination, test, or treatment that is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in WD-2500. Any examination, repair, test, or treatment required by the material specification or this Article may be performed by the Material Organization or the Certificate Holder as provided in WD-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

#### WD-2124 Size Ranges

Material outside the limits of size, weight, or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition, mechanical properties, or both are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-4256).

#### WD-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

**WD-2130 CERTIFICATION OF MATERIAL**

All material used in the construction or installation of internal support structures shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for internal support material except as provided by NCA-3861. A Certificate of Compliance may be provided in lieu of Certified Material Test Reports for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in an internal support structure shall be furnished with the material.

**WD-2140 WELDING MATERIAL**

For the requirements governing the material to be used for welding, see [WD-2400](#).

**WD-2150 MATERIAL IDENTIFICATION**

The identification of material for internal support structures shall meet the requirements of NCA-4256. Material for small items shall be controlled during manufacture of the internal support structures so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of internal support structures so that they are identifiable as acceptable material until the material is actually consumed in the process ([WD-4122](#)).

**WD-2160 DETERIORATION OF MATERIAL IN SERVICE**

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications ([WA-3351](#)), with specific attention being given to the effects of service conditions upon the properties of the material.

**WD-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES**

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

**WD-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL**

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and temperature-calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material

or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

**WD-2190 TEMPORARY ATTACHMENT MATERIAL**

Material used for temporary attachments need not comply with [Article WD-2000](#) and may be welded to the internal support structure provided the requirements of [WD-4430](#) are met.

**WD-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL****WD-2210 HEAT TREATMENT REQUIREMENTS****WD-2211 Test Coupon Heat Treatment for Ferritic Material**

Where ferritic steel material is subjected to heat treatment during construction, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the internal support structures, except that test coupons and specimens for P-No. 1 Groups Nos. 1 and 2 material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rates to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

**WD-2212 Test Coupon Heat Treatment for Quenched and Tempered Material**

**WD-2212.1 Cooling Rates.** Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings ([WD-2223.3](#)). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in [WD-2212.2](#) or one of the specific procedures described in [WD-2220](#) shall be used for each product form.

**WD-2212.2 General Procedures.** One of the general procedures stipulated in (a) through (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with WD-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used that can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ( $1/4t$ ) and no nearer any heat treated edge than a distance equal to the nominal thickness  $t$  being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in WD-2220 are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least  $t$  from a quenched edge, where  $t$  equals the material thickness;

(2) attaching a steel pad at least  $t$  wide by a partial penetration weld, which completely seals the buffered surface, to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

## **WD-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL**

### **WD-2221 General Requirements**

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by this subarticle. References to dimensions signify nominal values.

### **WD-2222 Plates**

**WD-2222.1 Number of Tension Test Coupons.** The number of tension test coupons required shall be in accordance with the material specification and SA-20, except that from carbon steel plates weighing 42,000 lb (19 000 kg) and over and alloy steel plates weighing

40,000 lb (18 000 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

**WD-2222.2 Orientation and Location of Coupons.** Coupons shall be taken so that specimens shall have their longitudinal axes at least  $1/4t$  from a rolled surface and with the midlength of the specimen at least  $t$  from any heat treated edge, where  $t$  is the nominal thickness of the material.

**WD-2222.3 Requirements for Separate Test Coupons.** Where a separate test coupon is used to represent the internal support structure material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least  $1/4t$  deep and  $t$  from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with WD-2212.2(b), the dimensions of the coupon shall be not less than  $3t \times 3t \times t$ , where  $t$  is the nominal material thickness.

### **WD-2223 Forgings**

**WD-2223.1 Location of Coupons.** Coupons shall be taken so that specimens shall have their longitudinal axes at least  $1/4t$  from any surface and with the midlength of the specimens at least  $t$  from any second surface, where  $t$  is the maximum heat treated thickness. A thermal buffer as described in WD-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in WD-2212.2.

**WD-2223.2 Very Thick and Complex Forgings.** Test coupons for forgings that are both very thick and complex, such as contour nozzles, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than  $3/4$  in. (19 mm) to any heat treated surface and the midlength of the specimens shall be at least  $1\frac{1}{2}$  in. (38 mm) from any second heat treated surface.

**WD-2223.3 Coupons From Separately Produced Test Forgings.** Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in the following:

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the forging thickness except when the thickness-to-length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with [WD-2223.2](#).

### WD-2224 Location of Coupons

(a) *Bars.* Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from the outside or rolled surface and with the midlength of the specimens at least  $t$  from a heat treated end, where  $t$  is either the bar diameter or thickness

(b) *Bolting Material.* For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

### WD-2225 Tubular Products and Fittings

**WD-2225.1 Location of Coupons.** Coupons shall be taken so that specimens shall have their longitudinal axes at least  $\frac{1}{4}t$  from the inside or outside surface and with the midlength of the specimens at least  $t$  from a heat treated end, where  $t$  is the nominal wall thickness of the tubular product.

**WD-2225.2 Separately Produced Coupons Representing Fittings.** Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of [WD-2223.3](#) shall be met.

## WD-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

### WD-2310 MATERIAL TO BE IMPACT TESTED

#### WD-2311 Components for Which Impact Testing of Material Is Required

(a) When the Design Specification for internal support structures requires impact testing, they shall be impact tested in accordance with the requirements of [WD-2300](#) or Section III Appendices, Nonmandatory Appendix G may be used as an alternative procedure for assuring protection against nonductile fracture, except that the following materials are not to be impact tested as a requirement of this Subsection:

(1) material with a nominal section thickness of  $\frac{5}{8}$  in. (16 mm) and less

(2) bolting, including studs, nuts, and bolts with a nominal size of 1 in. (25 mm) and less

(3) bars with a nominal cross-sectional area of 1 in.<sup>2</sup> (650 mm<sup>2</sup>) and less

(4) all thicknesses of materials for pipe, tube, and fittings with an NPS 6 (DN 150) diameter and smaller

(5) austenitic stainless steels, including precipitation-hardened austenitic Grade 660 (UNS S66286)

(6) nonferrous material

(b) Drop weight tests are not required for martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The other requirements of [WD-2331](#) and [WD-2332](#) apply for these steels. For nominal wall thickness greater than  $2\frac{1}{2}$  in. (64 mm), the required  $C_v$  value shall be 40 mils (1.00 mm) lateral expansion.

## WD-2320 IMPACT TEST PROCEDURES

### WD-2321 Types of Tests

**WD-2321.1 Drop Weight Tests.** The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-1, P-2, or P-3 may be used. The orientations and locations of all test specimens and the results of all tests performed to meet the requirements of [WD-2330](#) shall be reported in the Certified Material Test Report.

**WD-2321.2 Charpy V-Notch Tests.** The Charpy V-notch test ( $C_v$ ), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Fig. 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral



expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of [WD-2330](#) shall be reported in the Certified Material Test Report.

## WD-2322 Test Specimens

**WD-2322.1 Location of Test Specimens.** Impact test specimens for quenched and tempered material shall be removed from the locations in each product form specified in [WD-2220](#) for tensile test specimens. For material in other heat treated conditions, impact test specimens shall be removed from the locations specified for tensile specimens in the material specification. For all other material, the number of tests shall be in accordance with [WD-2340](#). For bolting, the  $C_v$  impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

### WD-2322.2 Orientation of Impact Test Specimens.

(a) Specimens for Charpy V-notch tests shall be oriented as follows:

(1) Specimens for forgings, other than bolting and bars, shall be oriented in a direction normal to the principal direction in which the material was worked. Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate, shall be oriented in the axial direction.

(3) Specimens from bolting material and bars shall be oriented in the axial direction.

(4) Specimens for all plate material, including those used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) In (1) through (4) above, the length of the notch of the  $C_v$  specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

## WD-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS<sup>23</sup>

### WD-2331 Material for Internal Support Structures Not Exceeding 2 in. (50 mm) Maximum Thickness

Material for internal support structures (other than bolting) with nominal thickness 2 in. (50 mm) and less shall be tested as required in the following:

(a) Test three  $C_v$  specimens at a temperature lower than or equal to the lowest service temperature. All three specimens shall meet the requirements of [Table WD-2331\(a\)-1](#).

(b) Apply the procedures of (a) above to:

(1) base material,<sup>24</sup>

(2) the base material, the heat affected zone, and weld metal from the weld procedure qualification tests in accordance with [WD-4330](#), and

(3) the weld metal of [WD-2431](#).

### WD-2332 Material With Thickness Exceeding 2 in. (50 mm)

Material for internal support structures (other than bolting) with nominal thickness over 2 in. (50 mm) shall meet the following requirements:

(a) Establish a reference temperature  $RT_{NDT}$ ; this shall be done as required in (1) through (5) below:

(1) Determine a temperature  $T_{NDT}$  that is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than [ $T_{NDT} + 60^\circ\text{F}$  ( $33^\circ\text{C}$ )], each specimen of the  $C_v$  test ([WD-2321.2](#)) shall exhibit at least 35 mils (0.89 mm) lateral expansion and not less than 50 ft-lb (68 J) absorbed energy. Retesting in accordance with [WD-2350](#) is permitted. When these requirements are met,  $T_{NDT}$  is the reference temperature  $RT_{NDT}$ .

(3) In the event that the requirements of (2) above are not met, conduct additional  $C_v$  tests in groups of three specimens ([WD-2321.2](#)) to determine the temperature  $T_{C_v}$  at which they are met. In this case, the reference

**Table WD-2331(a)-1  
Required  $C_v$  Values for Internal Support  
Structure Material With 2 in. (50 mm)  
Maximum Thickness (Other Than Bolting)**

Nominal Thickness, in. (mm),	Lateral Expansion, mils (mm)
$\frac{5}{8}$ (16) or less	No test required
Over $\frac{5}{8}$ to $\frac{3}{4}$ (16 to 19), incl.	20 (0.50)
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	25 (0.64)
Over $1\frac{1}{2}$ to 2 (38 to 50), incl.	40 (1.00)



temperature  $RT_{NDT} = T_{C_v} - 60^\circ\text{F}$  ( $33^\circ\text{C}$ ). Thus, the reference temperature  $RT_{NDT}$  is the higher of  $T_{NDT}$  or [ $T_{C_v} - 60^\circ\text{F}$  ( $33^\circ\text{C}$ )].

(4) When a  $C_v$  test has not been performed [ $T_{NDT} + 60^\circ\text{F}$  ( $33^\circ\text{C}$ )] or when the  $C_v$  test at [ $T_{NDT} + 60^\circ\text{F}$  ( $33^\circ\text{C}$ )] does not exhibit a minimum of 50 ft-lb (68 J) energy absorption and 35 mils (0.89 mm) lateral expansion, a temperature representing a minimum of 50 ft-lb (68 J) energy absorption and 35 mils (0.89 mm) lateral expansion may be obtained from a full  $C_v$  impact curve developed from the minimum data points of all the  $C_v$  tests performed.

(5) The lowest service temperature shall be not lower than  $RT_{NDT} + 100^\circ\text{F}$  ( $56^\circ\text{C}$ ) unless a lower temperature is justified by using methods similar to those contained in Section III Appendices, Nonmandatory Appendix G.

(b) Apply the procedures of (a) above to

(1) the base material

(2) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with [WD-4330](#)

(3) the weld metal of [WD-2431](#)

(c) Product forms having dimensions that prohibit obtaining drop weight test specimens shall be tested in accordance with [WD-2331](#).

(d) Consideration shall be given to the effects of irradiation on material toughness properties. The Design Specification shall include additional requirements, as necessary, to assure adequate fracture toughness for the service lifetime of the internal support structures. The toughness properties may be verified in service periodically by a material surveillance program using the methods of ASTM E185 and the material conditions monitored by the inservice inspection requirements of Section XI.

### WD-2333 Bolting

For bolting material, including studs and nuts, test three  $C_v$  specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is the lesser. All three specimens shall meet the requirements of [Table WD-2333-1](#).

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
1 (25) through 4 (100)	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

### WD-2340 NUMBER OF IMPACT TESTS REQUIRED

#### WD-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the nonheat-treated condition and qualified by heat treated test specimens, one test shall be made for each plate as-rolled. The term as-rolled refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

#### WD-2342 Forgings

(a) Where the weight of an individual forging is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

(c) One test shall be made for each forging of 1,000 lb to 10,000 lb (450 kg to 4 500 kg) in weight.

(d) As an alternative to (c) above, a separate test forging may be used to represent forgings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or  $C_v$  impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging 180 deg apart.

#### WD-2343 Bars

One test shall be made for each diameter or size having a nominal cross-sectional area greater than 1 in.<sup>2</sup> in each lot, where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

#### WD-2344 Tubular Products and Fittings

On products that are seamless or welded without filler metal, one test shall be made from each lot. On products that are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than  $\frac{1}{4}$  in. (6 mm); such a lot shall be in a single heat treatment load or in the same

continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

### WD-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight the following:

Diameter, in. (mm)	Weight, lb (kg)
1 <sup>3</sup> / <sub>4</sub> (45) and less	1,500 (700)
Over 1 <sup>3</sup> / <sub>4</sub> to 2 <sup>1</sup> / <sub>2</sub> (45 to 64)	3,000 (1 350)
Over 2 <sup>1</sup> / <sub>2</sub> to 5 (64 to 125)	6,000 (2 700)
Over 5 (125)	10,000 (4 500)

### WD-2346 Test Definition

Unless otherwise stated in [WD-2341](#) through [WD-2345](#), the term *one test* is defined to include the combination of the drop weight test and the  $C_v$  test when  $RT_{NDT}$  is required ([WD-2332](#)) and only the  $C_v$  test when determination of  $RT_{NDT}$  is not required ([WD-2331](#)).

### WD-2350 RETESTS

(a) For  $C_v$  tests required by [WD-2330](#), one retest at the same temperature may be conducted, provided:

- (1) the average value of the test results meets the minimum requirements
- (2) not more than one specimen per test is below the minimum requirements
- (3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb (13.6 J) or 5 mils (0.13 mm) below the specified requirements

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retest, both specimens shall meet the minimum requirements.

### WD-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and  $C_v$  impact test machines used in impact testing shall be performed at the frequency specified in the following:

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-4258.2 at least once in each 3-month interval.

(b)  $C_v$  test machines shall be calibrated and the results recorded to meet the requirements of NCA-4258.2. The calibrations shall be performed using the frequency and methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology, or any supplier of subcontracted calibration services accredited in accordance with the requirements of [WA-3123](#) and NCA-4258.2(c).

## WD-2400 WELDING MATERIAL

### WD-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for hard surfacing, shall conform to the requirements of the material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this subarticle and to the rules covering identification in [WD-2150](#).

(b) The Certificate Holder shall provide the organization performing the testing with the following information, as applicable:

- (1) welding process
- (2) SFA Specification and classification
- (3) other identification if no SFA Specification applies
- (4) minimum tensile strength [[WD-2431.1\(e\)](#)] in either the as-welded or heat-treated condition or both [[WD-2431.1\(c\)](#)]
- (5) drop weight test for material as-welded or heat treated or both ([WD-2332](#))
- (6) Charpy V-notch test for material as-welded or heat treated or both ([WD-2331](#)); the test temperature, and the lateral expansion or the absorbed energy, shall be provided
- (7) the preheat and interpass temperatures to be used during welding of the test coupon [[WD-2431.1\(c\)](#)]
- (8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [[WD-2431.1\(c\)](#)]
- (9) elements for which chemical analysis is required per the SFA Specification or WPS, and [WD-2432](#)
- (10) minimum delta ferrite ([WD-2433](#))

### WD-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, and PAW processes (Section IX); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; or for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by [Article WD-4000](#) and this subarticle are made and the results conform to the requirements of this Article. The following definitions apply:

(a) *dry batch of covering mixture*: the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be

subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes [see (c)].

(b) *dry blend*: one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) *wet mix*: the combination of a dry batch or dry blend [(a) and (b), respectively] and liquid binder ingredients at one time in one mixing vessel.

(d) *lot of covered, flux cored, or fabricated electrodes*: the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrodes.

(1) *chemically controlled tube, wire, or strip*: consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to ensure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed, except those coils that are splice free need only be analyzed on one end of the coil.

(2) *chemically controlled mixes of flux*: flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) *heat of bare electrode, rod, wire, or consumable insert*: the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with SAW, OFW, GMAW, GTAW, and PAW, processes, a *heat* may be defined as either the material produced from the same melt of metal, or the material produced from one type and size of wire when produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled wire, subject to the following requirements:

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil

of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be determined to identify the material to ensure that it conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) *dry blend of supplementary powdered filler metal*: one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9 000 kg), from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel.

(h) *chemically controlled mix of powdered filler metal*: powdered filler metal material that has been chemically analyzed to ensure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

## WD-2430 WELD METAL TESTS

### WD-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding material used to join P-Nos. 1, 3 through 7, 9, and 11 base materials in any combination, with the following exceptions:

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers.

(b) consumable inserts (backing filler material).

(c) welding material used for GTAW root deposits with a maximum of two layers.

(d) welding material to be used for the welding of base material exempted from impact testing by WD-2300 shall likewise be exempted from the impact testing required by this paragraph.

**WD-2431.1 General Test Requirements.** The welding test coupon shall be made in accordance with (a) through (f) below using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. The base material shall conform with the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component.

(d) The tensile specimens, and the  $C_v$  impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1 or the applicable SFA Specification. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of [WD-2321.1](#) and [WD-2321.2](#) shall apply. The longitudinal axis of the specimen shall be at a minimum depth of  $\frac{1}{4}t$  from a surface, where  $t$  is the thickness of the test weld.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the requirements of [WD-2330](#) applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

**WD-2431.2 Standard Test Requirements.** In lieu of the use of the General Test Requirements specified in [WD-2431.1](#), tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in [WD-2431](#), shall apply for this Standard Test

Requirements option. The limitations and testing under this Standard Test Requirements option shall be in accordance with the following:

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specification SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of  $C_v$  specimens and the drop weight test specimens required by [WD-2330](#), where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat treated condition. The postweld heat treatment (PWHT) temperatures shall be in accordance with [Table WD-4622.1-1](#) for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). Where the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required above, the general test of [WD-2431.1](#) shall be used.

(d) The tensile and  $C_v$  specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in [WD-2431.1\(d\)](#).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of [WD-2431.1\(f\)](#) shall be applicable to the impact testing of this option.

## WD-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with [WD-2420](#) and as required by the following subparagraphs.

**WD-2432.1 Test Method.** The chemical analysis test shall be performed in accordance with this subparagraph and [Table WD-2432.1-1](#), and the results shall conform to [WD-2432.2](#).

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal



of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for either the filler metal analysis or the undiluted weld deposit analysis or for *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA Specification, the sample shall be removed from a weld pad, groove, or other test weld made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The methods given in the Appendix of SFA-5.9 shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution. The weld for A-No. 8 material to be used with the GMAW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. Where a chemical analysis is required for a welding material that does not have a Mechanical Properties Test requirement, a chemical analysis test coupon shall be prepared as required by WD-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of WD-2431.1(c) do not apply.

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion-resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214. The removal of chemical analysis samples shall conform with Table QW-453 for the minimum thickness for which the Welding Procedure Specification is qualified.

**WD-2432.2 Requirements for Chemical Analysis.**

The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with the following:

(a) All welding material shall be analyzed for the elements listed in Table WD-2432.2-1 and for other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

**Table WD-2432.1-1  
Sampling of Welding Materials for Chemical Analysis**

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3862.1. Elements listed in Table WD-2432.2-1 but not specified in the welding material specification shall be reported for information only.

**WD-2433 Delta Ferrite Determination**

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

**WD-2433.1 Method.** Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding

**Table WD-2432.2-1  
Welding Material Chemical Analysis**

Materials	Elements
Carbon and low alloy materials	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cu
Chromium and Cr-Ni stainless material	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb + Ta, Ti, Cu
Nickel and Ni-alloy materials	C, Cr, Mo, Ni, Mn, Si, S, Cb + Ta, Cu, Fe, Co

materials may be performed by the use of chemical analysis of [WD-2432](#) in conjunction with [Figure WD-2433.1-1](#).

(a) Calibration of magnetic instruments shall conform to AWS A4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with [WD-2432.1\(c\)](#).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

**WD-2433.2 Acceptance Standards.** The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of [WD-2130](#) or [WD-4120](#).

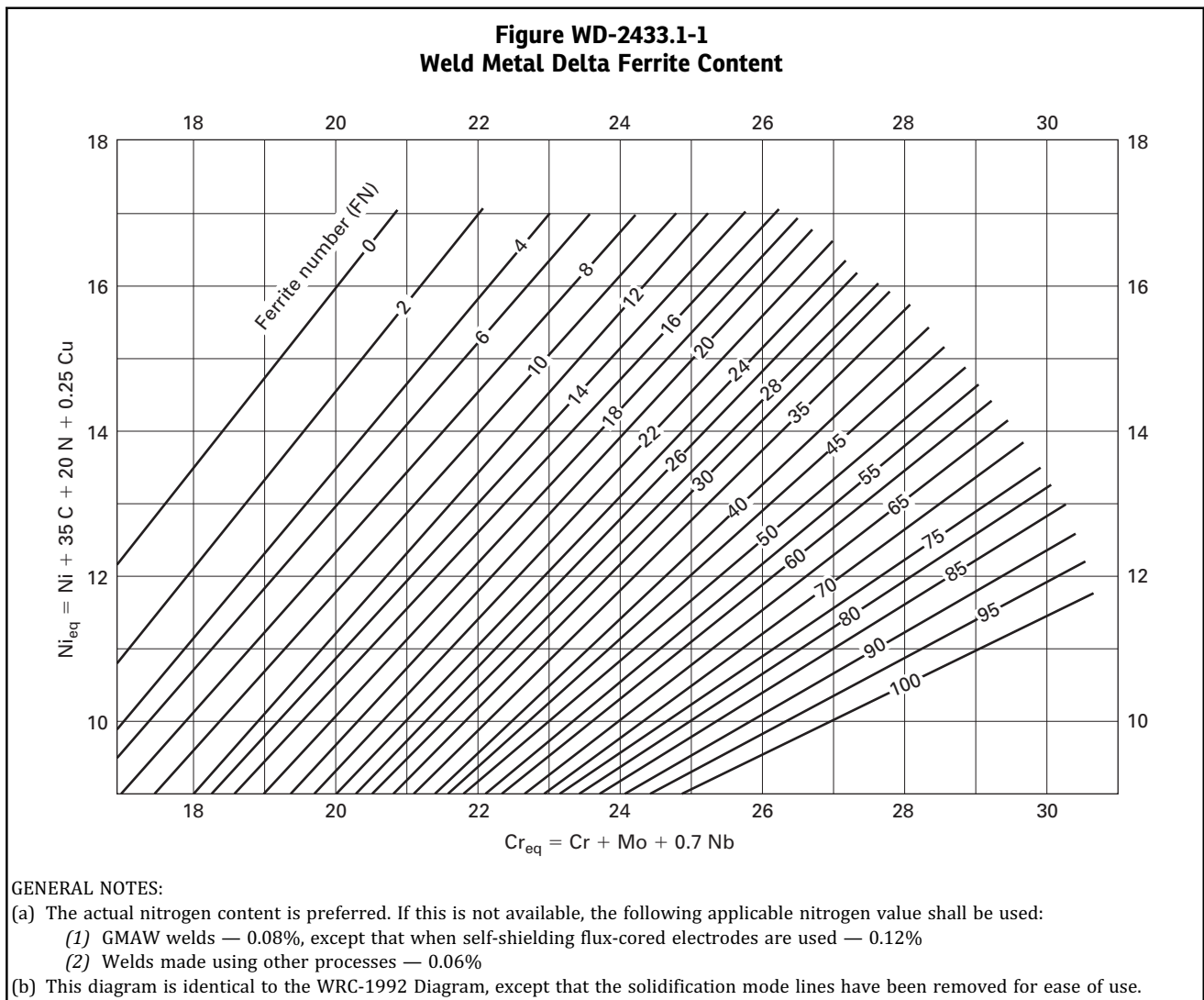
**WD-2440 STORAGE AND HANDLING OF WELDING MATERIAL**

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

**WD-2500 EXAMINATION AND REPAIR OF INTERNAL SUPPORT STRUCTURE MATERIAL**

**WD-2510 EXAMINATION OF INTERNAL SUPPORT STRUCTURE MATERIAL**

Material for internal support structures shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this subarticle.





## WD-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this subarticle for each product form after the quenching and tempering phase of the heat treatment.

## WD-2530 EXAMINATION AND REPAIR OF PLATE

### WD-2531 Required Examination

All plates for internal support structures greater than  $\frac{3}{4}$  in. (19 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with [WD-2532.1](#).

### WD-2532 Examination Procedures

**WD-2532.1 Straight Beam Examination.** The requirements for straight beam examination shall be in accordance with SA-578, Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in the following:

(a) *Extent of Examination.* 100% of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

(b) *Acceptance Standards*

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (75 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the largest imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

### WD-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in the following:

(a) *Ultrasonic examination* shall be performed after rolling to size and after heat treatment, except postweld heat treatment.

(b) *Radiographic examination* of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) *Magnetic particle or liquid penetrant examination of repair welds* in ferritic material shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No. 1 material 2 in. (50 mm) and less nominal thickness. All repair welds in austenitic and nonferrous material may be liquid penetrant examined prior to any required postweld heat treatment.

## WD-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining provided the following requirements are met:

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface with not less than a 3:1 taper.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with [WD-2545](#) or the liquid penetrant method in accordance with [WD-2546](#) to assure that the defect has been removed or reduced to an imperfection of an acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of [Article WD-3000](#), the product shall be repaired in accordance with [WD-2539](#).

### WD-2539 Repair by Welding

Material from which defects have been removed may be repaired by welding, provided the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for any repair of plates to be used in the manufacture of internal support structures.

**WD-2539.1 Defect Removal.** The defect shall be removed or reduced to an imperfection of an acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair ([WD-4211](#)).

**WD-2539.2 Qualification of Welding Procedures and Welders.** The welding procedure and welders or welding operators shall be qualified in accordance with [WD-4300](#) and Section IX.

**WD-2539.3 Blending of Repaired Areas.** After repair, the surface shall be blended uniformly into the surrounding surface.

**WD-2539.4 Examination of Repair Welds.** Each repair weld shall be examined by the magnetic particle method ([WD-2545](#)) or by the liquid penetrant method ([WD-2546](#)). In addition, when the depth of the repair cavity exceeds the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with [Article WD-5000](#) and to the acceptance standards of [WD-5320](#) or shall be ultrasonically examined after repair in accordance with [WD-2532.1](#).

**WD-2539.5 Heat Treatment After Repairs.** The product shall be heat treated after repair in accordance with the heat treatment requirements of [WD-4620](#).

**WD-2539.6 Material Report Describing Defects and Repairs.** Each defect repair exceeding in depth the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness and, in addition, all repair welds exceeding an accumulated area

of 20% of the area of the part or 15 in.<sup>2</sup> (9 700 mm<sup>2</sup>), whichever is less, shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

## **WD-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS**

### **WD-2541 Required Examinations**

(a) Forgings and bars except as noted in [WD-2551\(a\)](#) shall be examined by the ultrasonic method in accordance with [WD-2542](#), except that forgings or sections of forgings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods in accordance with Section V, Article 2, and the acceptance standards of [WD-5320](#). In addition, selected surfaces, as designated by the Certificate Holder, shall be liquid penetrant examined in accordance with [WD-2546](#) or magnetic particle examined in accordance with [WD-2545](#).

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of [WD-2550](#).

(c) Bar material used for bolting shall be examined in accordance with [WD-2580](#).

### **WD-2542 Ultrasonic Examination**

**WD-2542.1 Examination Procedure.** All forgings in the rough forged or finished condition, and bars, shall be examined in accordance with one of the following specifications: SA-745, Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings; or SA-388, Recommended Practice for Ultrasonic Testing and Inspection of Heavy Steel Forgings, as shown in Section V, Article 23. Contact, immersion, or water column coupling is permissible. The following techniques are required, as applicable:

(a) All forgings and bars shall be examined by the ultrasonic method using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examination impractical.

(c) Forgings may be examined by the use of alternative ultrasonic methods that utilize distance amplitude corrections provided the acceptance standards are shown to be equivalent to those listed in [WD-2542.2](#).

#### **WD-2542.2 Acceptance Standards.**

(a) *Straight Beam General Rule.* A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors that produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations.

Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(b) *Angle Beam Rule.* A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors that produce indications exceeding in amplitude the indication from the appropriate calibration notches.

### **WD-2545 Magnetic Particle Examination**

**WD-2545.1 Examination Procedure.** The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

#### **WD-2545.2 Evaluation of Indications.**

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications that are not relevant.

(b) Any indication in excess of the [WD-2545.3](#) acceptance standards that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

#### **WD-2545.3 Acceptance Standards.**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for material less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for material from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for material 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated

**WD-2546 Liquid Penetrant Examination**

**WD-2546.1 Examination Procedure.** The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

**WD-2546.2 Evaluation of Indications.**

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications that are not relevant.

(b) Any indication in excess of the [WD-2546.3](#) acceptance standards that is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

**WD-2546.3 Acceptance Standards.**

(a) Only imperfections producing indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than  $\frac{1}{16}$  in. (1.5 mm) long for material less than  $\frac{5}{8}$  in. (16 mm) thick, greater than  $\frac{1}{8}$  in. (3 mm) long for material from  $\frac{5}{8}$  in. (16 mm) thick to under 2 in. (50 mm) thick, and  $\frac{3}{16}$  in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than  $\frac{1}{8}$  in. (3 mm) for thicknesses less than  $\frac{5}{8}$  in. (16 mm) and greater than  $\frac{3}{16}$  in. (5 mm) for thicknesses  $\frac{5}{8}$  in. (16 mm) and greater

(3) four or more relevant indications in a line separated by  $\frac{1}{16}$  in. (1.6 mm) or less edge to edge

(4) ten or more relevant indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated

**WD-2547 Time of Examination**

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in the following:

(a) Ultrasonic examination may be performed at any time after forging, and the maximum practical volume shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

**WD-2548 Elimination of Surface Defects**

Elimination of surface defects shall be made in accordance with [WD-2538](#).

**WD-2549 Repair by Welding**

Repair by welding shall be in accordance with [WD-2539](#), except that:

(a) the depth of repair that is permitted is not limited, and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic methods in accordance with the requirements of [WD-2542](#) in lieu of radiography.

**WD-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED TUBULAR PRODUCTS AND FITTINGS****WD-2551 Required Examination**

(a) The examination performed shall be practical and yield meaningful pertinent information for the product form being examined. Certain examination methods are ineffective for some material conditions and product configuration. Some examples are:

(1) it may not be practical or meaningful to examine irregular shapes such as welding flanges and fittings by ultrasonic methods

(2) ultrasonic examination employing special techniques is required on coarse-grained austenitic stainless steel or coarse-grained, nickel-base alloy materials

(b) Welded tubular products, including flanges and fittings, made from plate material greater than  $\frac{3}{4}$  in. (19 mm) in thickness shall be ultrasonically or radiographically examined in accordance with [WD-2552](#) or [WD-2553](#).

(c) All welds in welded tubular products, including flanges and fittings, shall be ultrasonically or radiographically examined in accordance with [WD-2552](#) or [WD-2553](#). In addition, all welds shall be magnetic particle or liquid penetrant examined on all accessible surfaces in accordance with [WD-2555](#) or [WD-2556](#).

(d) Wrought seamless tubular products, including flanges and fittings machined from forgings and bars, greater than  $\frac{3}{8}$  in. (10 mm) thickness, shall be ultrasonically or radiographically examined in accordance with [WD-2552](#) or [WD-2553](#).

**WD-2552 Ultrasonic Examination**

**WD-2552.1 Examination Procedure.** The procedure for ultrasonic examination shall provide a sensitivity that will consistently detect defects that produce indications equal to and greater than the indication produced by standard defects included in the reference specimen specified in [WD-2552.2](#). Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimens are unacceptable unless the defects are eliminated or repaired in

accordance with [WD-2558](#) or [WD-2559](#), as applicable. Examinations shall be performed in two opposite circumferential directions using the angle beam technique.

#### **WD-2552.2 Reference Specimens.**

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product that is being examined. The standard defects shall be axial notches or grooves on the outside and the inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed  $\frac{1}{16}$  in. (1.5 mm), and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. The reference specimen may be the product being examined.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification.

#### **WD-2552.3 Checking and Calibration of Equipment.**

The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

- (a) at the beginning of each production run of a given size and thickness of a given material.
- (b) after each 4 hr or less during the production run.
- (c) at the end of the production run.
- (d) at any time that malfunctioning is suspected.

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

#### **WD-2553 Radiographic Examination**

The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by [WD-5111](#), using the acceptance requirements of [WD-5320](#).

#### **WD-2555 Magnetic Particle Examination**

The magnetic particle examination shall be performed in accordance with the requirements of [WD-2545](#).

#### **WD-2556 Liquid Penetrant Examination**

The liquid penetrant examination shall be performed in accordance with the requirements of [WD-2546](#).

#### **WD-2557 Time of Examination**

Time of acceptance examination, including that of repair welds, shall be in accordance with [WD-2537](#).

#### **WD-2558 Elimination of Surface Defects**

Surface defects shall be removed by grinding or machining provided the following requirements are met:

- (a) The depression, after defect elimination, is blended uniformly into the surrounding surface.
- (b) After defect elimination, the area is reexamined by the method that originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size.
- (c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of [Article WD-3000](#), the product shall be repaired in accordance with [WD-2559](#).

#### **WD-2559 Repair by Welding**

Repair welding of base material defects shall be in accordance with [WD-2539](#). Repair welding of seam defects shall be made in accordance with [WD-4450](#).

### **WD-2580 EXAMINATION OF BOLTING**

#### **WD-2581 Required Examinations**

Bolting shall be visually examined in accordance with [WD-2582](#). In addition, externally threaded bolting  $\frac{3}{8}$  in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by either the magnetic particle or liquid penetrant method in accordance with [WD-2583](#). In addition, nominal sizes greater than  $\frac{1}{2}$  in. (13 mm) but not over 4 in. (100 mm) shall be examined by ultrasonic methods in accordance with [WD-2584](#), and nominal sizes greater than 4 in. (100 mm) shall be examined by ultrasonic methods in accordance with both [WD-2584](#) and [WD-2585](#).

#### **WD-2582 Visual Examination**

The final surfaces of threads, shanks, and heads shall be visually examined for workmanship, finish and appearance in accordance with the requirements of ASTM F788 for bolting material and ASTM F812 for nuts. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to [WD-5100](#) or by personnel qualified in accordance with [WD-5500](#).

#### **WD-2583 Magnetic Particle or Liquid Penetrant Examination**

Externally threaded bolting  $\frac{3}{8}$  in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by a magnetic particle method ([WD-2545](#)) or a liquid penetrant method ([WD-2546](#)). Such examination shall be performed on the finished bolting after threading and prior to plating or other surface protection type treatments. On threaded surfaces, no relevant indications are permitted. Relevant indications include any linear



indications or rounded indications greater than  $\frac{1}{16}$  in. (1.5 mm). Indications, caused by a particular manufacturing method, that may appear to be relevant, such as the crest of rolled threads or root of cut threads, may be shown to be nonrelevant and acceptable by prior process qualification or destructive metallographic examination. On all other accessible surfaces, no linear indications or rounded indications greater than  $\frac{1}{16}$  in. (1.5 mm) are permitted, except that linear axial indications less than one diameter or 1 in. (25 mm) in length are permitted.

#### **WD-2584 Ultrasonic Examination for Sizes Greater Than $\frac{1}{2}$ in. (13 mm)**

All bolting greater than  $\frac{1}{2}$  in. (13 mm) nominal bolt size shall be ultrasonically examined over the entire cylindrical surface prior to threading, in accordance with the requirements of the following subparagraphs.

**WD-2584.1 Ultrasonic Method.** Examination shall be carried out by the straight beam, radial scan method.

**WD-2584.2 Examination Procedure.** Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure necessitate the use of a 1 MHz frequency in order to assure adequate penetration, with a search unit not to exceed 1 in.<sup>2</sup> (650 mm<sup>2</sup>) area.

**WD-2584.3 Calibration of Equipment.** Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full-screen height.

**WD-2584.4 Acceptance Standards.** Any imperfection that causes an indication in excess of 20% of the height of the first back reflection or any imperfection that prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

#### **WD-2585 Ultrasonic Examination for Sizes Over 4 in. (100 mm)**

In addition to the requirements of [WD-2584](#), all bolting over 4 in. (100 mm) shall be ultrasonically examined over the entire surface of each end before or after threading in accordance with the requirements of the following subparagraphs.

**WD-2585.1 Ultrasonic Method.** Examination shall be carried out by the straight beam, longitudinal mode scan method.

**WD-2585.2 Examination Procedure.** Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure necessitate the use of a 1 MHz frequency in order to assure adequate penetration with a search unit having a circular cross section with a diameter not less than  $\frac{1}{2}$  in. (13 mm) nor more than  $1\frac{1}{8}$  in. (29 mm).

**WD-2585.3 Calibration of Equipment.** Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A  $\frac{3}{8}$  in. (10 mm) diameter  $\times$  3 in. (75 mm) deep flat bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance–amplitude correction curve shall be established by scanning from both ends of the test bar.

**WD-2585.4 Acceptance Standards.** Any imperfection that causes an indication in excess of 50% of that produced by the calibration hole in the reference specimen, as corrected by the distance–amplitude correction curve, is not acceptable.

#### **WD-2586 Elimination of Surface Defects**

Surface defects may be eliminated by grinding or machining, provided the final dimension of the affected portion meets the requirements of the design and the area is reexamined by the magnetic particle or liquid penetrant method in accordance with [WD-2583](#).

### **WD-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS**

#### **WD-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS**

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of [WA-3800](#).

(b) The requirements of NCA-3862 shall be met as required by [WD-2130](#). The other requirements of [WA-3800](#) need not be used by Material Organizations for small products, as defined in (c), and for material that is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program ([Article WA-4000](#)) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable special requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in the following:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges 2 in. nominal pipe size (DN 50) and less

(2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less

(3) bars with a nominal cross-sectional area of 1 in.<sup>2</sup> (650 mm<sup>2</sup>) and less

# ARTICLE WD-3000

## DESIGN

### WD-3100 GENERAL REQUIREMENTS FOR DESIGN

#### WD-3110 LOADING CRITERIA

#### WD-3111 Loading Conditions

The loadings that shall be taken into account in designing internal support structures identified in the Design Specification include, but are not limited to, those in (a) through (f) below:

(a) weight of the internal support structure including the contents it is supporting;

(b) superimposed static loads and reactions induced by the supported system components;

(c) impact loads, either internal or external, that may be caused by drop events, non-mechanistic tip-over, missile impact, design-basis aircraft crash, earthquake-induced impact, or other dynamic events;

(d) loads due to temperature effects, which may be caused by thermal gradients or differential expansion, or both;

(e) cyclical loads such as transportation, shock, earthquake, thermal, and vibration loads;

(f) interface loads between the internal support structure and the containment.

Each loading to which the structure may be subjected shall be classified in accordance with WA-2123 and the Design and Service Limits (WA-2123.4) designated in the Design Specification in such detail as to provide a complete basis for design in accordance with these rules. Test Conditions, Test Loadings and Test Limits of WA-2120 are not applicable to internal support structures. Design Pressure and other operating pressure loadings are not applicable to internal support structures. As such, internal support structures shall not be designed or be capable of providing a pressure boundary. Internal support structures with enclosed cavities shall be vented/drained to prevent entrapment of fluids.

#### WD-3112 Design Loadings

The Design Loadings applicable to the design of internal support structures are as defined in the following subparagraphs.

**WD-3112.1 Design Temperature.** The Design Temperature shall be established in accordance with WA-2123.1(b).

(a) All temperatures referred to in this Subsection are the metal temperatures expressed in degrees Fahrenheit (°F) (degrees Celsius, °C).

(b) Where an internal support structure is heated by internal heat generation, the effect of such heating shall be incorporated into the establishment of the Design Temperature.

**WD-3112.2 Design Mechanical Loads.** The specified Design Mechanical Loads shall be those identified in the Design Specification (WA-3351) and designated as the Design Mechanical Loads in accordance with WA-2123.1(c).

**WD-3112.3 Design Stress Intensity Values.** Materials shall not be used at temperatures that exceed the temperature limit established in the applicable stress tables. The stress values in the tables may be interpolated for intermediate temperatures.

(a) When the procedures of design by analysis (WD-3220 and WD-3240) are employed, the applicable design stress intensity values  $S_m$  at temperature listed in Section II, Part D, Subpart 1, Tables 2A and 2B shall be used. Only those materials in Tables 2A and 2B whose P-numbers are listed in Table WD-4622.1-1 shall be used.

(b) When the procedures of linear elastic analysis for bolting (WD-3230) are employed, the allowable stress values shall be the applicable ultimate tensile strength  $S_u$  at temperature (Section II, Part D, Subpart 1, Table U) as modified by the design factors given in WD-3234. Stresses in bolts shall not exceed the yield strength  $S_y$  (Section II, Part D, Subpart 1, Table Y-1) of the material at temperature.

(c) When the procedures of WD-3300 are employed, the allowable stress values shall be the applicable yield strength values  $S_y$  at temperature listed in Section II, Part D, Subpart 1, Table Y-1 as modified by the design factors given in NF-3322.

(d) In no case shall the metal temperature exceed the material specific maximum temperatures noted in WD-3113(d).

#### WD-3113 Operating Conditions

(a) Internal support structures (WA-1110) are subject to operating conditions, resulting in Design (WA-2123.1) and operating loadings (WA-2123.2) that are required to be considered in the design in order to satisfy applicable safety criteria.



(b) The selection of operating conditions is beyond the scope of this Division. The Design Specification shall specify those conditions using appropriate guidance from safety criteria documents and the requirements of regulatory and enforcement authorities having jurisdiction.

(c) The actual metal temperature at the point under consideration (or a more conservative temperature that yields conservative structural responses) shall be used in all computations for the applicable operating conditions and shall be determined using accepted heat transfer procedures or by measurement from equipment in service under system-equivalent operating conditions.

(d) In no case shall the metal temperature exceed the material specific maximum temperatures noted below.

Material	$T_{max}$ , °F (°C)
Low alloy steel	700 (370)
Martensitic stainless steel	700 (370)
Carbon steel	700 (370)
Austenitic stainless steel	800 (425)
Nickel-chromium-iron	800 (425)
Nickel-copper	800 (425)

#### WD-3114 Stress Limits

Stress limits associated with operating conditions are specified in [WD-3200](#) and [WD-3300](#).

#### WD-3120 SPECIAL CONSIDERATIONS

##### WD-3121 Corrosion

Material subject to thinning by corrosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the structure by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas. Material added or included for these purposes need not be of the same thickness for all areas of the structure if different rates of attack are expected for the various areas. It should be noted that the tests on which the design fatigue curves (Section III Appendices, Mandatory Appendix I) are based did not include tests in the presence of corrosive environments that might accelerate fatigue failure.

##### WD-3122 Cladding

The rules of this paragraph apply to the design of clad plate- and shell-type structures constructed of material permitted in Section II, Part D, Subpart 1, Tables 2A and 2B. Cladding is material metallurgically bonded to the base metal for the specific purpose of acting as a barrier to environmental attack, without structural function. No structural strength shall be attributed to the cladding. Any significant loads induced by the cladding shall be considered in the design of the structure.

**WD-3122.1 Primary Stresses.** No structural strength shall be attributed to the cladding in satisfying [WD-3200](#).

**WD-3122.2 Secondary and Peak Stresses.** In satisfying [WD-3200](#), the presence of the cladding shall be considered with respect to both the thermal analysis and the stress analysis. The stresses in both materials shall be limited to the values specified in [WD-3200](#). However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the structure, the presence of the cladding may be neglected.

**WD-3122.3 Bearing Stresses.** In satisfying [WD-3227.1](#), the presence of cladding shall be included.

#### WD-3123 Designs Using Dissimilar Metals

In satisfying the requirements of this Subsection, caution should be exercised in design and construction involving dissimilar metals having different chemical compositions, mechanical properties and coefficients of thermal expansion in order to avoid difficulties in service.

#### WD-3124 Environmental Effects

Changes in material properties may occur due to environmental effects such as thermal degradation. If specified in the Design Specification, these effects shall be considered in the design.

#### WD-3125 Criticality Control

Maintaining the geometric configuration of the internal support structure (i.e., relative physical location of the contents) may be a key design provision of the internal support structure in order to ensure criticality control. When criticality control is required, an upper bound calculation shall be performed to assure a conservative estimate of permanent deformation is established. This analysis may not be the same analysis that is performed to calculate stresses in [WD-3200](#) and [WD-3300](#). Acceptable deformations shall be defined by the Design Specification.

#### WD-3130 GENERAL DESIGN RULES

##### WD-3131 Design Reports

The N3 Certificate Holder shall prepare a Design Report showing compliance with this Subsection and the requirements of [WA-3350](#).

##### WD-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in [Table WA-7100-1](#) when the standard or specification is referenced in this Subsection. However, compliance with these standards does not replace or eliminate the requirements for stress analysis.

## WD-3200 DESIGN RULES FOR PLATE- AND SHELL-TYPE INTERNAL SUPPORT STRUCTURES

### WD-3210 GENERAL REQUIREMENTS

Plate- and shell-type internal support structures are fabricated from plate and shell elements and are normally subjected to a biaxial stress field. The design procedures shall ensure that deformation criteria are satisfied as required in [WD-1110\(b\)](#). The design procedures recognized for the plate and shell elements are:

(a) Design by analysis based on maximum shear stress theory using elastic analyses with the rules of [WD-3220](#) (for Design, Level A and C);

(b) Section III Appendices, Nonmandatory Appendix F, Table F-1200-1 for plate and shell-type supports (for Level D).

### WD-3211 Requirements for Acceptability

The requirements for the acceptability of a design by analysis are those set forth in (a) through (d) below. In addition, when control of the geometric configuration [[WD-1110\(b\)](#) and [WD-3125](#)] of the contents is required, the deformation limits prescribed by the Design Specification shall be met.

(a) The design shall be such that stress intensities will not exceed the limits of [WD-3200](#).

(b) The design shall conform to the rules given in [WD-3100](#).

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, the critical buckling stress shall be calculated; see [WD-3229](#).

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G.

### WD-3212 Basis for Determining Stresses

The theory of failure used in the rules of this subarticle for combining stresses is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

### WD-3213 Terms Relating to Stress Analysis

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs. The following stress terms discuss a variety of applied loads in order to achieve understanding and clarity but not all of these loads are applicable to internal support structures.

**WD-3213.1 Stress Intensity.**<sup>8</sup> Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress

and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

**WD-3213.2 Normal Stress.** Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components, one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

**WD-3213.3 Shear Stress.** Shear stress is the component of stress tangent to the plane of reference.

**WD-3213.4 Membrane Stress.** Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

**WD-3213.5 Bending Stress.** Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

**WD-3213.6 Primary Stress.** Primary stress is any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to pressure, inertial, or distributed loads

(b) bending stress in the central portion of a flat head due to pressure or inertial loads.

Refer to [Table WD-3217-1](#) for examples of primary stress.

**WD-3213.7 Secondary Stress.** Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are

(a) general thermal stress [[WD-3213.12\(a\)](#)];

(b) bending stress at a gross structural discontinuity.

Refer to [Table WD-3217-1](#) for examples of secondary stress.

**WD-3213.8 Local Primary Membrane Stress.** Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a

discontinuity would, if not limited, produce excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary stress.

A stressed region may be considered local if the distance over which the membrane stress intensity exceeds  $1.1S_m$  does not extend in the meridional direction more than  $1.0\sqrt{Rt}$ , where  $R$  is the minimum midsurface radius of curvature and  $t$  is the minimum thickness in the region considered. Regions of local primary stress intensity involving axisymmetric membrane stress distributions that exceed  $1.1S_m$  shall not be closer in the meridional direction than  $2.5\sqrt{R_L t_L}$ , where  $R_L$  is defined as  $(R_1 + R_2)/2$  and  $t_L$  is defined as  $(t_1 + t_2)/2$  (where  $t_1$  and  $t_2$  are the minimum thicknesses at each of the regions considered, and  $R_1$  and  $R_2$  are the minimum midsurface radii of curvature at these regions where the membrane stress intensity exceeds  $1.1S_m$ ). Discrete regions of local primary membrane stress intensity, such as those resulting from concentrated loads acting on brackets or flat plates, where the membrane stress intensity exceeds  $1.1S_m$ , shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds  $1.1S_m$ .

**WD-3213.9 Peak Stress.** Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [WD-3213.12(b)], or localized application of dynamic load including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stress are

- (a) the thermal stress in the austenitic steel cladding of a carbon steel part;
- (b) certain thermal stresses that may cause fatigue but not distortion;
- (c) the stress at a local structural discontinuity;
- (d) surface stresses produced by thermal shock.

Refer to [Table WD-3217-1](#) for examples of peak stress.

**WD-3213.10 Total Stress.** Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

**WD-3213.11 Load Controlled Stress.** Load controlled stress is the stress resulting from application of a loading, such as internal pressure, inertial loads, or gravity, whose magnitude is not reduced as a result of displacement.

**WD-3213.12 Thermal Stress.** Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from

assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in [Table WD-3217-1](#). Examples of general thermal stresses are

- (1) stress produced by an axial temperature distribution in a cylindrical shell;
- (2) stress produced by the temperature difference between a nozzle and the shell to which it is attached;
- (3) the equivalent linear stress<sup>9</sup> produced by the radial temperature distribution in a cylindrical shell.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in [Table WD-3217-1](#). Examples of local thermal stress are:

- (1) the stress in a small hot spot in a wall;
- (2) the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell;
- (3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal.

**WD-3213.13 Gross Structural Discontinuity.** Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

**WD-3213.14 Local Structural Discontinuity.** Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

**WD-3213.15 Limit Analysis — Collapse Load.** The methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry.

The deformations of an ideally plastic structure increase without bound at this load, which is termed the *collapse load*. Among the methods used in limit analysis is a technique that assumes elastic, perfectly plastic, material behavior and a constant level of moment or force in those redundant structural elements in which membrane yield, plastic hinge, or critical buckling load has been reached. Any increase in load must be accompanied by a stable primary structure until a failure mechanism defined by the lower bound theorem of limit analysis is reached in the primary structure.

**WD-3213.16 Collapse Load — Lower Bound.** If, for a given load, any system of stresses can be found that everywhere satisfies equilibrium and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis that permits calculations of a lower bound to the collapse load.

**WD-3213.17 Critical Buckling.** Critical buckling occurs when an internal support structure is loaded to a state at which an infinitesimal additional load or disturbance causes the internal support structure to change from an equilibrium condition to one of instability.

**WD-3213.18 Operational Cycle.** Operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of operating conditions that may occur are further defined in [WD-3113](#).

**WD-3213.19 Stress Cycle.** Stress cycle is a condition in which the alternating stress difference goes from an initial value through an algebraic maximum value to an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

**WD-3213.20 Fatigue Strength Reduction Factor.** Fatigue strength reduction factor is a stress concentration factor that accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. In the absence of experimental data, the theoretical stress concentration factor may be used.

**WD-3213.21 Deformation.** Deformation of a component is an alteration of its shape or size.

**WD-3213.22 Ratcheting.** Ratcheting is a progressive incremental inelastic deformation or strain that can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both.

**WD-3213.23 Shakedown.** Shakedown of a structure occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

## WD-3214 Stress Analysis

A detailed stress analysis of the internal support structure shall be prepared in sufficient detail to show that each of the stress limitations of [WD-3220](#), [WD-3230](#), and [WD-3240](#) are satisfied when the internal support structure is subjected to the loadings of [WD-3110](#).

## WD-3215 Derivation of Stress Intensities

One requirement for the acceptability of a design ([WD-3210](#)) is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e) below.

(a) At the point on the structure that is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts  $t$ ,  $l$ , and  $r$ . The stress components in these directions are then designated  $\sigma_t$ ,  $\sigma_l$ , and  $\sigma_r$  for normal stresses and  $\tau_{lt}$ ,  $\tau_{lr}$ , and  $\tau_{rt}$  for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories [see [Table WD-3217-1](#) and [Figure WD-3222-1](#), [Note \(4\)](#)]:

(1) general primary membrane stress  $P_m$  ([WD-3213.4](#) and [WD-3213.6](#))

(2) local primary membrane stress  $P_L$  ([WD-3213.8](#))

(3) primary bending stress  $P_b$  ([WD-3213.5](#) and [WD-3213.6](#))

(4) secondary stress  $Q$  ([WD-3213.7](#))

(5) peak stress  $F$  ([WD-3213.9](#))

(c) For each category, calculate the algebraic sum of the values of  $\sigma_t$ , which result from the different types of loadings, and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the  $t$ ,  $l$ , and  $r$  directions into principal stresses  $\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$ . In many structure calculations, the  $t$ ,  $l$ , and  $r$  directions may be so chosen that the shear stress components are zero and  $\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$  are identical to  $\sigma_t$ ,  $\sigma_l$ , and  $\sigma_r$ .

(e) Calculate the stress differences  $S_{12}$ ,  $S_{23}$ , and  $S_{31}$  from the relations

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$



The stress intensity  $S$  is the largest absolute value of  $S_{12}$ ,  $S_{23}$ , and  $S_{31}$ .

NOTE: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c) above.

### WD-3216 Derivation of Stress Differences and Alternating Stress Intensities

If the specified operation of the internal support structure does not meet the conditions of WD-3222.5(d), the ability of the structure to withstand the specified cyclic operation without fatigue failure shall be determined as provided in WD-3222.5(e). The determination shall be made on the basis of the stresses at a point throughout the structure, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic operating loadings as specified in the Design Specifications need be considered.

**WD-3216.1 Constant Principal Stress Direction.** For any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a) through (c) shall be taken to determine the alternating stress intensity.

(a) *Principal Stresses.* Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects that vary during the cycle. These are designated as  $\sigma_1$ ,  $\sigma_2$ , and  $\sigma_3$  for later identification.

(b) *Stress Differences.* Determine the stress differences  $S_{12} = \sigma_1 - \sigma_2$ ;  $S_{23} = \sigma_2 - \sigma_3$ ;  $S_{31} = \sigma_3 - \sigma_1$  versus time for the complete cycle. In what follows, the symbol  $S_{ij}$  is used to represent any one of these three stress differences.

(c) *Alternating Stress Intensity.* Determine the extremes of the range through which each stress difference  $S_{ij}$  fluctuates and find the absolute magnitude of this range for each  $S_{ij}$ . Call this magnitude  $S_{rij}$  and let  $S_{alt\ ij} = 0.5S_{rij}$ . The alternating stress intensity  $S_{alt}$  is the largest of the  $S_{alt\ ij}$  values.

**WD-3216.2 Varying Principal Stress Direction.** For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e) below.

(a) Consider the values of the six stress components  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$ ,  $\tau_{rt}$  versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects that vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript  $i$ . In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may

be necessary to try different points in time to find the one that results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components  $\sigma_{ti}$ ,  $\sigma_{li}$ , etc., from the corresponding stress components  $\sigma_t$ ,  $\sigma_l$ , etc., at each point in time during the cycle and call the resulting components  $\sigma'_{t'}$ ,  $\sigma'_{l'}$ , etc.

(d) At each point in time during the cycle, calculate the principal stresses  $\sigma'_{1'}$ ,  $\sigma'_{2'}$ ,  $\sigma'_{3'}$  derived from the six stress components  $\sigma'_{t'}$ ,  $\sigma'_{l'}$ , etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences  $S'_{12} = \sigma'_{1'} - \sigma'_{2'}$ ,  $S'_{23} = \sigma'_{2'} - \sigma'_{3'}$ ,  $S'_{31} = \sigma'_{3'} - \sigma'_{1'}$  versus time for the complete cycle and find the largest absolute magnitude of any stress difference at any time. The alternating stress intensity  $S_{alt}$  is one-half of this magnitude.

### WD-3217 Classification of Stress

Table WD-3217-1 provides assistance in the determination of the category to which a stress should be assigned.

## WD-3220 DESIGN BY ANALYSIS REQUIREMENTS FOR PLATE- AND SHELL-TYPE INTERNAL SUPPORT STRUCTURE MEMBERS

Plate- and shell-type internal support structures shall satisfy the stress intensity limits in WD-3220 and the acceptable deformation limits set forth in the Design Specification to ensure criticality control.

(a) To satisfy stress intensity limits, an elastic analysis shall be performed except as permitted by WD-3225.

(b) To satisfy deformation limits in those cases where stresses exceed  $S_y$  at temperature, an analysis that maximizes deformations as discussed in WD-3125 shall be performed.

### WD-3221 Design Limits

The stress intensity limits that shall be satisfied for the Design Loadings (WD-3112) stated in the Design Specification are the three limits of this paragraph and the special stress limits of WD-3227. The design stress intensity values  $S_m$  at the Design Temperature are described in WD-3112.3. The limits are summarized by Figure WD-3221-1.

**WD-3221.1 General Primary Membrane Stress Intensity.** This stress intensity (derived from  $P_m$  in Figure WD-3221-1) is derived from the average value across the thickness of a section of the general primary stresses (WD-3213.6) produced by specified Design Mechanical Loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is  $S_m$  at the Design Temperature.

**Table WD-3217-1  
Classification of Stress Intensities for Some Typical Cases**

Internal Support Structure	Location	Origin of Stress	Type of Stress	Classification
Any	Plate or shell remote from discontinuities	Axial thermal gradient	Membrane	$Q$
			Bending	$Q$
	Any section across entire plate or shell	External load or moment	General membrane averaged across full section. Stress component perpendicular to cross section.	$P_m$
			Bending across full section. Stress component perpendicular to cross section.	$P_m$ or $P_b$ [Note (1)]
	Near opening or discontinuity	External load or moment	Local membrane	$P_L$
			Bending	$Q$
			Peak (fillet or corner)	$F$
Any		Differential expansion	Membrane	$Q$
			Bending	$Q$
		Thermal gradient through plate or shell thickness [Note (2)]	Stress due to equivalent bending portion	$Q$ [Note (3)]
			Stress due to nonlinear portion	$F$
Any	Stress concentration (notch effect)	$F$		

NOTES:

- (1) Use  $P_m$  for those geometries where there is not a stress reversal through the thickness of the portion of the full section under consideration. Otherwise, use  $P_b$  for those geometries where there is a stress reversal through the thickness of the portion of the full section under consideration.
- (2) Consider the possibility of thermal stress ratchet.
- (3) Equivalent linear stress is defined as the linear stress distribution that has the same net force and net bending moment as the actual stress distribution.

**WD-3221.2 Local Primary Membrane Stress Intensity.** This stress intensity (derived from  $P_L$  in Figure WD-3221-1) is derived from the average value across the thickness of a section of the local primary stresses (WD-3213.8) produced by Design Mechanical Loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is  $1.5S_m$ .

**WD-3221.3 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity.** This stress intensity [derived from  $(P_m$  or  $P_L) + P_b$  in Figure WD-3221-1] is derived from the highest value across the thickness of a section of the general or local primary membrane stresses plus primary bending stresses produced by specified Design Mechanical Loads, but excluding all secondary and peak stresses. For solid rectangular sections, the allowable value of this stress intensity is  $1.5S_m$ . For other than solid rectangular sections, a value of  $\alpha$  times the limit established in WD-3221.1 may be used, where the factor  $\alpha$  is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the

respective ratios of the individual loads in the specified design load set. The value of  $\alpha$  shall not exceed the value calculated for bending only ( $P_m = 0$ ). In no case shall the value of  $\alpha$  exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated. The  $\alpha$  factor is not permitted for Level D Service Limits when inelastic component analysis is used as permitted in Section III Appendices, Nonmandatory Appendix F, F-1340.

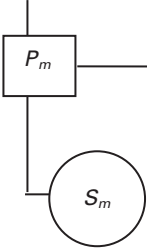
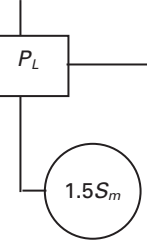
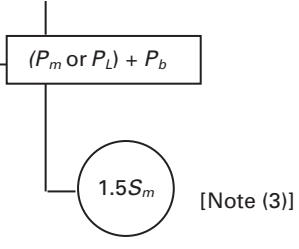
**WD-3222 Level A Service Limits**

The Level A Service Limits shall be satisfied for the normal loadings for which these limits are designated in the Design Specification and are the limits of this paragraph and WD-3227. The design stress intensity values  $S_m$  at the coincident normal operating temperature are described in WD-3112.3. The limits are summarized by Figure WD-3222-1.

**WD-3222.1 General Primary Membrane Stress Intensity.** This stress intensity (derived from  $P_m$  in Figure WD-3222-1) is derived from the average value across the thickness of a section of the general primary stresses (WD-3213.6) produced by the specified mechanical loads associated with normal loadings, but excluding all secondary and peak stresses. Averaging is to be applied to



**Figure WD-3221-1  
Stress Categories and Limits of Stress Intensities for Design Loadings**

Stress Category	Primary [Notes (1) and (2)]		
	General Membrane	Local Membrane	Bending
Description (for examples, see Table WD-3217-1)	Average primary stress across solid section. Excludes discontinuities and concentrations.	Average stress across any solid section. Considers discontinuities but not concentrations.	Component of primary stress proportional to distance from centroid of solid section. Excludes effects of discontinuities and concentrations.
Symbol	$P_m$	$P_L$	$P_b$
Combination of stress components and allowable limits of stress intensities.			

Legend:

- = Allowable value
- = Calculated Value

NOTES:

- (1) The symbols  $P_m$ ,  $P_L$ , and  $P_b$  do not represent single quantities, but rather sets of six quantities representing the six stress components  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$ , and  $\tau_{rt}$ .
- (2) For configurations where compressive stresses occur, the stress limits shall take into account critical buckling stresses [WD-3229].
- (3) Values shown are for a solid rectangular section. See WD-3221.3 for other than a solid rectangular section.

the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is  $S_m$ .

**WD-3222.2 Local Primary Membrane Stress Intensity.** This stress intensity (derived from  $P_L$  in Figure WD-3222-1) is derived from the average value across the thickness of a section of the local primary stresses (WD-3213.8) produced by the specified mechanical loads associated with normal loadings, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is  $1.5S_m$ .

**WD-3222.3 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity.** The combined stresses due to primary membrane and bending stresses [derived from  $(P_m \text{ or } P_L) + P_b$  in Figure WD-3222-1] are

developed from the specified mechanical loads associated with normal loadings. For solid rectangular sections, the allowable value of this stress intensity is  $1.5S_m$ . For other than solid rectangular sections, a value of  $\alpha$  times the limit established in WD-3222.1 may be used, where the factor  $\alpha$  is defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section. In the evaluation of the initial yield and fully plastic section capacities, the ratios of each individual load in the respective load set to each other load in that load set shall be the same as the respective ratios of the individual loads in the specified design load set. The value of  $\alpha$  shall not exceed the value calculated for bending only ( $P_m = 0$ ). In no case shall the value of  $\alpha$  exceed 1.5. The propensity for buckling of the part of the section that is in compression shall be investigated (see WD-3229).

**Figure WD-3222-1**  
**Stress Categories and Limits of Stress Intensities for Normal Loadings**

Stress Category	Primary [Notes (1), (2) and (3)]			Secondary [Notes (1) and (4)]	Peak [Notes (1) and (4)]
	General Membrane	Local Membrane	Bending	Membrane Plus Bending	
Description (for examples, see Table WD-3217-1).	Average primary stress across solid section. Excludes discontinuities and concentrations.	Average stress across any solid section. Considers discontinuities but not concentrations.	Component of primary stress proportional to distance from centroid of solid section. Excludes effects of discontinuities and concentrations.	Self-equilibrating stress necessary to satisfy continuity of structure discontinuities. Excludes local stress concentrations.	Increment added to primary or secondary stress by a concentration (notch).  Certain thermal stresses that may cause fatigue but not distortion.
Symbol	$P_m$	$P_L$	$P_b$	$Q$	$F$
Combination of stress components and allowable limits of stress intensities					
Level A Service Limits	Elastic [Note (5)]	Elastic [Note (5)]	Elastic [Notes (5) and (6)]	Elastic [Note (7)]	Elastic-Plastic Fatigue [Notes (8) and (9)]

Legend:

○ = Allowable value      □ = Calculated Value

NOTES:

- (1) The symbols  $P_m$ ,  $P_L$ ,  $P_b$ ,  $Q$  and  $F$  do not represent single quantities, but rather sets of six quantities representing the six stress components  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$  and  $\tau_{rt}$ .
- (2) For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [WD-3229].
- (3) When loads are transiently applied, consideration should be given to the use of dynamic load amplification.
- (4) The stresses in Category  $Q$  are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses that may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of  $P_m + P_L + P_b + Q$  and not  $Q$  alone. Similarly, if the stress in Category  $F$  is produced by a stress concentration, the quantity  $F$  is the additional stress produced by the stress concentration, over and above the nominal stress. For example, if a plate has a nominal stress intensity,  $P_m = S$ ,  $P_b = 0$ ,  $Q = 0$ , and a notch with a stress concentration  $K$  is introduced, then  $F = P_m (K - 1)$  and the peak stress intensity equals  $P_m + P_m (K - 1) = K P_m$ .
- (5) The triaxial stresses represent the algebraic sum of the three primary principal stresses ( $\sigma_1 + \sigma_2 + \sigma_3$ ) for the combination of stress components. Where uniform tension loading is present, triaxial stresses are limited to  $4S_m$ . See WD-3227.4.
- (6) Values shown are for a solid rectangular section. See WD-3222.3 for other than a solid rectangular section.
- (7) This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of  $S_m$  shall be taken as the average of the  $S_m$  values tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B for the highest and the lowest temperature of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of  $S_m$  shall be taken as the  $S_m$  value for the highest temperature of the metal during the transient.
- (8)  $S_a$  is obtained from the fatigue curves, Section III Appendices, Mandatory Appendix I. The allowable value of the stress intensity for the full range of fluctuation is  $2S_a$ .
- (9) Values of  $S_{alt}$ , calculated on an elastic basis, shall not exceed the  $S_a$  value associated with 10 cycles when using the fatigue curves of Section III Appendices, Mandatory Appendix I.

**WD-3222.4 Primary Plus Secondary Stress Intensity.** This stress intensity [derived from  $(P_m \text{ or } P_L) + P_b + Q$  in Figure WD-3222-1] is derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses, plus primary bending stresses, plus secondary stresses, produced by the specified mechanical loads and by general thermal effects associated with normal loadings. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included.

NOTE: The concept of stress differences discussed in WD-3216 is essential to determination of the maximum range, since algebraic signs must be retained in the computation. Note that this limitation on range is applicable to the entire history of normal loadings, not just to the stresses resulting from each individual transient.

The allowable value for the maximum range of this stress intensity is  $3S_m$  [Figure WD-3222-1, Note (6)], except for certain cyclic events that may exceed the  $3S_m$  limit. For this exception, in lieu of meeting the  $3S_m$  limit, an elastic-plastic fatigue analysis in accordance with WD-3228 may be performed to demonstrate that the cumulative fatigue usage attributable to the combination of these low cycle events plus all other cyclic events does not exceed a value of 1.0 when calculated in accordance with WD-3222.5.

#### WD-3222.5 Analysis for Cyclic Operation.

(a) *Suitability for Cyclic Operation.* The suitability of an internal support structure for specified operating loadings involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength bolts shall be determined by the methods of WD-3235 and the possibility of thermal stress ratcheting shall be investigated in accordance with WD-3222.6. If the specified normal loadings of the structure meet all of the conditions of (d) below, no analysis for cyclic operation is required, and it may be assumed that the limits on peak stress intensities, as governed by fatigue, have been satisfied by compliance with the applicable requirements for material, design, fabrication, and examination of this Subsection. If the normal loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with Section III Appendices, Mandatory Appendix II, II-1500.

(b) *Peak Stress Intensity.* This stress intensity is derived from the highest value at any point across the thickness of a section of the combination of all primary, secondary, and peak stresses produced by specified mechanical loads, and by general and local thermal effects associated with normal conditions and including the effects of gross and local structural discontinuities.

(c) *Conditions and Procedures.* The conditions and procedures of WD-3222.5 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength

curves of Section III Appendices, Mandatory Appendix I. These curves show the allowable amplitude  $S_a$  of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves in Section III Appendices, Mandatory Appendix I are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable value of the stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero. As a consequence of this procedure, it is essential that the requirements of WD-3222.4 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(5) below.

(d) *Structures Not Requiring Analysis for Cyclic Operation.* An analysis for cyclic operation is not required, and it may be assumed that the limits on peak stress intensities, as governed by fatigue, have been satisfied for a structure by compliance with the applicable requirements for material, design, fabrication, and examination of this Subsection, provided the specified normal loadings of the structure, or portion thereof, meets all the conditions stipulated in (1) through (4) below.

(1) *Temperature Difference – Loading and Unloading of Contents.* The temperature difference in °F (°C) between any two adjacent points<sup>10</sup> does not exceed  $S_a/(2E\alpha)$ , where  $S_a$  is the value obtained from the applicable design fatigue curves of Section III Appendices, Mandatory Appendix I for the specified number of load and unload cycles,  $\alpha$  is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Table TE, and  $E$  is taken from Section II, Part D, Subpart 2, Table TM at the mean value of the temperatures at the two points.

(2) *Temperature Difference – Normal Conditions.* The temperature difference in °F (°C) between any two adjacent points<sup>10</sup> does not change (the algebraic range of the difference shall be used) during normal conditions by more than the quantity  $S_a/(2E\alpha)$ , where  $S_a$  is the value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall

be considered to be significant if its total algebraic range exceeds the quantity  $S/(2E\alpha)$  where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(3) *Temperature Difference – Dissimilar Materials.* For internal support structures fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, or both, the total algebraic range of temperature fluctuation in °F (°C) experienced by the structure during normal conditions does not exceed the magnitude  $S_a/2(E_1\alpha_1 - E_2\alpha_2)$ , where  $S_a$  is the value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant temperature fluctuations,  $E_1$  and  $E_2$  are the moduli of elasticity, and  $\alpha_1$  and  $\alpha_2$  are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction (Section II, Part D, Subpart 2, Tables TE and TM). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity  $S/2(E_1\alpha_1 - E_2\alpha_2)$ , where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of  $S_a$  shall be used in applying the rules of this paragraph.

(4) *Mechanical Loads.* The specified full range of mechanical loads does not result in load stresses whose range exceeds the  $S_a$  value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the  $S_a$  value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the quantity of  $S$ , where  $S$  is defined as follows:

(-a) If the total specified number of cycles is  $10^6$  cycles or less,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for  $10^6$  cycles.

(-b) If the total specified number of cycles exceeds  $10^6$  cycles,  $S$  is the value of  $S_a$  obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) *Procedure for Analysis for Cyclic Loading.* If the specified normal loadings for the structure do not meet the conditions of (d) above, the ability of the internal support structure to withstand the specified cyclic operation without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point and the allowable stress cycles shall be adequate for the specified normal loadings at every point. Only the stress differences due to cycles as specified in the Design Specification need be considered. Compliance with these requirements means only that the structure is suitable from the standpoint of possible fatigue failure; complete suitability for the specified normal loadings is also dependent on meeting the general stress limits of WD-3222 and any applicable special stress limits of WD-3227 and WD-3229.

(1) *Stress Differences.* For each normal condition, determine the stress differences and the alternating stress intensity  $S_a$  in accordance with WD-3216.

(2) *Local Structural Discontinuities.* These effects shall be evaluated for all normal conditions using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or numerical stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when stated herein or when determined in accordance with the procedures of Section III Appendices, Mandatory Appendix II, II-1600. Except for the case of crack-like defects, no fatigue strength reduction factor greater than five need be used.

(3) *Design Fatigue Curves.* Section III Appendices, Mandatory Appendix I contain the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each curve to material of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein, the strength level is the specified minimum room temperature value.

(4) *Effect of Elastic Modulus.* Multiply  $S_{alt}$  (WD-3216.1 or WD-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the operating cycle being considered is the only one that produces significant fluctuating stresses, this is the allowable number of cycles

(5) *Cumulative Damage.* If there are two or more types of stress cycle that produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

*Step 1.* Designate the specified number of times each type of stress cycle of Types 1, 2, 3, etc., will be repeated during the life of the structure as  $n_1, n_2, n_3, \dots, n_n$ , respectively.

NOTE: In determining  $n_1, n_2, n_3, \dots, n_n$ , consideration shall be given to the superposition of cycles of various origins that produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to -50,000 psi, the two types of cycles to be considered are defined by the following parameters:

$$\begin{aligned} \text{Type 1 cycle: } n_1 &= 1,000, \\ S_{\text{alt1}} &= (60,000 + 50,000)/2 = 55,000 \text{ psi} \end{aligned}$$

$$\begin{aligned} \text{Type 2 cycle: } n_2 &= 9,000, \\ S_{\text{alt2}} &= (50,000 + 0)/2 = 25,000 \text{ psi} \end{aligned}$$

*Step 2.* For each type of stress cycle, determine the alternating stress intensity  $S_{\text{alt}}$  by the procedures of [WD-3216.1](#) or [WD-3216.2](#) above. Call these quantities  $S_{\text{alt1}}, S_{\text{alt2}}, S_{\text{alt3}}, \dots, S_{\text{alt } n}$ .

*Step 3.* For each value  $S_{\text{alt1}}, S_{\text{alt2}}, S_{\text{alt3}}, \dots, S_{\text{alt } n}$ , use the applicable design fatigue curve (Section III Appendices, Mandatory Appendix I) to determine the maximum number of repetitions that would be allowable if this type of cycle were the only one acting. Call these values  $N_1, N_2, N_3, \dots, N_n$ .

*Step 4.* For each type of stress cycle, calculate the usage factors  $U_1, U_2, U_3, \dots, U_n$ , from  $U_1 = n_1/N_1, U_2 = n_2/N_2, U_3 = n_3/N_3, \dots, U_n = n_n/N_n$ .

*Step 5.* Calculate the cumulative usage factor  $U$  from  $U = U_1 + U_2 + U_3 + \dots + U_n$ .

*Step 6.* The cumulative usage factor  $U$  shall not exceed 1.0.

**WD-3222.6 Stress Ratcheting.** It should be noted that under certain combinations of steady-state and cyclic loadings, there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Ratcheting can occur in a structure that is subjected to variations of mechanical stress, thermal stress, or both. Examples of this phenomenon are treated in this subparagraph and in [WD-3227.3](#).

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell or plate with steady-state loading in order to prevent cyclic progressive distortion is determined as follows. Let

$y'$  = maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength  $S_y$  taken at the average temperature of the transient under consideration

$x$  = maximum general membrane stress divided by the yield strength  $S_y$  taken at the average temperature of the transient under consideration

NOTE: For both  $x$  and  $y'$ , it is permissible to use  $1.5S_m$  whenever it is greater than  $S_y$ .

(1) *Case 1:* linear variation of temperature through the wall

$$\begin{aligned} y' &= 1/x \text{ for } 0 < x < 0.5 \\ y' &= 4(1 - x) \text{ for } 0.5 < x < 1.0 \end{aligned}$$

(2) *Case 2:* parabolic, constantly increasing or constantly decreasing, variation of temperature through the wall

$$y' = 5.2(1 - x) \text{ for } 0.615 \leq x < 1.0 \text{ and, approximately, for } x < 0.615 \text{ as follows:}$$

$$y' = 4.65, 3.55, \text{ and } 2.70, \text{ for } x = 0.3, 0.4, \text{ and } 0.5, \text{ respectively.}$$

(b) Use of yield strength  $S_y$  in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to  $S_y$ . If the yield strength of the material is higher than two times the  $S_a$  value for the maximum number of cycles on the applicable fatigue curve of Section III Appendices, Mandatory Appendix I for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

(c) Similar methodology shall be used for mechanical-applied ratcheting loads specified in the Design Specification. The Design Specification may prescribe specific methodology.

**WD-3222.7 Deformation Limits.** Any deformation limits prescribed by the Design Specification shall be satisfied. See [WD-3125](#).

### WD-3224 Level C Service Limits

The Level C Service Limits shall be satisfied for off-normal loadings for which they are designated by the Design Specification and are summarized by [Figure WD-3224-1](#). Dynamic instability shall be considered in meeting the load, stress, and deformation limits.

**WD-3224.1 Primary Stress Intensity Limits.** The permissible values for Level C Service Limits shall be taken as 150% of the values given in [WD-3221](#). See [WD-3221.3](#) when evaluating other than solid rectangular sections.

**WD-3224.2 Special Stress Limits.** The permissible values for special stress limits shall be taken as 150% of the values given in [WD-3227](#). The requirements of [WD-3227.2\(c\)](#) and [WD-3227.3](#) need not be satisfied.

**WD-3224.3 Deformation Limits.** Any deformation limits prescribed by the Design Specification shall be satisfied. See [WD-3125](#).

### WD-3225 Level D Service Limits

If the Design Specification specifies any accident loadings for which Level D Service Limits are designated [[WA-2123.4\(b\)](#)], the rules contained in Section III



**Figure WD-3224-1  
Stress Categories and Limits of Stress Intensities for Off-Normal Loadings**

Stress Category	Primary [Notes (1), (2), and (3)]		
	General Membrane	Local Membrane	Bending
Description (for examples, see Table WD-3217-1).	Average primary stress across solid section. Excludes discontinuities and concentrations.	Average stress across any solid section. Considers discontinuities but not concentrations.	Component of primary stress proportional to distance from centroid of solid section. Excludes effects of discontinuities and concentrations.
Symbol	$P_m$	$P_L$	$P_b$
Combination of stress components and allowable limits of stress intensities.  Level C Service Limits			

Legend:

○ = Allowable value      □ = Calculated Value

NOTES:

- (1) The symbols  $P_m$ ,  $P_L$ ,  $P_b$  do not represent single quantities, but rather sets of six quantities representing the six stress components  $\sigma_t$ ,  $\sigma_l$ ,  $\sigma_r$ ,  $\tau_{lt}$ ,  $\tau_{lr}$  and  $\tau_{rt}$ .
- (2) For configurations where compressive stresses occur, the stress limits shall be revised to take into account critical buckling stresses (WD-3229).
- (3) When loads are dynamically applied, consideration should be given to the use of dynamic load amplification.
- (4) Values shown are for a solid rectangular section. See WD-3224.1 for other than a solid rectangular section.

Appendices, Nonmandatory Appendix F shall be used in evaluating these loadings, independently of all other operating loadings. The rules in Section III Appendices, Nonmandatory Appendix F, Table F-1200-1 for plate- and shell-type supports shall apply. The requirements of WD-3229.3 shall be satisfied. Any deformation limits prescribed by the Design Specification shall be satisfied. See WD-3125.

### WD-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special operating loadings or configurations. Some of these deviations are more restrictive, and some are less restrictive, than the basic stress limits. Rules governing application of these special stress limits for Level C and Level D Service Limit applications are contained in WD-3224.2 and WD-3225, respectively. In cases of conflict between these requirements and the basic stress limits, the rules of WD-3227 take precedence for the particular situations to which they apply. WD-3227 does not apply to bolted joints (WD-3230).

### WD-3227.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings or normal loadings for which Design or Level A Service Limits, respectively, are designated, shall be limited to  $S_y$ , at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of  $1.5S_y$  at temperature is permitted. For clad surfaces, the strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load stress only, the average shear stress shall be limited to  $0.6S_m$ . In the case of load stress plus secondary stress, the average shear stress shall not exceed (1) or (2) below:

(1) for materials to which Section II, Part D, Subpart 1, Table 2A, Note G7 or Table 2B, Note G1, applies, the lower of  $0.5S_y$  at 100°F (38°C) and  $0.67S_y$  at temperature;

(2) for all other material,  $0.5S_y$  at temperature.



(c) For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(d) When considering bearing stresses in pins and similar members, the  $S_y$  at temperature value is applicable, except that a value of  $1.5S_y$  may be used if no credit is given to bearing area within one pin diameter from a plate edge.

#### WD-3227.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings or normal loadings for which Design or Level A Service Limits, respectively, are designated (for example, keys, shear rings), shall be limited to  $0.6S_m$ .

(b) The maximum primary shear, experienced as a result of Design Loadings or normal loadings for which Design or Level A Service Limits, respectively, are designated, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to  $0.8S_m$ .

(c) Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and, as such, shall not exceed the basic stress limits of WD-3222.4 and WD-3222.5.

**WD-3227.3 Progressive Distortion of Nonintegral Connections.** Screwed-on caps, screwed-in plugs, shear ring closures, and breechlock closures are examples of nonintegral connections that are subject to failure by bell mousing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (WD-3222.4) that result in slippage between the parts of a nonintegral connection, in which disengagement could occur as a result of progressive distortion, shall be limited to the value  $S_y$  (Section II, Part D, Subpart 1, Table Y-1) at the temperature under consideration.

**WD-3227.4 Triaxial Stresses.** The algebraic sum of the three primary principal stresses ( $\sigma_1 + \sigma_2 + \sigma_3$ ) shall not exceed four times the tabulated value of  $S_m$ , except for Service Level D.

**WD-3227.5 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.** Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of  $3S_m$  (WD-3222.4) has been placed at a level that assures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore

(a) in evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis

(b) in evaluating stresses for comparison with fatigue allowables, all stresses except those that result from local thermal stresses [WD-3213.12(b)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression

$$\nu = 0.5 - 0.2 \frac{S_y}{S_a}, \text{ but not less than } 0.3$$

where

$S_a$  = alternating stress intensity determined in WD-3222.5(e) prior to the elastic modulus adjustment in WD-3222.5(e)(4)

$S_y$  = the yield strength of the material at the mean value of the temperature of the cycle

#### WD-3228 Simplified Elastic-Plastic Analysis

The  $3S_m$  limit on the range of primary plus secondary stress intensity (WD-3222.4) may be exceeded, provided that the requirements of (a) through (f) below are met

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be  $\leq 3S_m$ .

(b) The value of  $S_a$  used for entering the design fatigue curve is multiplied by the factor  $K_e$  where

$$\begin{aligned} K_e &= 1.0 \text{ for } S_n \leq 3S_m \\ &= 1.0 + \frac{(1-n)}{n(m-1)} \left( \frac{S_n}{3S_m} - 1 \right) \\ &\quad \text{for } 3S_m < S_n < 3mS_m \\ &= 1/n \text{ for } S_n \geq 3mS_m \end{aligned}$$

$S_n$  = range of primary plus secondary stress intensity

The values of the material parameters  $m$  and  $n$  for the various classes of permitted materials are as follows:

Material	$m$	$n$	$T_{max}$ , °F (°C)
Low alloy steel	2.0	0.2	700 (370)
Martensitic stainless steel	2.0	0.2	700 (370)
Carbon steel	3.0	0.2	700 (370)
Austenitic stainless steel	1.7	0.3	800 (425)
Nickel-chromium-iron	1.7	0.3	800 (425)
Nickel-copper	1.7	0.3	800 (425)

(c) The rest of the fatigue evaluation remains the same as required in [WD-3222.5](#), except that the procedure of [WD-3227.5](#) need not be used.

(d) The temperature does not exceed those listed in the above table for the various classes of materials.

(e) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

(f) The structure meets the stress ratcheting requirement of [WD-3222.6](#).

### WD-3229 Buckling

The internal support structures are typically composed of rectangular plates, shells, and tubular structural members. Care should be used when utilizing open cross-sections (angles, channels, I-beams, etc.) because these items are susceptible to torsional and lateral-torsional buckling.

The allowable compression stress values for plates and shells for all loadings associated with Design and Level A Service Limits shall be determined by one of the following methods:

(a) classical buckling analysis ([WD-3229.1](#) or [WD-3229.2](#)) reduced by margins that reflect the difference between the theoretical and actual load capacities;

(b) detailed stability analysis, such as by the finite element method;

For all loadings associated with Level C and Level D Service Limits, the same methodology used for Design and Level A Service Limit loads shall be followed but the allowable compression stress values shall be adjusted per the requirements of [WD-3229.3](#).

**WD-3229.1 Cylindrical Shells Under Axial Compression.** The allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below.

(a) The  $S_m$  value for the applicable material at Design Temperature (or the temperature under consideration for operating loadings associated with Level A, C, or D Service Limits) given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) The value of the factor  $B$  determined from the applicable chart contained in Section II, Part D, Subpart 3, using the following definitions for the symbols on the charts:

$R$  = inside radius of the cylindrical shell or tubular product, in. (mm);

$T$  = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in. (mm).

The value of  $B$  shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 in the manner given in Steps 1 through 5

*Step 1.* Using the selected values of  $T$  and  $R$ , calculate the value of factor  $A$  using the following equation:

$$A = 0.125/(R/T)$$

*Step 2.* Using the value of  $A$  calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material /temperature line for the Design Temperature (or the temperature under consideration for operating loadings associated with Level A, C, or D Service Limits). Interpolation may be made between lines for intermediate temperatures. In cases where the value at  $A$  falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of  $A$  falling to the left of the material /temperature line, see [Step 4](#).

*Step 3.* From the intersection obtained in [Step 2](#), move horizontally to the right and read the value of factor  $B$ . This is the maximum allowable compressive stress for the values of  $T$  and  $R$  used in [Step 1](#).

*Step 4.* For values of  $A$  falling to the left of the applicable material /temperature line, the value of  $B$  shall be calculated using the following equation (where  $E$  is the modulus of elasticity at Design Temperature or the temperature under consideration for operating loadings associated with Level A, C, or D Service Limits):

$$B = AE/2$$

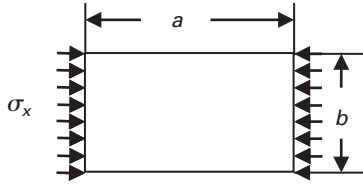
This is the maximum allowable compressive stress for the values of  $T$  and  $R$  used in [Step 1](#).

*Step 5.* Compare the value of  $B$  determined in [Step 3](#) or [4](#) with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of  $T$  and  $R$ . If the value of  $B$  is smaller than the computed compressive stress, a greater value of  $T$  shall be selected and the design procedure repeated until a value of  $B$  is obtained (the allowable compression stress) that is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

**WD-3229.2 Rectangular Plates Under Compressive Loading.** The internal support structural members that are subjected to compressive loading shall be designed

based on the performance of the individual members rather than the entire structure. The elastic stress analysis of the internal support structure shall be performed to determine the axial forces and moments on individual members. These forces and moments shall be used to size the members in accordance with the allowable compressive stress provided in (c).

(a) *Rectangular Plate Under Uniaxial Compression.* The critical buckling stress  $\sigma_{cr}$  for a plate of dimension  $a$  by  $b$  and thickness  $t$  shall be calculated using the following equation:

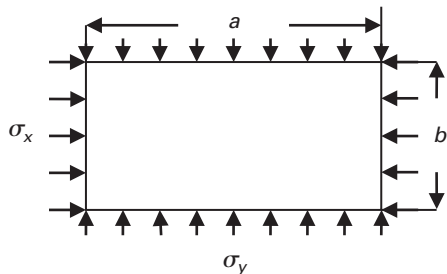


$$\sigma_{cr} = K \frac{E}{1 - \nu^2} \left( \frac{t}{b} \right)^2 \quad (1)$$

In the above equation,  $E$  is the elastic modulus of the plate material at operating temperature,  $\nu$  is Poisson's ratio, and  $K$  is the plate buckling coefficient, which is a function of the boundary conditions of the plate. The smaller plate width should be greater than 10 times the thickness of the plate.

The plate geometry, the values of  $K$  for various boundary conditions, and  $a/b$  ratio are given in Table WD-3229.2-1. Values of  $K$  are provided for various combinations of simply supported, clamped, and free edge constraints. Values not provided in the table shall be justified in the Design Report.  $K$  values for other combinations of edge constraints shall be justified in the Design Report.

(b) *Rectangular Plate Under Biaxial Compression.* The critical buckling stress shall be calculated using the following equations for a plate under biaxial compression that have all edges simply supported:



$$\sigma_{x(cr)} \frac{m^2}{a^2} + \sigma_{y(cr)} \frac{n^2}{b^2} = 0.823 \frac{E}{1 - \nu^2} t^2 \left( \frac{m^2}{a^2} + \frac{n^2}{b^2} \right)^2 \quad (2)$$

Here  $m$  and  $n$  are integers and denote the number of half waves in which a plate buckles in the  $x$  and  $y$  directions, respectively. The positive values of the  $\sigma_x$  and  $\sigma_y$  indicate compressive stresses. Equations (2) through (6)

provide the values of  $\sigma_x$  and  $\sigma_y$  at which buckling may occur. For a given  $\sigma_x$ ,  $\sigma_{y(cr)}$  shall be determined from the above equation taking  $m = 1$  and  $n = 1$ , if the following inequality is satisfied:

$$C \left( 1 - 4 \frac{a^4}{b^4} \right) < \sigma_x < C \left( 5 + 2 \frac{a^2}{b^2} \right) \quad (3)$$

where

$$C = \frac{0.823Et^2}{(1 - \nu^2)a^2} \quad (4)$$

If  $\sigma_x$  is too large to satisfy the inequality in eq. (3), taking  $n = 1$ , the value of  $m$  shall be determined that satisfies the inequality in eq. (5)

$$C \left( 2m^2 - 2m + 1 + 2 \frac{a^2}{b^2} \right) < \sigma_x < C \left( 2m^2 + 2m + 1 + 2 \frac{a^2}{b^2} \right) \quad (5)$$

Using the calculated value of  $m$  and  $n = 1$ , eq. (2) shall be used to provide the critical buckling stress,  $\sigma_{y(cr)}$ .

If  $\sigma_x$  is too small to satisfy eq. (3), taking  $m = 1$ , the value of  $n$  shall be determined that satisfies the inequality in eq. (6).

$$C \left( 1 - n^2(n-1)^2 \frac{a^4}{b^4} \right) > \sigma_x > C \left( 1 - n^2(n+1)^2 \frac{a^4}{b^4} \right) \quad (6)$$

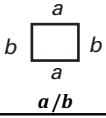
Using the calculated value of  $n$  and  $m = 1$ , eq. (2) shall be used to calculate the critical buckling stress  $\sigma_{y(cr)}$ .

(c) *Allowable Compression Stress.* For Design Loadings and normal loadings for which Design and Level A Service Limits, respectively, are designated, the allowable compressive stress shall be one-half of the critical buckling stress as calculated in (a) or (b) above, but shall not exceed  $S_m$  for compressive primary membrane stress and  $1.5S_m$  for compressive primary membrane plus primary bending stress.

**WD-3229.3 Allowable Elastic Compressive Stress for Level C and D Service Limits.** For off-normal loadings for which Level C Service Limits are designated, 120% of the Design and Level A Service allowable compression stress shall not be exceeded. For accident loadings for which Level D Service Limits are designated, 150% of the Design and Level A Service allowable compressive stress shall not be exceeded.

**WD-3229.4 Inelastic Buckling.** An inelastic buckling analysis of thin plates and shells may be performed. This is considerably more difficult to analyze than the elastic buckling. Finite element methods and testing are recommended for stability analysis of plates in the inelastic region and shall be justified in the Design Report. The methods and margins shall also be justified in the Design Report.

**Table WD-3229.2-1**  
**Values of  $K$  for Various Boundary Conditions and  $a/b$  Ratios**

 $a/b$	$K$				
	All Edges Simply Supported	Edges $b$ Simply Supported, Edges $a$ Clamped	Edges $b$ Simply Supported, One Edge $a$ Simply Supported and Other Free	Edges $b$ Simply Supported, One Edge $a$ Clamped and Other Free	Edges $b$ Clamped, Edges $a$ Simply Supported
0.2	22.2	...	...	...	...
0.3	10.9	...	...	...	...
0.4	6.92	7.76	...	...	...
0.5	...	6.32	3.62	...	...
0.6	4.23	5.80	...	...	11.0
0.7	...	5.76	...	...	...
0.8	3.45	6.00	...	...	7.18
1.0	3.29	6.32	1.18	1.40	5.54
1.1	...	...	...	1.28	...
1.2	3.40	5.80	0.934	1.21	4.80
1.3	...	...	...	1.16	...
1.4	3.68	5.76	0.784	1.12	4.48
1.5	...	...	...	1.10	...
1.6	3.45	6.00	0.687	1.09	4.39
1.7	...	...	...	1.09	4.39
1.8	3.32	5.80	0.622	1.10	4.26
1.9	...	...	...	1.12	...
2.0	3.29	...	0.574	1.14	3.99
2.1	...	5.76	...	...	...
2.2	3.32	...	...	1.19	...
2.4	3.40	...	...	1.21	...
2.5	...	...	0.502	...	3.72
2.7	3.32	...	...	...	...
3.0	3.29	...	0.464	...	3.63
4.0	...	...	0.425	...	...
5.0	...	...	0.416	...	...
$\infty$	3.29	5.73	...	...	...

**WD-3230 DESIGN REQUIREMENTS FOR PLATE- AND SHELL-TYPE INTERNAL SUPPORT STRUCTURE BOLTED JOINTS**

The evaluation of bolting requires a number of analysis considerations, including (a) through (d) below and the criteria specified in this subarticle for the loads imposed.

(a) The bolting analysis shall consider the effects of loading eccentricities due to puncture loads and eccentric impact loads.

(b) The bolting analysis shall consider prying effects, which cause amplification of the bolt loads due to rotation of the closure surfaces.

(c) Bolting analysis shall consider bolt preload application methodology and resulting bolt forces.

(d) The deformation limits specified in the Design Specification shall be satisfied.

**WD-3231 Design Limits**

The rules and stress limits that shall be satisfied for any Design Loading stated in the Design Specification are those given in WD-3234.

**WD-3232 Friction-Type Joints**

Multiplying factors normally used to increase the Level C and D Service Limits are not applicable to friction-type joints [see WD-3234.1(d)].

**WD-3234 Design Requirements for Bolted Joints**

The stress limits that shall be satisfied for any loadings associated with Design and Level A, C and D Service Limits, shall be those given in this paragraph, multiplied by the appropriate stress limit factors given in Table WD-3234-1 (excluding bearing stresses) for the particular loading specified in the Design Specification. Stresses in bolts shall not exceed the yield strength  $S_y$  of the material at temperature.

**WD-3234.1 Allowable Stresses.** Allowable tensile, shearing, and bearing stresses in bolts and threaded parts shall be as given in the paragraphs below. All allowable stresses are expressed in ksi (MPa) acting on the actual bolt area available in the shear planes of the connected parts. All are expressed in terms of the ultimate tensile strength  $S_u$  at temperature (Section II, Part D, Subpart

**Table WD-3234-1**  
**Stress Limit Factors for Bolt Design by Analysis**

Stress Limit Factors for Loading Levels Stated in Design Specification				
[Note (1)]				
Stress Category	Design	Service Level A	Service Level C	Service Level D
Tension and shear	$K_{bo} = 1.0$	$K_{bo} = 1.0$	$K_{bo} = 1.25$	[Note (2)]

## GENERAL NOTE:

$K_{bo}$  = stress limit factor applicable to the allowable tensile and shear stresses

## NOTES:

(1) Not to be used for friction-type connections.

(2) Use Section III Appendices, Nonmandatory Appendix F, F-1335.

1, Table U). The shear capacity of bolts is directly proportional to the shear area available in the shear planes. Shear strength is unaffected by shear plane location.

(a) *Tensile Stress Only*. Bolts loaded in direct tension shall be so proportioned that their average tensile stress  $F_{tb}$ , computed on the basis of the actual tensile stress area available (independent of any initial tightening force), shall not exceed:

for ferritic steels:

$$F_{tb} = \frac{S_u}{2}$$

for austenitic steels:

$$F_{tb} = \frac{S_u}{3.33}$$

$S_u$  = the specified minimum tensile strength ksi (MPa) at temperature

The applied load shall be the sum of the external load and any tension resulting from prying action produced by deformation of the connected parts.

(b) *Shearing Stress Only*(1) *Bearing-Type Joints*

(-a) *Threads Excluded From Shear Planes*. The allowable shear stress  $F_{vb}$  in bolts and threaded parts loaded in direct shear, expressed in ksi (MPa) of actual shear stress area available (applicable to the total nominal bolt area in the shear planes in this case), shall not exceed:

for ferritic steels:

$$F_{vb} = \frac{0.62S_u}{3}$$

for austenitic steels:

$$F_{vb} = \frac{0.62S_u}{5}$$

(-b) *Threads Not Excluded From Shear Planes*. The allowable shear stress  $F_{vb}$  in bolts and threaded parts loaded in direct shear, expressed in ksi (MPa) of actual shear stress area available (applicable to the total bolt root area in the shear planes in this case), shall not exceed for ferritic steels:

$$F_{vb} = \frac{0.62S_u}{3}$$

for austenitic steels:

$$F_{vb} = \frac{0.62S_u}{5}$$

(c) *Combined Tensile and Shear Stresses*

(1) *Bearing-Type Joints*. Bolts subjected to combined shear and tension shall be so proportioned that either the shear stress  $f_v$  or the tensile stress  $f_t$ , expressed in ksi (MPa) of actual cross-sectional area, shall not exceed the value derived from the ellipse equation below when the corresponding computed tensile or shearing stress is substituted

$$\frac{f_t^2}{F_{tb}^2} + \frac{f_v^2}{F_{vb}^2} = 1$$

The allowable tensile stress and shear stress values shall be those derived from the equations given in (a) and (b).

(2) *Friction-Type Joints*. A bolt in a connection designed as a friction-type joint is not subjected to shear (provided the joint does not slip into bearing); it experiences tension only. Friction-type joints shall be designed as given in (d).

(d) *Slip Resistance — Friction-Type Joints.* The maximum slip resistance to which a friction-type joint may be designed shall not exceed the value of  $P_s$ , calculated in the following equation [see [Table WD-3234.1\(d\)-1](#)]:

$$P_s = mnT_i k_s$$

where

- $k_s$  = the effective slip coefficient for the particular surface conditions taken from [Table WD-3234.1\(d\)-1](#).
- $m$  = the number of shear planes per bolt
- $n$  = the number of bolts in the joint
- $T_i$  = initial clamping force per bolt, lb (N)

For materials or surface conditions not listed, the slip coefficient used shall be justified in the Design Report.

SA-307 and austenitic steel bolting shall not be used for friction-type joints.

If the joint clamping force will be reduced by any direct tension load on the joint, the  $T_i$  value shall be reduced by an equivalent amount before substituting in the above equation.

(e) *Bearing Stress.* Allowable bearing stress on the projected area of bolts in bearing-type connections  $F_p$  shall be:

$$F_p = \frac{LS_u}{2d} \leq 1.5S_u$$

where

- $d$  = the nominal diameter of bolt, in. (mm)
- $L$  = the distance from center of bolt hole to edge of connected part, in. (mm)

**WD-3234.2 Size of Holes.** The maximum size of holes for bolts shall be as shown in [Table WD-3234.2-1](#).

- $H$  = standard hole diameter
- $H'$  = oversized hole diameter

Surface Condition	Eff. Slip Coefficient, $k_s$
Clean mill scale, grit-blasted heat treated steel and machined surfaces	0.25
Grit-blasted carbon and low alloy high-strength steel	0.41
Aluminum	0.45

**WD-3234.3 Minimum Edge Distance.**

(a) *Minimum Edge Distance in Line of Load.* In both bearing- and friction-type joints, the minimum distance from the center of the end bolt in a connection to that edge of the connected part toward which the load is directed shall be determined in accordance with either (1) or (2).

(1) The edge distance shall satisfy all of the following:

$$L/d \geq 0.5 + 1.43(f_p/S_u)$$

$$L/d \geq 1.2$$

$$f_p/S_u \leq 1.5$$

where

- $d$  = the nominal diameter of bolt, in. (mm)
- $f_p$  = the computed bearing stress, ksi (MPa)  
 $= P/dt$
- $L$  = the distance from center of bolt hole to edge of connected part, in. (mm)
- $P$  = force transmitted by a bolt, kips (N)
- $t$  = the thickness of a connected part, in. (mm)

(2) The edge distance shall be as shown in [Table WD-3234.3\(a\)-1](#).

**WD-3234.4 Minimum Spacing.** The distance between centers of standard, oversized, or slotted bolt holes shall not be less than three times the nominal diameter of the bolt. Along a line of transmitted force, the distance between centers of holes shall not be less than the following:

(a) *Standard Holes:*

$$2P/S_u t + d/2$$

where

- $d$  = the nominal diameter of bolt, in. (mm)
- $P$  = the force transmitted by one bolt to the connected part, kips (N)
- $S_u$  = the specified minimum tensile strength of the connected part, ksi (MPa) at temperature
- $t$  = the thickness of the connected part, in. (mm)

(b) *Oversized and Slotted Holes.* The distance required for standard holes, above, plus the applicable increment C1 in [Table WD-3234.4-1](#), but the clear distance between holes shall not be less than the bolt diameter.

**WD-3234.5 Effective Bearing Area.** The effective bearing area of bolts loaded in shear shall be the nominal diameter of the bolt multiplied by the length in bearing, except that for countersunk bolts one-half the depth of the countersink shall be deducted.



**Table WD-3234.2-1  
Maximum Sizes of Bolt Holes**

Nominal Bolt Diameter ( <i>d</i> ) in. (mm)	Standard Hole Diameter ( <i>H</i> ) in. (mm)	Oversize Hole Diameter ( <i>H'</i> ) in. (mm)	Short-Slotted Hole Dimensions (Width × Length) in. (mm)	Long-Slotted Hole Dimensions (Width × Length) in. (mm)
1/2 (13)	9/16 (14)	11/16 (17)	9/16 (14) × 3/4 (19)	9/16 (14) × 1 1/4 (32)
5/8 (16)	11/16 (17)	13/16 (21)	11/16 (17) × 7/8 (22)	11/16 (17) × 1 7/16 (40)
3/4 (19)	13/16 (21)	15/16 (24)	13/16 (21) × 1 (25)	13/16 (21) × 1 7/8 (48)
7/8 (22)	15/16 (24)	1 1/16 (27)	15/16 (24) × 1 1/8 (29)	15/16 (24) × 2 3/16 (56)
1 (25)	1 1/16 (27)	1 1/4 (32)	1 1/16 (27) × 1 7/16 (33)	1 1/16 (27) × 2 1/2 (64)
≥ 1 1/8 (29)	<i>H</i> + 1/16 (2)	<i>H'</i> + 5/16 (8)	[ <i>d</i> + 1/16 (2)] × [ <i>d</i> + 3/8 (10)]	[ <i>d</i> + 1/16 (2)] × 2 1/2 (64) × <i>d</i>

**WD-3234.6 Long Grips.** For bolts that have a grip that exceeds five diameters, the effect of bolt length (such as bending and prying) shall be considered in the Design Report.

**WD-3234.7 Thread Engagement.** The thread engagement of any bolt shall be evaluated for thread shear failure. The shear stresses in the external threads of the bolt and the internal threads of the mating material shall not exceed the allowable shear for the applicable material. This evaluation is not required for standard bolts when used with standard nuts of the appropriate material.

**WD-3235 High-Cycle Fatigue Design for Bolted Joints**

**WD-3235.1 Scope.** Members and their connections, subject to a number of cycles (>20,000) of fatigue loading resulting in damage as defined in [WD-3235.2](#), shall be proportioned to satisfy the stress-range limitations provided herein.

**WD-3235.2 Definitions.** High-cycle fatigue, as used in this subsubarticle, is defined as the damage that may result in fracture after a sufficient number of fluctuations of stress. *Stress range* is defined as the numerical sum of maximum repeated tensile and compressive stresses or the sum of maximum shearing stresses of opposite direction at a given point, resulting from differing arrangements of load.

**WD-3235.3 Design Considerations.** In the design of members and connections subject to repeated variation of live load stress, consideration shall be given to the number of stress cycles, the expected range of stress, and the type and location of members or detail.

**WD-3235.4 Classification of Loading Conditions.** Loading conditions shall be classified as shown in [Table WD-3235.4-1](#).

**WD-3235.5 Stress Categories.** Stress categories for use in establishing the maximum range of stress in relation to the type of member or part, material, and location shall be as stipulated in [Table WD-3235.5-1](#).

**WD-3235.6 Allowable Stresses.** The maximum stress shall not exceed the basic allowable stress permitted in [WD-3234.1](#) and the maximum range of stress shall not exceed that given in [Table WD-3235.6-1](#).

**WD-3235.7 Provisions for Bolting.** Range in tensile stress in properly tightened bolts in friction-type connections need not be considered, but the maximum computed stress, including prying action, shall not exceed the values given in [WD-3235.6](#), subject to the following stipulations.

(a) Connections subject to more than 20,000 cycles, but not more than 500,000 cycles, of direct tension may be designed for the stress produced by the sum of applied and prying loads, if the prying load does not exceed 10% of the externally applied load. If the prying load exceeds 10%, the allowable tensile stress given in [WD-3234.1\(a\)](#) shall be reduced 40%, applicable to the external load alone.

(b) Connections subject to more than 500,000 cycles of direct tension may be designed for the stress produced by the sum of applied and prying loads, if the prying load

**Table WD-3234.3(a)-1  
Minimum Edge Distances**

Bolt Diameter in. (mm)	Minimum Edge Distance for Punched, Reamed, or Drilled Holes, in. (mm)	
	At Sheared Edges	At Rolled Edges of Plates, Shapes, or Bars, or Gas Cut Edges [Note (1)]
1/2 (13)	7/8 (22)	3/4 (19)
5/8 (16)	1 1/8 (29)	7/8 (22)
3/4 (19)	1 1/4 (32)	1 (25)
7/8 (22)	1 1/2 (38)	1 1/8 (29)
1 (25)	1 3/4 (44)	1 1/4 (32)
1 1/8 (29)	2 (51)	1 1/2 (38)
1 1/4 (32)	2 1/4 (57)	1 7/8 (41)
> 1 1/4 (32)	1 3/4 (44) × <i>d</i>	1 1/4 (32) × <i>d</i>

NOTE:

(1) All edge distances in this column may be reduced 1/8 in. (3 mm) when the hole is at the point where stress does not exceed 25% of the maximum allowed stress in the part.

**Table WD-3234.4-1  
Increment C1 for Minimum Spacing Between Oversized and Slotted Holes**

Nominal Bolt Diameter in. (mm)	C1 for Oversized Holes in. (mm)	C1 for Slotted Holes in. (mm)		
		Perpendicular to Line of Force	Parallel to Line of Force	
			Short-Slotted	Long-Slotted
1/2 (13)	1/8 (3)	0	3/16 (5)	11/16 (17)
5/8 (16)	1/8 (3)	0	3/16 (5)	7/8 (22)
3/4 (19)	1/8 (3)	0	3/16 (5)	1 1/16 (27)
7/8 (22)	1/8 (3)	0	3/16 (5)	1 1/4 (32)
1 (25)	3/16 (5)	0	1/4 (6)	1 7/16 (37)
1 1/8 (29)	1/4 (6)	0	5/16 (8)	1 5/8 (41)
1 1/4 (32)	1/4 (6)	0	5/16 (8)	1 13/16 (46)
Over 1 1/4 (32)	1/4 (6)	0	5/16 (8)	1 1/2 (38) × $d - 1/16$ (2)

GENERAL NOTE: When the length of the slot is less than the maximum allowable (Table WD-3234.2-1), C1 may be reduced by the difference between the maximum and actual slot lengths.

does not exceed 5% of the externally applied load. If the prying load exceeds 5%, the allowable tensile stress given in WD-3234.1(a) shall be reduced 50%, applicable to the external load alone. The use of other bolts and threaded parts subject to tensile fatigue loading is not recommended. Bolts and threaded parts subjected to cyclic loading in shear may be designed for the bearing-type shear stresses given in WD-3234.1(b) insofar as the fatigue strength of the bolts is concerned.

**WD-3236 Special Considerations**

The provisions of WD-3120 apply.

**WD-3240 DESIGN REQUIREMENTS FOR PLATE- AND SHELL-TYPE INTERNAL SUPPORT STRUCTURE WELDED JOINTS**

Welded joints shall be evaluated per the requirements of WD-3220, providing the quality factor *n* and fatigue factor *f* used in the analysis meet the requirements of Table WD-3240-1 for the method of examination employed. The quality factor *n* is used by multiplying the allowable stress limit for primary and primary plus secondary stress categories by the quality factor in evaluating the design. The use of weld quality factor *n* is not required for fatigue applications. In performing a fatigue analysis, multiply the alternating stress by the fatigue factor *f*, designated in Table WD-3240-1, and use the results with the applicable fatigue curve in Section III Appendices, Mandatory Appendix I to determine the allowable number of fatigue cycles.

**WD-3241 Welded Joint Categories**

(a) The term *weld joint category* as used herein defines the location of a joint. The categories established by this paragraph are for use elsewhere in this Subsection to identify special restrictions regarding type of joints permitted for the location. Joints whose design functions are neither to restrain nor support the internal support structure do not fall into any category.

(b) The *types* of joints that may be used at the various locations are defined in WD-3242.

**WD-3241.1 Joints of Category A.** Joints of Category A are longitudinal joints in plate and shell members. Category A joints may be of Type I, II, or, with the following restriction, Type IV. When a Type IV joint is used in Category A, the quality factor *n* shall be one-half that permitted for Type I or II by Table WD-3240-1 for the examination used.

**Table WD-3235.4-1  
Classification of Loading Conditions**

Loading Condition	Number of Loading Cycles	
	From	To
1	20,000 [Note (1)]	100,000 [Note (2)]
2	100,001	500,000 [Note (3)]
3	500,001	2,000,000 [Note (4)]
4	>2,000,000	

NOTES:

- (1) Approximately equivalent to two applications every day for 25 yr.
- (2) Approximately equivalent to ten applications every day for 25 yr.
- (3) Approximately equivalent to 50 applications every day for 25 yr.
- (4) Approximately equivalent to 200 applications every day for 25 yr.

**Table WD-3235.5-1  
Stress Categories**

General Condition	Situation	Type of Stress [Note (1)]	Stress Category
			(See Table WD-3235.6-1)
Mechanically fastened connections	Base metal at gross section of high-strength bolted slip-critical connections, except axially loaded joints that induce out-of-plane bending in connected material	<i>T</i> or Rev.	B
	Base metal at net section of other mechanically fastened joints [Note (2)]	<i>T</i> or Rev.	D
	Base metal at net section of fully tensioned high-strength, bolted-bearing connections	<i>T</i> or Rev.	B

## NOTES:

(1) *T* signifies range in tensile stress only and Rev. signifies a range involving reversal of tensile or compressive stress.

(2) When stress reversal is involved, use of low strength bolts (e.g., SA-307) is not recommended.

**WD-3241.2 Joints of Category B.** Joints of Category B are girth welds in plate and shell members. Category B joints may be of Type I, II, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category B, the quality factor *n* shall be one-half that permitted for Type I or II by Table WD-3240-1 for the examination used.

**WD-3241.3 Joints of Category C.** Joints of Category C are for joints at the ends of plates and shell members. Category C joints may be of Type I, II, III, IV, V, VI, VII, or VIII.

**WD-3242 Permissible Types of Welded Joints**

Subject to the limitations given in WD-3241, internal support structures may use any of the types of joints described in the following subparagraphs. When evaluating the load capacity of Type IV, V, VI, or VII Joints, the area of the weld connection shall be determined as the product of the weld throat thickness times the length of the weld.

**WD-3242.1 Type I Joints.** Full penetration welds between plates or other elements that lie approximately in the same plane or have an offset angle not greater than 30 degrees meet the categorizing intent of this subparagraph. This subparagraph is applicable when these welds are made either as double welded butt joints, or with

consumable inserts or gas backup, or with metal backing strips that are later removed, provided the backface of such joints meets the requirements of WD-4424.

**WD-3242.2 Type II Joints.** Full penetration welds between plates or other elements meet the categorizing intent of this subparagraph when made either according to WD-3242.1 or with edges of the joint prepared with opposing lips to form an integral backing strip, or with metal backing strips that are not later removed. When used, backing strips shall be continuous and any splices shall be full penetration welded. In addition, the suitability for cyclic operation shall be analyzed by the method of WD-3222.5.

**WD-3242.3 Type III Joints.** Full penetration welds between plates or other elements that may have an offset angle up to 90 degrees meet the categorizing intent of this subparagraph when either are made according to WD-3242.2 or are corner welds. Attachment of connections using deposited weld metal as reinforcement and oblique connections meet the intent of this subparagraph.

**WD-3242.4 Type IV Joints.** Partial penetration welds of double groove design (minimum depth of each groove equals one-eighth times the thickness of the thinnest

**Table WD-3235.6-1  
Allowable Stress Ranges**

Stress Category Used in Table WD-3235.5-1	Allowable Range of Stress, $F_{sr}$ , ksi (MPa)			
	Loading Condition 1, $F_{sr1}$	Loading Condition 2, $F_{sr2}$	Loading Condition 3, $F_{sr3}$	Loading Condition 4, $F_{sr4}$
B	49 (340)	29 (200)	18 (125)	16 (110)
D	28 (195)	16 (110)	10 (70)	7 (50)

## NOTE:

(1) Flexural stress range of 12 ksi (83 MPa) permitted at toe of stiffener welds on webs or flanges.

**Table WD-3240-1  
Permissible Welded Joints and Design Factors**

Type of Welded Joint [Note (1)]		Permissible for Category Shown Below	Quality Factors ( <i>n</i> ) and Fatigue Factors ( <i>f</i> )				
			RT or UT and PT or MT Examination WD-5220	Progressive PT or MT Examination WD-5231	Root and Final PT or MT Examination WD-5232	Surface PT or MT Examination WD-5233	Surface Visual Examination WD-5260
I.	Full penetration	A, B, C	$n = 1.00 \quad f = 1$	$n = 0.90 \quad f = 1$	$n = 0.75 \quad f = 1$	$n = 0.65 \quad f = 1$	$n = 0.50 \quad f = 1$
II.	Full penetration	A, B, C	$n = 1.00 \quad f = 2$	$n = 0.90 \quad f = 2$	$n = 0.75 \quad f = 2$	$n = 0.65 \quad f = 2$	$n = 0.50 \quad f = 2$
III.	Full penetration	C	$n = 1.00 \quad f = 1$	$n = 0.90 \quad f = 1$ [Note (2)]	$n = 0.75 \quad f = 1$ [Note (2)]	$n = 0.65 \quad f = 1$ [Note (2)]	$n = 0.50 \quad f = 1$ [Note (2)]
IV.	Double groove partial penetration (RT not applicable)	A, B	$n = 0.50 \quad f = 4$	$n = 0.45 \quad f = 4$	$n = 0.40 \quad f = 4$	$n = 0.35 \quad f = 4$	$n = 0.25 \quad f = 4$
		C	$n = 0.90 \quad f = 4$	$n = 0.80 \quad f = 4$	$n = 0.70 \quad f = 4$	$n = 0.60 \quad f = 4$	$n = 0.40 \quad f = 4$
V.	Double fillet (RT not applicable)	B	$n = 0.50 \quad f = 4$	$n = 0.45 \quad f = 4$	$n = 0.40 \quad f = 4$	$n = 0.35 \quad f = 4$	$n = 0.25 \quad f = 4$
		C	$n = 0.90 \quad f = 4$	$n = 0.80 \quad f = 4$	$n = 0.70 \quad f = 4$	$n = 0.60 \quad f = 4$	$n = 0.40 \quad f = 4$
VI.	Single groove partial penetration (RT not applicable)	C	$n = 0.60 \quad f = 4$	$n = 0.55 \quad f = 4$	$n = 0.45 \quad f = 4$	$n = 0.40 \quad f = 4$	$n = 0.35 \quad f = 4$
VII.	Single fillet (RT not applicable)	C	$n = 0.60 \quad f = 4$	$n = 0.55 \quad f = 4$	$n = 0.45 \quad f = 4$	$n = 0.40 \quad f = 4$	$n = 0.35 \quad f = 4$
VIII.	Intermittent fillet or plug	C	Not applicable	$n = 0.45 \quad f = 4$	$n = 0.40 \quad f = 4$	$n = 0.35 \quad f = 4$	$n = 0.30 \quad f = 4$

NOTES:

(1) See [WD-3242](#) for definitions.

(2) A minimum fatigue strength reduction factor of 1.0 is permitted when both sides of the weld are examined; otherwise a factor of 2.0 shall be used in analysis for cyclic operation.

element) meet the categorizing intent of this subparagraph when the area of the weld connection is determined per [WD-3242](#).

**WD-3242.5 Type V Joints.** Double fillet welds meet the categorizing intent of this subparagraph when the area of the weld connection is determined per [WD-3242](#). Joints made having one side a single fillet and the other side a single groove meet the intent of this subparagraph.

**WD-3242.6 Type VI Joints.** Partial penetration welds of single groove design meet the categorizing intent of this subparagraph when the area of the weld connection is determined per [WD-3242](#).

**WD-3242.7 Type VII Joints.** Single fillet welds meet the categorizing intent of this subparagraph when the area of the weld connection is determined per [WD-3242](#).

**WD-3242.8 Type VIII Joints.** Intermittent fillet or plug welds meet the categorizing intent of this subparagraph when the area of the intermittent fillet weld connection is determined as the product of the theoretical throat thickness times the sum of weld lengths and the area of plug weld connection is determined as the product of the number of plug welds times the area of the minimum cross-section.

**WD-3242.9 Limitations on Types of Joints.** The type of joint used for service shall be one of those permitted for the category of the joint ([WD-3241](#)). Reduced quality factors shall be used for certain types of joints when used in Categories A, B, and C ([Table WD-3240-1](#)).

## **WD-3300 DESIGN RULES FOR LINEAR-TYPE INTERNAL SUPPORT STRUCTURES**

### **WD-3310 GENERAL REQUIREMENTS**

A linear-type internal support structure is defined as acting under essentially a single component of direct stress. Such elements may also be subjected to shear stresses. For members subjected to torsion, the rules of [WD-3200](#) apply. Support structures with thermal loads, thermal gradients, or both shall be evaluated to

[WD-3200](#) requirements unless it can be shown in the Design Report that the resulting stresses due to thermal and thermal gradient loads are less than 10% of  $S_y$  at temperature. Design procedures applicable to linear-type internal support structures are provided in NF-3320 and NF-3330 of Division 1.<sup>25</sup> These Division 1 design procedures shall be used unless the design procedures of [WD-3200](#) are used. The design procedures shall ensure that deformation criteria are satisfied as required in [WD-1110\(b\)](#).

Welds in linear-type internal support structures shall be evaluated per the requirements of NF-3320 and NF-3330 providing the quality factor  $n$  and fatigue factor  $f$  used in the analysis meet the requirements of [Table WD-3240-1](#) for the method of examination employed. The quality factor  $n$  is used by multiplying the allowable stress limit for primary and primary plus secondary stress categories by the quality factor in evaluating the design. The use of weld quality factor  $n$  is not required for fatigue applications. In performing a fatigue analysis, multiply the alternating stress by the fatigue factor  $f$ , designated in [Table WD-3240-1](#), and use the results with the applicable allowable stress ranges of [Table NF-3332.4-1](#) to determine the allowable number of fatigue cycles.

### **WD-3311 Requirements for Acceptability**

The requirements for the acceptability of a design by analysis are those set forth in (a) through (b) below and the general requirements of [WD-3100](#). In addition, when geometric configuration [[WD-1110\(b\)](#) and [WD-3125](#)] of the contents is required, the deformation limits prescribed by the Design Specification shall be met.

(a) The design shall conform to the general requirements of NF-3310 and the design rules of NF-3320 and NF-3330 except as noted in (1) and (2) below.

(1) The use of single angle members is not allowed.

(2) The use of NF-3324.1(a)(3), NF-3324.3, and NF-3324.4(b) is not allowed.

(b) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G.

# ARTICLE WD-4000 FABRICATION

## WD-4100 GENERAL REQUIREMENTS

### WD-4110 INTRODUCTION

Internal support structures (WD-1120) shall be fabricated in accordance with the requirements of this Article and shall be manufactured from materials that meet the requirements of Article WD-2000.

### WD-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY CERTIFICATE HOLDER

#### WD-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Certification Mark and completion of the appropriate Data Report in accordance with Article WA-8000, that the materials used comply with the requirements of Article WD-2000 and that the fabrication complies with the requirements of this Article.

**WD-4121.1 Certification of Treatments, Tests, and Examinations.** If the Certificate Holder performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (WA-3800 or WA-8410). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

**WD-4121.2 Repetition of Tensile or Impact Tests.** If during the fabrication of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (WD-2200), and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons that have been taken and treated in accordance with the requirements of Article WD-2000.

**WD-4121.3 Repetition of Surface Examination After Machining.** If, during the fabrication of an item, materials are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with WD-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with WD-2500; and

(b) the amount of material removed from the surface exceeds the lesser of  $\frac{1}{8}$  in. (3 mm) or 10% of the minimum thickness of the part required to satisfy the rules of Article WD-3000.

### WD-4122 Material Identification

Material for internal support structures shall have identification markings that shall remain distinguishable until the internal support structure is fabricated. If the original identification markings are cut off or the material is divided, the marks shall either be transferred to the cut parts or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication, unless otherwise provided by WD-2150. For studs, bolts, and nuts it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding material shall be identified and controlled so that they can be traced to the internal support structure, or else a control procedure shall be employed that ensures that the specified materials are used.

### WD-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of Article WD-4000, may be performed by the persons who perform or supervise the work. These visual examinations shall not be required to be performed by personnel and procedures qualified to WD-5500 and WD-5100, respectively, unless so specified.

### WD-4125 Testing of Welding Material

All welding material shall meet the requirements of WD-2400.

## WD-4130 REPAIR OF MATERIAL

### WD-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of WD-2500 are known or discovered during the process of fabrication shall be unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of WD-2500 for the applicable product form, except:



(a) the limitation on the depth of the weld repair shall not apply, and

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with [WD-5120](#).

### **WD-4132 Documentation of Repair Welds of Base Material**

The Certificate Holder who makes a repair weld, exceeding in depth the lesser of  $\frac{3}{8}$  in. (10 mm) or 10% of the section thickness, shall prepare a report that shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds. In addition, all repair welds exceeding an accumulated area of 20% of the area of the part or 15 in.<sup>2</sup> (9 700 mm<sup>2</sup>), whichever is less, shall require the same documentation as welds exceeding the minimum depth.

### **WD-4200 FORMING, FITTING, AND ALIGNING**

#### **WD-4210 CUTTING, FORMING, AND BENDING**

##### **WD-4211 Cutting**

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, grinding, or by thermal cutting.

##### **WD-4211.1 Preheating Before Thermal Cutting.**

When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules, such as suggested in Section III Appendices, Nonmandatory Appendix D.

**WD-4211.2 Material Preparation After Thermal Cutting for P-No. 8 Material.** When metal is to be removed by thermal cutting methods, additional material shall be removed by mechanical means to the extent required in the Design Specification.

### **WD-4212 Forming and Bending Processes**

Any process may be used to hot or cold form material, including weld metal, provided the required dimensions are attained (see [WD-4214](#)), and provided the specified impact properties of the material, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. Hot forming shall be defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material.

### **WD-4213 Qualification of Forming Processes for Impact Property Requirements**

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the structure. These specimens shall be subjected to the equivalent forming process and heat treatment as the material in the structure. Applicable tests shall be conducted to determine that the required impact properties of [WD-2300](#) are met after straining.

**WD-4213.1 Exemptions.** Procedure qualification tests are not required for material listed in (a) through (f) below:

(a) Hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens.

(b) Hot formed material represented by test coupons that have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts.

(c) Material that does not require impact tests in accordance with [WD-2300](#).

(d) Material that has a final strain less than 0.5%.

(e) Material when the final strain is less than that of a previously qualified procedure for that material.

(f) Material when the impact testing required by [WD-2300](#) is performed on each heat and lot, as applicable, after forming.

**WD-4213.2 Procedure Qualification Test.** The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material, both before straining and after straining and heat treatment, when applicable, to establish the effects of the forming and subsequent heat treatment, when applicable, operations.

(b) Specimens shall be taken in accordance with the requirements of [Article WD-2000](#) and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

(1) For cylinders:

$$\% \text{ strain} = \frac{50t}{R_f} \left( 1 - \frac{R_f}{R_o} \right)$$

(2) For spherical or dished surfaces

$$\% \text{ strain} = \frac{75t}{R_f} \left( 1 - \frac{R_f}{R_o} \right)$$

(3) For pipe

$$\% \text{ strain} = \frac{100r}{R}$$

where

- $R$  = nominal bending radius to the center line of the pipe
- $r$  = nominal radius of the pipe
- $R_f$  = final radius to center line of shell
- $R_o$  = original radius (equal to infinity for a flat part)
- $t$  = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a forming process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient  $C_v$  test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and absorbed energy data (WD-2300). In addition, drop weight tests shall be performed when required by WD-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(-a) the maximum change in lateral expansion and absorbed energy at the temperature under consideration; or

(-b) the maximum change in temperature at the lateral expansion and absorbed energy levels under consideration; or

(2) when lateral expansion is the acceptance criterion (WD-2300), either the maximum change in temperature or the maximum change in lateral expansion.

**WD-4213.3 Acceptance Criteria for Formed Material.** To be acceptable, the formed material used in the structure shall have impact properties, before forming, sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

**WD-4213.4 Requalification.** A new procedure qualification test is required when any of the changes are made in (a) through (c) below:

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering WD-2211. If the material is not postweld heat treated, the procedure shall be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

## WD-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article WD-3000, the material may be repaired in accordance with WD-4130.

## WD-4230 FITTING AND ALIGNING

### WD-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

**WD-4231.1 Tack Welds.** Tack welds used to secure alignment shall either be removed completely, when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined in accordance with WD-5360 and defective tack welds removed.

### WD-4232 Maximum Offset of Aligned Sections

Alignment of sections shall be such that the maximum offset of the finished welded joint will not be greater than  $\frac{1}{4}t$ , where  $t$  is the nominal thickness of the thinner section at the joint.

**WD-4232.1 Fairing of Offsets.** Any offset within the allowable limit provided shall be faired to at least a 3:1 taper, length to offset, over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld. In addition, offsets greater than those stated in WD-4232 are acceptable provided the requirements of Article WD-3000 are met.

### WD-4233 Complete Joint Penetration Weld

Complete joint penetration is considered to be achieved when the acceptance criteria for the examinations specified by this Subsection have been met. No other examination shall be required to assess that complete penetration has been achieved.

## WD-4300 WELDING QUALIFICATIONS

### WD-4310 GENERAL REQUIREMENTS

#### WD-4311 Types of Processes Permitted

Only those welding processes that are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding internal support structure

material or attachments thereto. Any process used shall be such that the records required by [WD-4320](#) can be prepared. Stud welds shall not be permitted.

**WD-4311.1 Capacitor Discharge Welding.** Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided that:

(a) temporary attachments are removed in accordance with the provisions of [WD-4435\(b\)](#),

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm), and

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

**WD-4311.2 Inertia and Continuous Drive Friction Welding.** Inertia and continuous drive friction welding shall not be used.

## **WD-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS**

### **WD-4321 Required Qualifications**

(a) Each Certificate Holder shall be responsible for the welding done by his organization, and each Certificate Holder shall establish the procedure and conduct the tests required by this Article and by Section IX to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to internal support structure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

(d) [WA-3131](#) provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Accreditation.

### **WD-4322 Maintenance and Certification of Records**

The Certificate Holder shall maintain a record of the qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned

to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program and shall be available to the Inspector.

### **WD-4322.1 Identification of Joints by Welder or Welding Operator.**

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, and weld metal cladding are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification;

(c) the identification of welder or welding operator shall not be required for tack welds.

### **WD-4323 Welding Prior to Qualification**

No welding shall be undertaken until after the welding procedures that are to be used have been qualified. Only welders and welding operators who are qualified in accordance with [WD-4320](#) and Section IX shall be used.

### **WD-4324 Transferring Qualifications**

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder except as provided in Section IX.

### **WD-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS**

#### **WD-4331 Conformance to Section IX Requirements**

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

### WD-4333 Heat Treatment of Qualification Welds for Ferritic Material

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of [WD-4600](#) and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the weld material. The postweld heat treatment total time may be applied in one heating cycle.

### WD-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the  $\frac{1}{4}t$  location required by this Subsection, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

**WD-4334.1 Coupons Representing the Weld Deposits.** Impact test specimens and testing methods shall conform to [WD-2321](#). The impact specimen shall be located so that the longitudinal axis of the specimen is at least  $\frac{1}{4}t$  and, where the thickness of the test assembly permits, not less than  $\frac{3}{8}$  in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in [WD-4620](#) and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of  $t$  from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the  $C_v$  specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test assembly.

**WD-4334.2 Coupons Representing the Heat-Affected Zone.** When impact tests of the heat-affected zone are required by [WD-4335.2](#), specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of [WD-2321.2](#). The specimens shall be removed from a

location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. The notch of the  $C_v$  specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line.

(c) For the comparison of heat-affected zone values with base material values [[WD-4335.2\(b\)](#)],  $C_v$  specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat-affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by [WD-4335.2\(b\)](#), drop weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of [WD-2321.1](#).

### WD-4335 Impact Test Requirements

When materials are required to be impact tested per [WD-2300](#), impact tests of the weld metal and heat-affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of [WD-2330](#) and [WD-4334](#). Retests in accordance with the provisions of [WD-2350](#) shall be permitted.

#### WD-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding  $\frac{5}{8}$  in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with [WD-2310](#). In addition, such testing of the weld metal shall be required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with [WD-2310](#), regardless of the depth of the repair. Exemption from impact testing under [WD-2311\(a\)](#) shall not apply to weld metal of welding procedure qualification tests for either production weld joints or base metal repairs unless the specific weld metal used is A-No. 8.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in [WD-2330](#) for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and



acceptance standards of either material may be used for the weld metal except where otherwise specified in the Design Specification.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection WB, WC, NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

#### WD-4335.2 Impact Tests of Heat-Affected Zone.

(a)  $C_v$  tests of the heat-affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds  $\frac{5}{8}$  in. (16 mm) and either of the base materials requires impact testing in accordance with the rules of WD-2310. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than thermit;

(2) the qualification for weld deposit cladding or hard-facing on any base material;

(3) that portion of the heat-affected zone associated with GTAW root deposits with a maximum of two layers or  $\frac{3}{16}$  in. (5 mm) thickness, whichever is less.

(b) The required testing shall be in accordance with (c) below for base material tested under WD-2332 and in accordance with (d) below for base material tested under WD-2331.

(c) For heat-affected zones associated with base material tested under WD-2332, the required testing shall be in accordance with (1) through (7) below.

(1) Determine the  $T_{NDT}$  of the unaffected base material to be used in the welding procedure qualification test assembly.

(2)  $C_v$  specimens representing both the heat-affected zone and the unaffected base material shall be tested at the ( $T_{NDT} + 60^\circ\text{F}$ ) ( $T_{NDT} + 33^\circ\text{C}$ ) temperature.

(3) The  $C_v$  tests of the unaffected base material shall meet the applicable requirements of WD-2332 or additional testing shall be performed at higher temperatures until the requirements of WD-2332 are met.

(4) The heat-affected zone specimens shall be tested at the test temperature determined in (3) above. If the average lateral expansion value of the specimens equals or exceeds the average lateral expansion value of the unaffected base material, the qualification test shall be acceptable for the essential and supplemental essential variables recorded on the Welding Procedure Qualification Record. If the heat-affected zone average lateral expansion value is less than the unaffected base material average lateral expansion value, the adjustment given in (5) through (7) below shall be determined and applied as provided in (e) below. Alternatively, another test coupon may be welded and tested.

(5) Additional  $C_v$  tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion

value of all three specimens tested is not less than 35 mils (0.89 mm). The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature between  $T_{HAZ}$  and  $T_{UBM}$ , where the heat-affected zone and the unaffected base material average lateral expansion values are the same and not less than 35 mils (0.89 mm), shall be used to determine the adjustment temperature  $T_{ADJ}$ , where

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If  $T_{ADJ} \leq 0$ , then  $T_{ADJ} = 0$ .

(6) As an alternative to (5) above, if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm) and the average of the heat-affected zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material specimens,  $T_{ADJ}$  may be taken as  $15^\circ\text{F}$  ( $8^\circ\text{C}$ )

(7) As a second alternative to (5) above, if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3) below.

(d) For heat-affected zones associated with base materials tested under WD-2331, the required testing shall be in accordance with (1) through (5) below.

(1) Three  $C_v$  specimens shall be removed from both the unaffected base material and the heat-affected zone. The unaffected base material specimens shall be tested at the lowest service temperature established in the Design Specification or additional testing shall be performed at higher temperatures until the applicable requirements of Table WD-2331(a)-1 are met for the thickness of material to be welded in production.

(2) The heat-affected zone specimens shall be tested at the test temperature determined in (1) above. If the average lateral expansion value of the specimens equals or exceeds the average lateral expansion value of the unaffected base material, the qualification test shall be acceptable for the essential and supplemental essential variables recorded on the Welding Procedure Qualification Record. If the heat-affected zone average lateral expansion value is less than the unaffected base material lateral expansion value, the adjustment given in (3) through (5) below shall be determined and applied as provided in (e) below. Alternatively, another test coupon may be welded and tested.

(3) Additional  $C_v$  tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than the values shown in Table WD-2331(a)-1 for the thickness of base material to be welded in production. The average lateral expansion value for each test meeting this requirement

shall be plotted on a lateral expansion versus temperature graph. The difference in temperature between  $T_{HAZ}$  and  $T_{UBM}$ , where the heat-affected zone and the unaffected base material average lateral expansion values are the same and not less than that specified in (2) above, shall be used to determine the adjustment temperature  $T_{ADJ}$ , where

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If  $T_{ADJ} \leq 0$ , then  $T_{ADJ} = 0$ .

(4) As an alternative to (3) above, if the average lateral expansion value of the heat-affected zone is no less than 35 mils (0.89 mm) and the average of the heat-affected zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material,  $T_{ADJ}$  may be taken as 15°F (8°C).

(5) As a second alternative to (3) above, if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3) below.

(e) At least one of the following methods shall be used to compensate for the heat-affected zone toughness decrease due to the welding procedure effects:

(1) The  $RT_{NDT}$  temperature established in WD-2332 or the lowest service temperature specified in the Design Specification (WD-2331) for all of the material to be welded in production Welding Procedure Specifications supported by this Welding Procedure Qualification Record shall be increased by the adjustment temperature  $T_{ADJ}$ .

(2) The specified testing temperature for the production material may be reduced by  $T_{ADJ}$ .

(3) The materials to be welded may be welded using the Welding Procedure Specification provided they exhibit  $C_v$  values that are no less than the minimum required lateral expansion value required by WD-2300 plus the difference in average lateral expansion values established in (c)(7) or (d)(5) above.

(f) The  $C_v$  testing results shall be recorded on the Welding Procedure Qualification Record and any offsetting  $T_{ADJ}$  or increased toughness requirements shall be noted on the Welding Procedure Qualification Record and on the Welding Procedure Specification. More than one compensation method may be documented on the Welding Procedure Qualification Record.

(g) A Welding Procedure Specification qualified to the impact testing requirements of Subsection WB, WC, NB, NC, or NE may be accepted as an alternative to the Welding Procedure impact testing requirements of this Division.

### WD-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of WD-4331 to WD-4335, inclusive.

### WD-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

#### WD-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

#### WD-4411 Identification, Storage, and Handling of Welding Material

Each Certificate Holder shall be responsible for control of the welding electrodes and other material that is used in the fabrication (WD-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

#### WD-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

### WD-4420 RULES FOR MAKING WELDED JOINTS

#### WD-4421 Backing Bars

Backing bars shall conform to the requirements of WD-3240. The material for backing bars, when used, shall be compatible with the base metal. Permanent backing bars, when permitted by WD-3240, shall be continuous, and any splices shall be made by full penetration welds. Spacer pins shall not be incorporated into the welds.

#### WD-4422 Peening

Controlled peening may be performed to minimize distortion. Peening shall not be used for stress mitigation. Peening shall not be used on the initial layer, root of the weld metal, or on the final layer unless the weld is post-weld heat treated.



**WD-4423 Double Welded Joints**

(a) Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

(b) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(c) Where single welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

**WD-4424 Surfaces of Welds**

As-welded surfaces shall be permitted. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and any other required nondestructive examinations of the weld. In those cases where there is a question regarding the surface condition of the weld on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements shall be permitted in accordance with WD-4426.

(c) Undercuts shall not exceed  $\frac{1}{32}$  in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single welded circumferential butt weld shall be permitted when the resulting thickness of the weld meets the requirements of Article WD-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

**WD-4425 Welding Items of Different Diameters**

When items of different diameters are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld. The slope of the transition shall be such that the length-offset ratio shall not be less than 3:1, unless greater slopes are shown to be acceptable by analysis in accordance with WD-3200 and WD-3300.

**WD-4426 Reinforcement of Welds**

The surface of the reinforcement of all butt welded joints may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thickness in the following tabulation:

Nominal Thickness, in. (mm)	Maximum Reinforcement,
	in. (mm)
Up to 1 (25), incl.	$\frac{3}{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$\frac{1}{8}$ (3.0)
Over 2 to 3 (50 to 75), incl.	$\frac{5}{32}$ (4.0)
Over 3 to 4 (75 to 100), incl.	$\frac{7}{32}$ (5.5)
Over 4 to 5 (100 to 125), incl.	$\frac{1}{4}$ (6.5)
Over 5 (125)	$\frac{5}{16}$ (8.0)

**WD-4427 Shape and Size of Fillet Welds**

Fillet welds may vary from convex to concave. The shape and size of the weld shall be in accordance with the requirements of Figure WD-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than  $\frac{1}{16}$  in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length.

**WD-4428 Welding of Clad Parts<sup>11</sup>**

The joint types and welding procedures used for cladding shall be such as to prevent the formation of brittle weld composition. Any such weld deposited cladding shall be examined by a liquid penetrant method in accordance with the requirements of WD-5110 and meet the acceptance standards of WD-5350. Parts welded to clad items shall be welded directly to the base metal and not to the cladding, except in the case of weld overlay cladding.

**WD-4430 WELDING OF ATTACHMENTS****WD-4431 Materials for Attachments**

Attachments welded to internal support structures shall be of materials that meet the requirements of WD-2120.

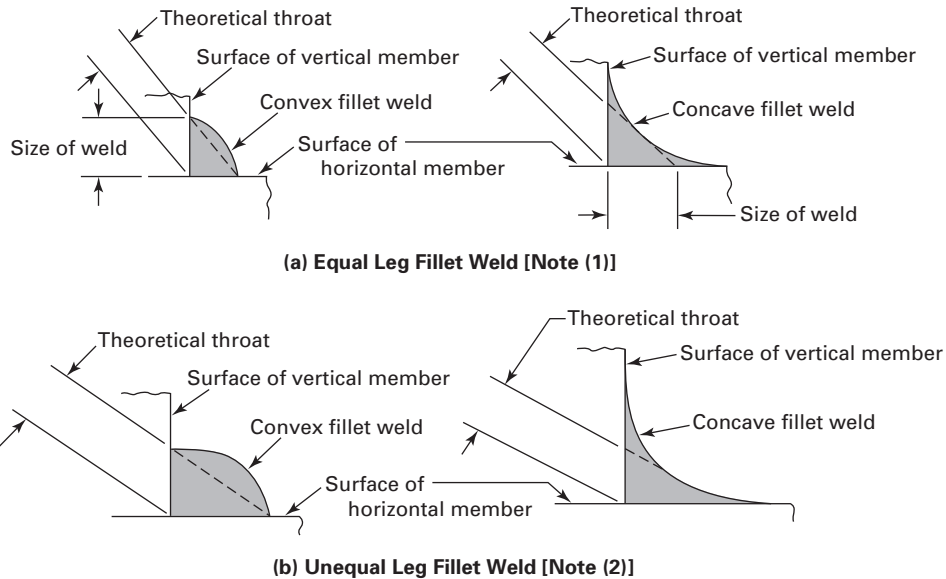
**WD-4432 Welding of Structural Attachments**

The rules of WD-4321 governing welding qualifications shall apply to the welding of structural attachments.

**WD-4433 Structural Attachments**

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous welds. When fillet and partial penetration welds are used on components, the requirements of WD-3200 and WD-3300 shall be met.

**Figure WD-4427-1  
Fillet Weld Details and Dimensions**



**NOTES:**

- (1) The size of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle. Theoretical throat =  $0.7 \times$  size of weld.  
 (2) The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross-section.

**WD-4434 Welding of Attachments to Clad Components**

Structural attachments on clad components shall be welded to the base metal and not to the cladding, except for weld overlay cladding.

**WD-4435 Welding of Temporary Attachments and Their Removal**

(a) Temporary attachments may be noncertified material and may be welded with continuous or intermittent fillet or partial penetration welds, provided the following conditions are met:

(1) The welding procedure and the welders have been qualified in accordance with [WD-4321](#).

(2) The base material is identified and is suitable for welding.

(3) The base material is compatible with the material to which it is attached.

(4) The welding material is identified and compatible with the materials joined, and

(5) The welds are postweld heat treated when required by [WD-4620](#).

(b) Removal of temporary attachments shall be accomplished as follows:

(1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.

(2) The temporary attachment is completely removed in accordance with the procedures of [WD-4211](#).

(3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of [WD-5110](#) and meets the acceptance standards of [WD-5340](#) or [WD-5350](#), whichever is applicable; this examination shall not be required if more than  $\frac{1}{8}$  in. (3.0 mm) of material will be removed by any subsequent machining operations.

(4) As an alternative to (a)(5) above, postweld heat treatment may be deferred until after removal of the attachment.

**WD-4440 SPECIAL REQUIREMENTS FOR WELDING**

**WD-4441 Through-Thickness Loading**

Welded joint configurations causing significant through thickness tensile stress (defined as being in excess of 50% of the allowable stress limits permitted by [Article WD-3000](#)) during fabrication or service on rolled product forms should be avoided. When this type of construction is used, weld volume and welding heat input on the rolled surfaces should be limited to the extent practical. When identified by the Design Output Documents, weld joints in primary members 1 in. (25 mm) or greater in thickness in component supports subjected to significant through

thickness tensile loads and any other weld joints identified in the Design Output Documents shall meet one of the following requirements:

(a) After completion of welding, the base material directly underneath the attachment shall be ultrasonically examined in accordance with the requirements of [Article WD-5000](#), as appropriate.

(b) A weld metal inlay or overlay shall be made in accordance with [Figure WD-4441-1](#) and ultrasonically examined in accordance with [Article WD-5000](#), prior to making the weld joining the attachment member to the inlay or overlay.

(c) The material shall meet the acceptance standards of SA-770, Through-Thickness Tension Testing of Steel Plates for Special Applications.

## WD-4450 REPAIR OF WELD METAL DEFECTS

### WD-4451 General Requirements

Defects in weld metal detected by the examinations required by [Article WD-5000](#) shall be eliminated and repaired when necessary.

### WD-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided that the following requirements are met:

(a) The remaining thickness of the section is not reduced below that required by [Article WD-3000](#).

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

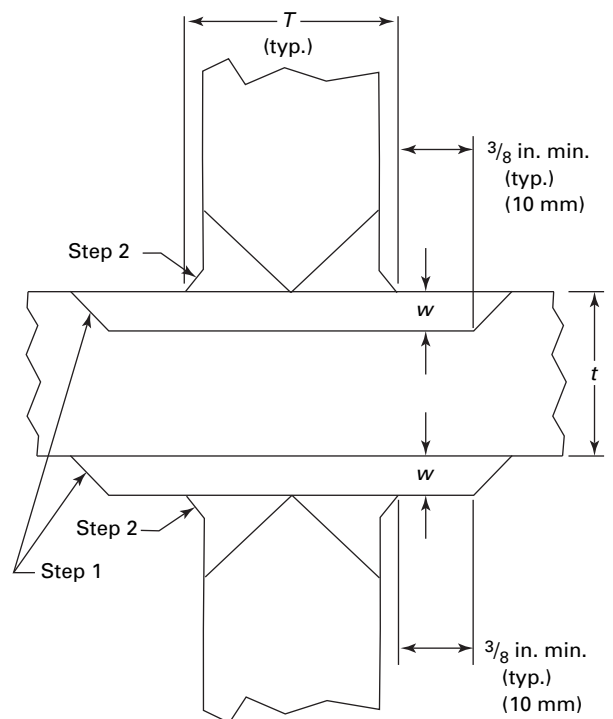
(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with [Article WD-5000](#) after blending and meets the acceptance standards of [Article WD-5000](#) to ensure volumetric method and located on an interior surface need only be reexamined by the method that initially detected the defect when the interior surface is inaccessible for surface examination.

### WD-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

**WD-4453.1 Defect Removal.** Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with [WD-5110](#) and meet the acceptance standards of [WD-5340](#) or [WD-5350](#). This examination shall not be required when defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

**Figure WD-4441-1**  
**Weld Inlay and Overlay Specifications**



Step 1: Inlay or overlay weldment

Step 2: Completion of weldment

#### GENERAL NOTES:

- $T$  is the width of the welded zone measured on the primary member surface.
- Members may be welded on one side only or from both sides.
- Inlay or overlay thickness shall be  $\frac{1}{4}$  in. (6 mm) min. for  $t = 1$  in. (25 mm) and shall be increased  $\frac{1}{16}$  in. (1.5 mm) for each additional  $\frac{3}{8}$  in. (10 mm) of  $t$  but not exceed  $\frac{1}{2}$  in. (13 mm).
- When  $T$  exceeds  $t$ ,  $w$  shall be increased by an additional  $\frac{1}{16}$  in. (1.5 mm) for each  $\frac{3}{8}$  in. (10 mm) of  $T$  over  $t$ , to a maximum of  $\frac{1}{2}$  in. (13 mm).
- The minimum specified tensile strength of the electrodes used for inlay or overlay shall not exceed the minimum specified tensile strength of the base metal by more than 12 ksi (83 MPa).

**WD-4453.2 Requirements for Welding Material, Procedures, and Welders.** The weld repair shall be made using welding material, welders, and welding procedures qualified in accordance with [WD-4125](#) and [WD-4300](#).

**WD-4453.3 Blending of Repaired Areas.** After repair the surface shall be blended uniformly into the surrounding surface.

**WD-4453.4 Examination of Repair Welds.** The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method

when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

- (a)  $\frac{1}{3}t$  for  $t \leq \frac{1}{2}$  in. (13 mm)
- (b)  $\frac{1}{4}$  in. (6 mm) for  $\frac{1}{2}$  in. (13 mm)  $< t \leq 2\frac{1}{2}$  in. (64 mm)
- (c) the lesser of  $\frac{3}{8}$  in. (10 mm) or 10%  $t$  for  $t > 2\frac{1}{2}$  in. (64 mm)

where  $t$  equals the thickness of the weld.

**WD-4453.5 Heat Treatment of Repaired Areas.** The area shall be heat treated in accordance with [WD-4620](#).

## WD-4500 BRAZING

Brazing shall not be permitted for internal support structures.

## WD-4600 HEAT TREATMENT

### WD-4610 WELDING PREHEAT AND INTERPASS REQUIREMENTS

#### WD-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, temperature, physical properties, and material thickness. Some practices used for preheating are given in Section III Appendices, Nonmandatory Appendix D as a general guide for the materials listed by P-Numbers of Section IX. It is cautioned that the preheating suggested in Section III Appendices, Nonmandatory Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

#### WD-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method that does not harm the base material or any weld metal already applied or that does not introduce deleterious material into the welding area that is harmful to the weld.

#### WD-4613 Interpass Temperature

Consideration shall be given to the limitations of interpass temperatures for quenched and tempered material to avoid detrimental effects on the mechanical properties.

## WD-4620 POSTWELD HEAT TREATMENT

### WD-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

### WD-4622 PWHT Time and Temperature Requirements

**WD-4622.1 General Requirements.** Except as otherwise permitted in [WD-4622.7](#), all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature range and for the minimum holding time specified in [Table WD-4622.1-1](#), except as otherwise permitted in [WD-4622.4\(c\)](#). P-Number groups in [Table WD-4622.1-1](#) are in accordance with Section IX, QW-420. Except as provided in [WD-4624.3](#), PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. Any postweld heat treatment time, which is anticipated to be applied to the material or item after it is completed, shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens. In addition, the requirements of the following subparagraphs shall apply.

**WD-4622.2 Time-Temperature Recordings.** Time-temperature recordings of all postweld heat treatments shall be made available for review by the Inspector. Identification on the time-temperature recording shall be to the applicable weld, part, or internal support structure. A summary of the time-temperature recording may be provided for permanent records in accordance with [WA-4134](#).

**WD-4622.3 Definition of Nominal Thickness Governing PWHT.** The nominal thickness in [Table WD-4622.7\(b\)-1](#) shall be the thickness of the weld, the base material, or the thinner of the base materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed  $\frac{1}{8}$  in. (3 mm). For fillet welds, the nominal thickness is the throat thickness, and for partial penetration and material repair welds, the nominal thickness shall be the depth of the weld groove or preparation.

#### WD-4622.4 Holding Times at Temperature.

(a) The holding time at temperature as specified in [Table WD-4622.1-1](#) shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat treat cycles.

**Table WD-4622.1-1  
Mandatory Requirements for Postweld Heat Treatment (PWHT) of Welds**

P-Number (Sect. IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal), in. (mm)			
		½ in. (13 mm) or less	Over ½ in. (13 mm) to 2 in. (50 mm)	Over 2 in. (50 mm) to 5 in. (125 mm)	Over 5 in. (125 mm)
1, 3	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
4	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
5A, 5B, 5C, 6 except P-No. 6 Gr. 4	1,250–1,400 (675–760)	30 min.	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
6 Gr. 4	1,050–1,150 (565–620)				
7	1,300–1,400 (705–760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9A Gr.1	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9B Gr. 1	1,100–1,175 (595–635)				
10F Gr. 1	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
10I Gr. 1	1,300–1,400 (705–760)				
11A Gr. 4	1,000–1,050 (540–565)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)
15E Gr. 1	1,350–1,425 (730–775)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
P-Nos. 8, 34, 42, 43, 45 and hard surfacing on P-No. 1 base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in [WD-4622.7](#).

NOTE:

(1) All temperatures are metal temperatures.



(b) Holding time at temperature in excess of the minimum requirements of Table WD-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with WD-2200, WD-2400, and WD-4300.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table WD-4622.1-1, it shall be permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table WD-4622.4(c)-1 and the following:

(1) Except for P-No. 1 materials, when welds in the materials listed in Table WD-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, impact test specimens for the welding procedure qualification required by WD-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table WD-4622.1-1 and at the lower temperature and increased minimum holding time permitted by Table WD-4622.4(c)-1, shall also be qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table WD-4622.1-1 and the alternative requirements from Table WD-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table WD-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by WD-2400 shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table WD-4622.1-1 and at the lower minimum temperatures and increased minimum holding time permitted by Table WD-4622.4(c)-1 shall also be certified for any temperatures in between.

(3) Base material certified in accordance with WD-2200 may be postweld heat treated at the lower minimum temperature ranges and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

**WD-4622.5 PWHT Requirements When Different P-Number Materials Are Joined.** When materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table WD-4622.1-1 for the material requiring the higher PWHT temperature range.

**WD-4622.7 Exemptions to Mandatory Requirements.** Postweld heat treatment in accordance with this subarticle shall not be required for:

- (a) Nonferrous materials.
- (b) Welds exempted in Table WD-4622.7(b)-1.

**Table WD-4622.4(c)-1  
Alternative Holding Temperatures and Times**

Material P-No.	Alternative Minimum Holding Temperatures, °F (°C)	Alternative Minimum Holding Times [Note (1)]
1, 3, 9A Gr. 1 9B Gr.1	1,050 (565)	2 hr/in. (4 min/mm) thickness
1, 3, 9A Gr.1 9B Gr.1	1,000 (540)	4 hr/in. (8 min/mm) thickness

NOTE:  
(1) All other requirements of WD-4622 shall apply.

(c) Welds subjected to temperatures above the PWHT temperature range specified in Table WD-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperature.

(d) Internal support structures constructed of P-No. 7 Type 405 material or of Type 410 material with carbon content not exceeding 0.08%, welded with electrodes that produce an austenitic chromium-nickel weld deposit or a non-air-hardening nickel-chromium-iron weld deposit, provided the plate thickness at the welded joint does not exceed  $\frac{3}{8}$  in. (10 mm).

### WD-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (425°C) the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches of the material being heat treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period, there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.5 m) interval of weld length. The following exceptions are permitted:

(a) P-No. 6 material may be cooled in air from the postweld heat treatment holding temperature specified in Table WD-4622.1-1.

(b) For P-No. 7 material, the cooling rate at temperatures above 1,200°F (650°C) shall not exceed 100°F/hr (56°C/h), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

### WD-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

**WD-4624.1 Furnace Heating — One Heat.** Heating the internal support structure or item in a closed furnace in one heat is the preferred procedure and shall be used



**Table WD-4622.7(b)-1  
Exemptions to Mandatory PWHT**

P-No. (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness, in. (mm) (WD-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)
1	All welds, where the materials being joined are 1½ in. (38 mm) and less	1¼ (32) and less	0.30 and less	...
		Over 1¼ to 1½ (32 to 38)	0.30 and less	200 (95)
		¾ (19) or less	Over 0.30	...
		Over ¾ to 1½ (19 to 38)	Over 0.30	200 (95)
	All welds in material over 1½ in. (38 mm)	¾ (19) or less	...	200 (95)
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of:	1½ in. (38 mm) or less	...	100 (38)
		Over 1½ in. to 3 in. (38 mm to 75 mm)	...	200 (95) [Note (4)]
		Over 3 in. (75 mm)	...	250 (120) [Note (5)]
			...	...
3 except Gr. 3	All welds, provided weld procedure qualification is made using equal or greater thickness base material than production weld [Note (6)]	5⁄8 (16) or less	0.25 or less	200 (95)
	Attachment welds joining containment to noncontainment material	1⁄2 (13) or less	0.25 or less	200 (95)
9A Gr. 1 or 9B Gr. 1	All welds provided weld procedure qualification is made using equal or greater thickness base material than production weld [Note (6)]	5⁄8 (16) or less	...	200 (95)
	Attachment welds joining containment to non-containment material over 5⁄8 in. (16 mm)	1⁄2 (13) or less	...	200 (95)
10I Gr. 1	All weld materials 1⁄2 in. (13 mm) or less	1⁄2 (13) or less	...	...
11A Gr. 4	All weld materials 1⁄2 in. (13 mm) or less	1⁄2 (13) or less	...	250 (120)

GENERAL NOTE: The exemptions noted in this Table do not apply to electron beam welds in ferritic materials over 1⁄8 in. (3 mm) in thickness.

NOTES:

- (1) Where the thickness of material is identified in the column Type of Weld, it is the thickness of the base material at the welded joint.
- (2) Carbon level of the materials being joined.
- (3) The maximum resulting hardness of the heat-affected zone, in the procedure qualification test plate, shall not exceed 35 Rc.
- (4) Intermediate postweld soak at not less than 200°F (95°C) for 2 hr minimum.
- (5) Intermediate postweld soak at not less than 300°F (150°C) for 2 hr minimum.
- (6) Weld Procedure Qualification coupon need not exceed 1.5 in. (38 mm) in thickness.

whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the weldment shall be prohibited.

**WD-4624.2 Furnace Heating — More Than One Heat.** The weldment may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of WD-4624.1 apply and overlap of the heated sections of the weldment is at least 5 ft (1.5 m). When this procedure is used, the portion of the weldment outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the weldment projects from the furnace shall not intersect a structural discontinuity.

**WD-4624.3 Local Heating.** Welds may be locally postweld heat treated when it is not practical to heat treat the entire weldment. Local postweld heat treatment shall consist of heating a circumferential band around the weldment at temperature within the ranges specified in this subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the weldment from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

**WD-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT**

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

**WD-4650 HEAT TREATMENT AFTER BENDING OR FORMING****WD-4651 Ferritic Materials**

Ferritic materials may be used in the as-formed or as-bent condition, heat treated in accordance with [WD-4620](#), fully annealed, normalized and tempered, or quenched and tempered, provided the requirements of [WD-2210](#), [WD-4212](#), and [WD-4213](#) are met.

**WD-4652 Austenitic and Nonferrous Materials**

Heat treatment of austenitic and nonferrous materials shall neither be required nor prohibited after forming operations.

**WD-4700 MECHANICAL JOINTS****WD-4710 BOLTING AND THREADING****WD-4711 Thread Engagement**

The threads of all bolts shall be engaged for the full length of thread in the load carrying nut unless otherwise specified in the Design Output Documents.

**WD-4712 Thread Lubricants**

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any material in the system.

**WD-4713 Removal of Thread Lubricants**

All threading lubricants or compounds shall be removed from surfaces that are to be welded.

**WD-4720 BOLTING****WD-4721 Bolt Holes**

For the purpose of this Article, high strength bolts shall be considered those with specified minimum yield strength greater than 80 ksi (550 MPa). Bolt holes shall meet the requirements of (a) through (e).

(a) Holes shall meet the requirements of [WD-3230](#). When the bolt hole size is  $\frac{1}{8}$  in. (3 mm) larger than the bolt, and the bolt is  $\frac{1}{2}$  in. (13 mm) or smaller, standard washers shall be used.

(b) Oversized or slotted bolt holes may be used with high strength bolts  $\frac{1}{2}$  in. (13 mm) in diameter and larger, except as restricted in (1), (2), and (3) below.

(1) Oversized holes shall not exceed the requirements of [WD-3230](#). They may be used in any or all plies of friction-type connections. Hardened washers shall be installed over exposed oversized holes.

(2) Short-slotted holes shall not be wider than permitted by [WD-3230](#) and shall not have a length exceeding the oversize diameter allowed in [WD-3230](#) by more than  $\frac{1}{16}$  in. (1.5 mm). They may be used in any or all plies of friction-type or bearing-type connections. The slots may be used without regard to direction of loading in friction-type connections, but shall be normal to the direction of the load in bearing-type connections. Hardened washers shall be installed over exposed short-slotted holes.

(3) Long-slotted holes shall not be wider than permitted by [WD-3230](#) and shall not have a length that exceeds  $2\frac{1}{2}$  times the bolt diameter. In friction-type connections, the long-slotted holes may be used without regard to direction of loading, provided the stress on the bolts does not exceed 75% of the allowable working stress given in [Article WD-3000](#). In bearing-type connections, the long diameter of the slot shall be normal to the direction of loading. Long-slotted holes may be used in only one of the connected parts of either a friction-type or bearing-type connection at an individual faying surface. Structural plate washers or a continuous bar not less than  $\frac{5}{16}$  in. (8 mm) in thickness shall be used to cover long slots that are in the outer plies of joints. These washers or bars shall have a size sufficient to cover the slot completely after installation and shall meet the requirements of [Article WD-3000](#).

(c) Except as specified in (d), holes may be punched, provided the thickness of the material is not greater than the nominal diameter of the bolt plus  $\frac{1}{8}$  in. (3 mm). When the thickness of the material is greater than the nominal diameter of the bolt plus  $\frac{1}{8}$  in. (3 mm), holes shall be drilled, subpunched and reamed, or thermally cut.

Thermal cutting shall not be used unless the load bearing surfaces are machined or ground smooth. For subpunched holes, the die shall be at least  $\frac{1}{16}$  in. (1.5 mm) smaller than the nominal diameter of the bolt.

(d) Bolt holes in material over  $\frac{1}{2}$  in. (13 mm) thick having a specified minimum yield strength greater than 80 ksi (550 MPa) shall be drilled.

(e) For bolts not subjected to shear, the limits for oversized and slotted holes in (d) may be increased if structural plate washers or continuous bars that meet the requirements of [Article WD-3000](#) are provided.

**WD-4722 Bolted Connections**

(a) Surfaces of bolted parts in contact with the bolt head and nut shall not have a slope of more than 1:20 with respect to a plane normal to the bolt axis. Where the surface of a high strength bolted part has a slope of more than 1:20, a beveled washer shall be used to compensate for the lack of parallelism.

(b) Bolts loaded in pure shear shall not have threads located in the load bearing part of the shank unless permitted by the Design Output Documents.

#### **WD-4723 Precautions Before Bolting**

All parts assembled for bolting shall have contact surfaces free from scale, chips, or other deleterious material. Surfaces and edges to be joined shall be smooth, uniform, and free from fins, tears, cracks, and other defects that would degrade the strength of the joint.

#### **WD-4724 Bolt Tension**

All high strength structural bolts shall be preloaded to a value not less than that given in the Design Output Documents. Preloading shall be monitored by the turn of nut method, by properly calibrated wrenches, by load indicating washers, or by direct extension indicators. Bolts preloaded by means of a calibrated wrench shall be installed with a hardened washer under the nut or bolt head, whichever is the element turned in preloading. Hardened washers shall be required under the bolt head and the nut when the direct extension or load indicating washer method is used. Hardened washers shall not be required when bolts are preloaded by the turn of nut method, except that hardened washers are required under the nut and bolt head when the bolts shall be used to connect material having a specified yield strength less than 40 ksi (270 MPa).

#### **WD-4725 Locking Devices**

**WD-4725.1 Types of Locking Devices.** Threaded fasteners shall be provided with locking devices to prevent loosening during service. Elastic stop nuts and thread

locking compounds (when compatible with service conditions), lock nuts, including full or jam, slotted, drilled and wired, free spinning and prevailing torque shall all be acceptable locking devices. Upset threads by cold working or tack welding may serve as locking devices. Internally and externally toothed washers, and disk and helical spring lock washers shall not be used as locking devices.

**WD-4725.2 Preloading of High Strength Fasteners.** Preloading threaded fasteners made of material with a yield strength of 80 ksi (550 MPa) or greater, loaded in tension to a value at least 20% above the maximum load on the fastener for the specified loading conditions, limited to 70% of the specified minimum tensile strength of the fastener material shall satisfy the requirement for locking.

**WD-4725.3 Preloading of Non-High Strength Fasteners.** When locking devices cannot be installed because of assembly geometry, preloading of the threaded fasteners in an assembly with fastener material of yield strength below 80 ksi (550 MPa) shall be an acceptable method for locking provided the resulting preload is at least 20% above the maximum load on the fastener for the specified loading conditions, but is limited to 70% of the specified minimum tensile strength of the fastener. The threaded assembly shall be tested for the dynamic loading conditions specified in the Design Specification, and the established preload shall be verified on the assembly by properly calibrated wrenches, direct extension indicators, or the turn of the nut method. The results of the test, required preload, and specified thread lubrication shall be provided in the Design Report.

## ARTICLE WD-5000 EXAMINATION

### WD-5100 GENERAL REQUIREMENTS FOR EXAMINATION

### WD-5110 PROCEDURES, QUALIFICATIONS, AND EVALUATION

#### WD-5111 General Requirements

Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be performed in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2, and the image quality indicators (IQIs) of [Table WD-5111-1](#) shall be used in lieu of those shown in Section V, Article 2, Table T-276. The requirements for the retention of electronic and digital radiographic images are the same as that for radiographic film. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and visual examination shall be in accordance with Section V, Article 9. The examinations required by this Article or by reference to this Article shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

#### WD-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures that have been proven by actual demonstration to the satisfaction of the Inspector. The procedures shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radiosopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

#### WD-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable material or procedure specifications.

#### WD-5120 TIME OF EXAMINATION OF WELDS

Acceptance examinations of welds required by [WD-5200](#) shall be performed at the time stipulated in the following subparagraphs during fabrication and installation:

(a) For welds in internal support structure components, radiographic or ultrasonic examination, when required, shall be performed after an intermediate or final postweld heat treatment if heat treatment is required by [WD-4622](#).

(b) Magnetic particle, liquid penetrant, or visual examinations shall be performed on the final surface after any required postweld heat treatment, except that welds in P-No. 1 material may be examined either before or after postweld heat treatment. Weld surfaces that are covered with weld metal cladding shall be examined before the weld metal cladding is applied. Weld surfaces that are not accessible after a postweld heat treatment shall be examined prior to the operations that caused this inaccessibility.

(c) All dissimilar metal weld joints, such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic material, shall be examined on the final surface after final postweld heat treatment.

#### WD-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All full penetration weld edge preparation surfaces in material 1 in. (25 mm) or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a) through (c) below.

(a) Only indications with major dimensions greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed  $\frac{1}{2}$  in. (13 mm). The extent of all laminar-type imperfections exceeding  $\frac{1}{2}$  in. (13 mm) shall be determined by ultrasonic examination. Imperfections exceeding  $\frac{1}{2}$  in. (13 mm) shall be repaired by

**Table WD-5111-1**  
**Thickness, IQI Designations, Essential Holes, and Wire Diameters**

Single Wall Material Thickness Range, in. (mm)	IQI(s) — Hole or Wire Type [Note (1)]							
	Source Side				Radiograph Side			
	Designation	Hole Size, in. (mm)	Essential Hole	Required Wire Diameter — IQI, in. (mm)	Designation	Hole Size, in. (mm)	Essential Hole	Required Wire Diameter — IQI, in. (mm)
Up to 1/4 (6) incl.	5	0.040 (1.02)	4 T	0.006 (0.15)	5	0.040 (1.02)	4 T	0.006 (0.15)
Over 1/4-3/8 (6-10)	7	0.040 (1.02)	4 T	0.006 (0.15)	7	0.040 (1.02)	4 T	0.006 (0.15)
Over 3/8-1/2 (10-13)	10	0.040 (1.02)	4 T	0.010 (0.25)	10	0.040 (1.02)	4 T	0.010 (0.25)
Over 1/2-5/8 (13-16)	12	0.050 (1.27)	4 T	0.013 (0.33)	12	0.050 (1.27)	4 T	0.013 (0.33)
Over 5/8-3/4 (16-19)	15	0.060 (1.52)	4 T	0.016 (0.41)	12	0.050 (1.27)	4 T	0.013 (0.33)
Over 3/4-1 (19-25)	20	0.040 (1.02)	2 T	0.016 (0.41)	17	0.035 (0.89)	2 T	0.013 (0.33)
Over 1-1 1/4 (25-32)	25	0.050 (1.27)	2 T	0.020 (0.51)	17	0.035 (0.89)	2 T	0.013 (0.33)
Over 1 1/4-1 1/2 (32-38)	30	0.060 (1.52)	2 T	0.025 (0.64)	20	0.040 (1.02)	2 T	0.016 (0.41)
Over 1 1/2-2 (38-50)	35	0.070 (1.78)	2 T	0.032 (0.81)	25	0.050 (1.27)	2 T	0.020 (0.51)
Over 2-2 1/2 (50-64)	40	0.080 (2.03)	2 T	0.040 (1.02)	30	0.060 (1.52)	2 T	0.025 (0.64)
Over 2 1/2-3 (64-75)	45	0.090 (2.29)	2 T	0.040 (1.02)	35	0.070 (1.78)	2 T	0.032 (0.81)
Over 3-4 (75-100)	50	0.100 (2.54)	2 T	0.050 (1.27)	40	0.080 (2.03)	2 T	0.040 (1.02)
Over 4-6 (100-150)	60	0.120 (3.05)	2 T	0.063 (1.60)	45	0.090 (2.29)	2 T	0.040 (1.02)
Over 6-8 (150-200)	80	0.160 (4.06)	2 T	0.100 (2.54)	50	0.100 (2.54)	2 T	0.050 (1.27)
Over 8-10 (200-250)	100	0.200 (5.08)	2 T	0.126 (3.20)	60	0.120 (3.05)	2 T	0.063 (1.60)
Over 10-12 (250-300)	120	0.240 (6.10)	2 T	0.160 (4.06)	80	0.160 (4.06)	2 T	0.100 (2.54)
Over 12-16 (300-400)	160	0.320 (8.13)	2 T	0.250 (6.35)	100	0.200 (5.08)	2 T	0.126 (3.20)
Over 16-20 (400-500)	200	0.400 (10.16)	2 T	0.320 (8.13)	120	0.240 (6.10)	2 T	0.160 (4.06)

## NOTE:

(1) Hole (plaque) type IQIs may be used on flat plates and on objects with geometries such that the IQI hole image is not distorted.

welding to a depth of 3/8 in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) The following relevant nonlaminar imperfections are unacceptable:

(1) any linear indication greater than 1/8 in. (3 mm) long for materials 1 in. (25 mm) thick to under 2 in. (50 mm) thick and 3/16 in. (5 mm) long for materials 2 in. (50 mm) thick and greater

(2) rounded indications with dimensions greater than 3/16 in. (5 mm)

(3) four or more indications greater than 1/16 in. (1.5 mm) long in a line separated by 1/16 in. (1.5 mm) or less edge to edge

(4) ten or more indications greater than 1/16 in. (1.5 mm) long in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated

(d) Weld repairs made to weld edge preparations for Types I, II, and III welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

#### WD-5140 EXAMINATION OF ADJACENT BASE MATERIAL

When performing the surface examinations of weld joints as required by WD-5200, the external weld surfaces and adjacent base material for at least 1/2 in. (13 mm) on each side of the weld shall be included in the examination. Acceptance standards for the weld shall be as stated in this Article while the acceptance standards for base material shall be as stated in WD-2500.

#### WD-5200 REQUIRED EXAMINATION OF WELDS

#### WD-5210 PERMISSIBLE EXAMINATION METHODS

Welds used in internal support structures shall be examined in accordance with the requirements of this sub-article for the type of examination specified by the Certificate Holder to meet the requirement of Table WD-3240-1. The Certificate Holder may upgrade the examination in Table WD-3240-1 to a level higher than originally specified.

**WD-5220 REQUIREMENTS FOR RADIOGRAPHY OR ULTRASONIC AND LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION**

When required by the Certificate Holder ([Table WD-3240-1](#)), welds shall be radiographically examined and the external and accessible internal weld surfaces and adjacent base metal for at least  $\frac{1}{2}$  in. (13 mm) on each side of the weld examined by either the magnetic particle or liquid penetrant method. Ultrasonic examination may be substituted for radiography except for those materials and welds that have coarse grains or configurations that do not yield meaningful results by ultrasonic methods.

**WD-5230 REQUIREMENTS FOR LIQUID PENETRANT OR MAGNETIC PARTICLE EXAMINATION****WD-5231 Requirements for Progressive Liquid Penetrant or Magnetic Particle Examination**

When required by the Certificate Holder ([Table WD-3240-1](#)), welds shall be either liquid penetrant or magnetic particle examined progressively at the lesser of either one-third of the thickness of the weld joint or each  $\frac{1}{2}$  in. (13 mm), and on the external and accessible internal weld surfaces and the adjacent base material for  $\frac{1}{2}$  in. (13 mm) on each side of the weld. For welds  $\frac{3}{8}$  in. (10 mm) thick or less, examination of the root, each subsequent layer, and the external and accessible internal weld surfaces and adjacent base material for at least  $\frac{1}{2}$  in. (13 mm) on each side of the weld is permitted in lieu of the above.

**WD-5232 Requirements for Root and Final Liquid Penetrant or Magnetic Particle Examination**

When required by the Certificate Holder ([Table WD-3240-1](#)), welds shall be either liquid penetrant or magnetic particle examined after the root and final passes on the external and accessible internal weld surfaces and the adjacent base material for at least  $\frac{1}{2}$  in. (13 mm) on each side of the weld.

**WD-5233 Requirements for Surface Liquid Penetrant or Magnetic Particle Examination**

When required by the Certificate Holder ([Table WD-3240-1](#)), welds shall be either liquid penetrant or magnetic particle examined on the external and accessible internal weld surfaces and the adjacent base material for at least  $\frac{1}{2}$  in. (13 mm) on each side of the weld.

**WD-5260 REQUIREMENTS FOR SURFACE VISUAL EXAMINATION****WD-5261 Visual Examination in Addition to Other NDT Examination**

All welds shall be visually examined to the acceptance criteria of [WD-5361](#). This visual examination shall be in addition to all other required examinations.

**WD-5262 Visual Examination for Weld Surface Integrity**

When required by the Certificate Holder ([Table WD-3240-1](#)), welds shall be visually examined on the final surface to the acceptance criteria of [WD-5362](#).

**WD-5270 SPECIAL WELDED JOINTS****WD-5272 Weld Metal Cladding**

Weld metal cladding shall be examined by the liquid penetrant method.

**WD-5273 Hard Surfacing**

Hard surfacing shall be examined by the liquid penetrant method in accordance with [WD-2546](#), and the acceptance standards applicable to materials less than  $\frac{5}{8}$  in. (16 mm) thick shall apply.

**WD-5277 Electron Beam Welds**

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electron beam welding process shall be ultrasonically examined.

**WD-5279 Special Exceptions**

When the joint detail, or environmental conditions (i.e., background radiation), does not permit radiographic examination to be performed in accordance with this Article, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made provided the examination is performed using a detailed written procedure that has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The nondestructive examination shall be in accordance with [WD-5110](#) and meet the acceptance standards of [WD-5300](#).



**WD-5300 ACCEPTANCE STANDARDS****WD-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS****WD-5321 Evaluation of Indications**

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration

(b) any other elongated indication that has a length greater than

(1)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(2)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. (19 mm) to  $2\frac{1}{4}$  in. (57 mm), inclusive

(3)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm) where  $t$  is the thickness of the thinner portion of the weld

(c) internal root weld conditions are acceptable when the density change or image brightness difference as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b)

(d) any group of aligned indications having an aggregate length greater than  $t$  in a length of  $12t$ , unless the minimum distance between successive indications exceeds  $6L$ , in which case the aggregate length is unlimited,  $L$  being the length of the largest indication

(e) any group of aligned indications whose aggregate length exceeds the permissible length of a single indication and with the minimum distance between these successive indications less than  $3L$ ,  $L$  being the length of the largest indication

(f) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI; four or more rounded indications shall constitute aligned rounded indications for welds covered by Appendix VI

**WD-5330 ULTRASONIC ACCEPTANCE STANDARDS**

All imperfections that produce a response equal to or greater than 50% of the reference level are unacceptable, except as noted in (a).

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding

(1)  $\frac{1}{4}$  in. (6 mm) for  $t$  up to  $\frac{3}{4}$  in. (19 mm), inclusive

(2)  $\frac{1}{3}t$  for  $t$  from  $\frac{3}{4}$  in. (19 mm) to  $2\frac{1}{4}$  in. (57 mm), inclusive

(3)  $\frac{3}{4}$  in. (19 mm) for  $t$  over  $2\frac{1}{4}$  in. (57 mm) where  $t$  is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld,  $t$  is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

**WD-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS****WD-5341 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications that are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

**WD-5342 Acceptance Standards**

(a) Only imperfections producing indications whose major dimensions are greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks and linear indications

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm)

(3) four or more rounded indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge

(4) ten or more rounded indications in any  $6 \text{ in.}^2$  ( $4000 \text{ mm}^2$ ) of surface with the major dimension of this area not to exceed 6 in. (150 mm), with the area taken in the most unfavorable location relative to the indications being evaluated

**WD-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS****WD-5351 Evaluation of Indications**

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks or surface conditions may produce similar indications that are nonrelevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the

reexamination. Nonrelevant indications and broad areas of pigmentation that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

#### **WD-5352 Acceptance Standards**

(a) Only imperfections producing indications whose major dimensions are greater than  $\frac{1}{16}$  in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications

(2) rounded indications with dimensions greater than  $\frac{3}{16}$  in. (5 mm)

(3) four or more rounded indications in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge

(4) ten or more rounded indications in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated

#### **WD-5360 VISUAL EXAMINATION ACCEPTANCE STANDARDS**

##### **WD-5361 General Acceptance Standards**

When visual examination is performed in accordance with [WD-5261](#), the following acceptance standards shall be met:

(a) Weld reinforcement, underfill, undercut, and overlap shall not exceed the allowable limits of this Subsection.

(b) The examined surface shall be free of abrupt irregularities.

##### **WD-5362 Acceptance Standards for Visual Examination for Weld Surface Integrity**

(a) When visual examination is performed in accordance with [WD-5262](#), the weld surface shall meet the acceptance criteria given in [WD-5361](#).

(b) The following imperfections are unacceptable:

(1) any imperfection characterized as a crack, or lack of penetration

(2) rounded imperfections whose major dimension exceeds  $\frac{1}{8}$  in. (3 mm)

(3) four or more rounded imperfections greater than  $\frac{1}{32}$  in. (0.8 mm) in a line separated by  $\frac{1}{16}$  in. (1.5 mm) or less edge to edge

(4) ten or more rounded imperfections greater than  $\frac{1}{32}$  in. (0.8 mm) in any 6 in.<sup>2</sup> (4 000 mm<sup>2</sup>) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the imperfections being evaluated

#### **WD-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL**

##### **WD-5510 GENERAL REQUIREMENTS**

Organizations performing Code-required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by [WD-5520](#). When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of [WD-5520](#). All nondestructive examinations required by this Subsection shall be performed by, and the results evaluated by, qualified nondestructive examination personnel.

##### **WD-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION**

###### **WD-5521 Qualification Procedure**

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.<sup>13,26</sup> The ACCP Level II and III provisions for qualification and certification and the ASNT administered Level II certification provision for qualification and certification of NDE Personnel shall not be used for Section III. The Employer's<sup>15</sup> written practice required by paragraph 5 of SNT-TC-1A shall identify Employer requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements except as modified in the following:

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in a written program when the basic and method examinations have been administered by ASNT that issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform a nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A of SNT-TC-1A. The training and experience times shall be described in written practice and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times for visual examination personnel identified in Table 6.3.1 A of SNT-TC-1A for Level II certification may be reduced from 16 hr to 8 hr.

(4) For the near-vision acuity examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographic film.

#### **WD-5522 Certification of Personnel**

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of the Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [see [WD-5521\(a\)\(2\)](#)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

#### **WD-5523 Verification of Nondestructive Examination Personnel Certification**

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Organizations qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

#### **WD-5530 RECORDS**

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

# **ARTICLE WD-8000 NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORT**

## **WD-8100 GENERAL REQUIREMENTS**

The requirements for nameplates, stamping with the Certification Mark, and reports shall be as given in [Article WA-8000](#).

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## ENDNOTES

- 1 Rules for Disposal Containments are not yet developed.
- 2 SA or SB Specifications listed under the heading Bars, Rods, Shapes, Forgings may be used as material for any of these product forms even though not all product forms are listed in the SA or SB Specification.
- 3 Part IV of ASME NQA-1 provides guidance for various applications.
- 4 Samples of the forms referred to in this subarticle may be found in this Subsection. Copies of these forms may be obtained from the Society (<http://www.asme.org/codes/publications/bpvc>).
- 5 In addition to providing a basis for acceptance standards for material, the test data are designated to be used as a basis for establishing inservice operation and for use in fracture prevention evaluation [WB-3211(d)].
- 6 The requirements for impact testing of the heat-affected zone (WB-4335.2) may result in reduced test temperatures or increased toughness requirements for the base metal.
- 7 The direction of ultrasonic examinations referenced is the direction of sound propagation.
- 8 This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.
- 9 *Equivalent linear stress* is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.
- 10 *Adjacent points* are defined in (a), (b), and (c) below:
  - (a) For surface temperature differences on surfaces of revolution in the meridional direction, adjacent points are defined as points that are less than the distance  $2\sqrt{Rt}$ , where  $R$  is the radius measured normal to the surface from the axis of rotation to the midjoint wall and  $t$  is the thickness of the part at the point under consideration. If the product  $Rt$  varies, the average value of the points shall be used.
  - (b) For surface temperature differences on surfaces of revolution in the circumferential direction and on flat parts, such as flanges and flat heads, adjacent points are defined as any two points on the same surface.
  - (c) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.
- 11 Welds that are exposed to corrosive action should have a resistance to corrosion that is not substantially less than that of the cladding. The use of filler metal that will deposit weld metal, which is similar to the composition of the cladding material, is recommended. If weld metal of different composition is used, it should have properties compatible with the application.
- 12 An *intermediate postweld heat treatment* for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld shall be subjected during the final postweld heat treatment.
- 13 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.
- 14 Personnel qualified by examination and certified to the previous editions of SNT-TC-1A are considered to be qualified when the recertification is based on continuing satisfactory performance.  
All reexaminations and new examinations shall be in accordance with the edition referenced in [Table WA-7100-2](#).
- 15 *Employer* as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Organizations who are qualified in accordance with NCA-3842, and organizations who provide subcontracted nondestructive examination services to organizations described above.



- 16 ANSI N14.5 may be purchased from the American National Standards Institute, 25 West 43rd Street, New York, NY 10036.
- 17  $T_{NDT}$  = temperature at or above the nil-ductility transition temperature NDT (ASTM E208);  $T_{NDT}$  is 10°F (5°C) below the temperature at which at least two specimens show no-break performance.
- 18 The requirements for impact testing of the heat-affected zone ([WC-4335.2](#)) may result in reduced impact test temperatures for the base material.
- 19 Section III Appendices, Mandatory Appendix XIII uses Division 1 rather than Division 3 terminology (e.g., *Service Loadings* versus *Operating Loadings*, *vessel* versus *containment*, *pressure boundary* versus *containment boundary*, etc.), but the application of these rules is identical for Division 3 use.
- 20 The head design curves have been developed considering membrane stress requirements, plastic collapse, cyclic load conditions, and the effects of maximum allowable tolerances in accordance with [WC-4222](#). See Section III Appendices, Nonmandatory Appendix A, Article A-4000 for the design equations for curves, of [Figure WC-3224.6-1](#).
- 21 Heads having  $D/2h = 2$  have equivalent torispherical properties of a torisphere of  $L/D = 0.090$  and  $r/D = 0.17$ .
- 22 Internal support structures are typically referred to as baskets.
- 23 In addition to providing a basis for acceptance standards for material, the test data are designated to be used as a basis for establishing inservice operation and for use in fracture prevention evaluation (Section III Appendices, Nonmandatory Appendix G).
- 24 The requirements for impact-testing of the heat-affected zone ([WD-4335.2](#)) may result in reduced test temperatures or increased toughness requirements for the base metal.
- 25 Subsection NF can be used with provisions defined in (a) and (b) below.
  - (a) Division 1 uses Division 1 rather than Division 3 terminology (e.g., *Service Loadings* versus *Operating Loadings*, *vessel* versus *containment*, *pressure boundary* versus *containment boundary*) but the application of these rules is identical for Division 3 use.
  - (b) Division 3 does not use Level B Service Limits.
- 26 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the edition referenced in [Table WA-7100-2](#) when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the edition referenced in [Table WA-7100-2](#).

# 2017 ASME Boiler and Pressure Vessel Code

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