INTRODUCTION

U-1 SCOPE

(a) See below.

(1) The Foreword provides the basis for the rules described in this Division.

(2) For the scope of this Division, pressure vessels are containers for the containment of pressure, either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof.

(3) This Division contains mandatory requirements, specific prohibitions, and nonmandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. The Code does not address all aspects of these activities, and those aspects which are not specifically addressed should not be considered prohibited. Engineering judgment must be consistent with the philosophy of this Division, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of this Division. See also informative and nonmandatory guidance regarding metallurgical phenomena in Section II, Part D, Nonmandatory Appendix A.

(b) This Division is divided into three Subsections, Mandatory Appendices, and Nonmandatory Appendices. Subsection A consists of Part UG, covering the general requirements applicable to all pressure vessels. Subsection B covers specific requirements that are applicable to the various methods used in the fabrication of pressure vessels. It consists of Parts UW, UF, and UB dealing with welded, forged, and brazed methods, respectively. Subsection C covers specific requirements applicable to the several classes of materials used in pressure vessel construction. It consists of Parts UCS, UNF, UHA, UCI, UCL, UCD, UHT, ULW, ULT, and Part UIG dealing with carbon and low alloy steels, nonferrous metals, high alloy steels, cast iron, clad and lined material, cast ductile iron, ferritic steels with properties enhanced by heat treatment, layered construction, low temperature materials, and impregnated graphite, respectively. Section II, Part D also contains tables of maximum allowable stress values for these classes of materials, except for impregnated graphite.

The Mandatory Appendices address specific subjects not covered elsewhere in this Division, and their requirements are mandatory when the subject covered is included in construction under this Division. The Nonmandatory Appendices provide information and suggested good practices.

(c) See below.

(1) The scope of this Division has been established to identify the components and parameters considered in formulating the rules given in this Division. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Division of the Code for vessels or components not considered to be within its scope. These laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given here.

(2) Based on the Committee's consideration, the following classes of vessels are not included in the scope of this Division; however, any pressure vessel which meets all the applicable requirements of this Division may be stamped with the Certification Mark with the U Designator:

(-a) those within the scope of other Sections;

(-b) fired process tubular heaters;

(-c) pressure containers which are integral parts or components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, engines, and hydraulic or pneumatic cylinders where the primary design considerations and/or stresses are derived from the functional requirements of the device;

(-d) structures whose primary function is the transport of fluids from one location to another within a system of which it is an integral part, that is, piping systems;

(-e) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, and fittings, and the pressure-containing parts of other components, such as strainers and devices which serve such purposes as mixing, separating, snubbing, distributing, and metering or controlling flow, provided that pressure-containing parts of such components are generally recognized as piping components or accessories;

(-f) a vessel for containing water[1] under pressure, including those containing air the compression of which serves only as a cushion, when none of the following limitations are exceeded:

(-1) a design pressure of 300 psi (2 MPa);

(-2) a design temperature of 210°F (99°C);

(-g) a hot water supply storage tank heated by steam or any other indirect means when none of the following limitations is exceeded:

(-1) a heat input of 200,000 Btu/hr (58.6 kW);

(-2) a water temperature of 210°F (99°C);

(-3) a nominal water containing capacity of 120 gal (450 L);

(-h) vessels not exceeding the design pressure (see 3-2), at the top of the vessel, limitations below, with no limitation on size [see UG-28(f), 9-1(c)]:

(-1) vessels having an internal or external pressure not exceeding 15 psi (100 kPa);

(-2) combination units having an internal or external pressure in each chamber not exceeding 15 psi (100 kPa) and differential pressure on the common elements not exceeding 15 psi (100 kPa) [see UG-19(a)];

(-i) vessels having an inside diameter, width, height, or cross section diagonal not exceeding 6 in. (152 mm), with no limitation on length of vessel or pressure;

(-j) pressure vessels for human occupancy.[2]

(d) The rules of this Division have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures not exceeding 3,000 psi (20 MPa). For pressures above 3,000 psi (20 MPa), deviations from and additions to these rules usually are necessary to meet the requirements of design principles and construction practices for these higher pressures. Only in the event that after having applied these additional design principles and construction practices the vessel still complies with all of the requirements of this Division may it be stamped with the applicable Certification Mark with the Designator.

(e) In relation to the geometry of pressure-containing parts, the scope of this Division shall include the following:

(1) where external piping; other pressure vessels including heat exchangers; or mechanical devices, such as pumps, mixers, or compressors, are to be connected to the vessel:

(-a) the welding end connection for the first circumferential joint for welded connections [see UW-13(i)];

(-b) the first threaded joint for screwed connections;

(-c) the face of the first flange for bolted, flanged connections;

(-d) the first sealing surface for proprietary connections or fittings;

(2) where nonpressure parts are welded directly to either the internal or external pressure-retaining surface of a pressure vessel, this scope shall include the design, fabrication, testing, and material requirements established for non-pressure-part attachments by the applicable paragraphs of this Division;[3]

(3) pressure-retaining covers for vessel openings, such as manhole or handhole covers, and bolted covers with their attaching bolting and nuts;

(4) the first sealing surface for proprietary fittings or components for which rules are not provided by this Division, such as gages, instruments, and nonmetallic components.

(f) The scope of the Division includes requirements for overpressure protection in UG-125 through UG-140 and Mandatory Appendix 11.

(g) Vessels That Generate Steam

(1) Unfired steam boilers shall be constructed in accordance with the rules of Section I or this Division [see UG-120(f), UG-125(b), and UW-2(c)].

(2) The following pressure vessels in which steam is generated shall not be considered as unfired steam boilers, and shall be constructed in accordance with the rules of this Division:

(-a) vessels known as evaporators or heat exchangers;

(-b) vessels in which steam is generated by the use of heat resulting from operation of a processing system containing a number of pressure vessels such as used in the manufacture of chemical and petroleum products;

(-c) vessels in which steam is generated but not withdrawn for external use.

(h) Pressure vessels or parts subject to direct firing from the combustion of fuel (solid, liquid, or gaseous), which are not within the scope of Sections I, III, or IV may be constructed in accordance with the rules of this Division [see UW-2(d)].

(i) Gas fired jacketed steam kettles with jacket operating pressures not exceeding 50 psi (345 kPa) may be constructed in accordance with the rules of this Division (see Mandatory Appendix 19).

(j) Pressure vessels exclusive of those covered in (c), (g), (h), and (i) that are not required by the rules of this Division to be fully radiographed, that are not provided with quick-actuating or quick-opening closures (see UG-35.2 and UG-35.3, respectively), and that do not exceed the following volume and pressure limits may be exempted from inspection by Inspectors, as defined in UG-91, provided that they comply in all other respects with the requirements of this Division:

(1) 5 ft^3 (0.14 m^3) in volume and 250 psi (1.7 MPa) design pressure; or

(2) 3 ft^3 (0.08 m^3) in volume and 350 psi (2.4 MPa) design pressure;

(3) $1^1/_2$ ft^3 (0.04 m^3) in volume and 600 psi (4.1 MPa) design pressure.

In an assembly of vessels, the limitations in (1) through (3) above apply to each vessel and not the assembly as a whole. Straight line interpolation for intermediate volumes and design pressures is permitted. Vessels fabricated in accordance with this rule shall be marked with the "UM" Symbol in Figure UG-116, sketch (b) and with the data required in UG-116. Certificates of Compliance shall satisfy the requirements of UG-120(a).

(19) U-2 GENERAL

(a) The user or his designated agent (see Nonmandatory Appendix NN) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration (see UG-22).

Such consideration shall include but shall not be limited to the following:

(1) the need for corrosion allowances;

(2) the definition of lethal services. For example, see UW-2(a).

(3) the need for postweld heat treatment beyond the requirements of this Division and dependent on service conditions;

(4) for pressure vessels in which steam is generated, or water is heated [see U-1(g) and U-1(h)], the need for piping, valves, instruments, and fittings to perform the functions covered by Section I, PG-59 through PG-61.

(5) the degree of nondestructive examination(s) and the selection of applicable acceptance standards when such examinations are beyond the requirements of this Division.

Sample User Design Requirements forms and guidance on their preparation are found in Nonmandatory Appendix KK. This sample form might not be applicable to all pressure vessels that may be constructed in accordance with this Division. The user is cautioned that input from the Manufacturer may be necessary for completion of this form.

(b) Responsibilities[4]

(1) The Manufacturer of any vessel or part to be marked with the Certification Mark has the responsibility of complying with all of the applicable requirements of this Division and, through proper certification, of assuring that all work done by others also complies. The vessel Manufacturer or, when applicable, the part Manufacturer is responsible for the preparation and accuracy of design calculations to show compliance with the rules of this Division, and his signature on the Manufacturer's Data Report Form shall be considered as certification that this has been done. The vessel or part Manufacturer shall have available for the Inspector's review the applicable design calculations. See 10-5 and 10-15(d).

(2) Some types of work, such as forming, nondestructive examination, and heat treating, may be performed by others (for welding, see UW-26 and UW-31). It is the vessel or part Manufacturer's responsibility to ensure that all work so performed complies with all the applicable requirements of this Division. After ensuring Code compliance, the vessel or part may be stamped with the Certification Mark and Designator by the appropriate Certificate holder after acceptance by the Inspector.

(c) A vessel may be designed and constructed using any combination of the methods of fabrication and the classes of materials covered by this Division, provided the rules applying to each method and material are complied with and the vessel is marked as required by UG-116.

(d) When the strength of any part cannot be computed with a satisfactory assurance of safety, the rules provide procedures for establishing its maximum allowable working pressure.

(e) It is the duty of the Inspector to make all of the inspections specified by the rules of this Division, and to monitor the quality control and the examinations made by the Manufacturer. The Inspector shall make such other inspections as in his judgment are necessary to permit certification that the vessel has been designed and constructed in accordance with the minimum requirements of this Division. The Inspector has the duty of verifying that the applicable design calculations have been made and are on file at Manufacturer's plant at the time the Data Report is signed. Any questions concerning the calculations raised by the Inspector must be resolved. See UG-90(c)(1).

NOTE: The term "applicable design calculations" means that all pressure-retaining components covered by the Certification Mark stamping are supported by calculations and/or proof tests that comply with the requirements of this Division. The method of verifying that applicable design calculations have been made will vary with the individual Inspector and depend largely on the Manufacturer's procedures for producing the design calculations and any subsequent quality checks performed by the Manufacturer.

(f) The rules of this Division shall serve as the basis for the Inspector to:

(1) perform the required duties;

(2) authorize the application of the Certification Mark;

(3) sign the Certificate of Shop (or Field Assembly) Inspection.

(g) This Division of Section VIII does not contain rules to cover all details of construction. Where complete details of construction are not given, the Manufacturer, subject to the acceptance of the Authorized Inspector, shall provide the appropriate details to be used.

(1) Where design rules do not exist in this Division, one of the following three methods shall be used:

(-a) Mandatory Appendix 46.

(-b) proof test in accordance with UG-101.

(-c) other recognized and generally accepted methods, such as those found in other ASME, EN, ISO, national, and industry standards or codes. This option shall provide details of design consistent with the allowable stress criteria provided in UG-23.

(2) The provisions of this paragraph shall not be used to justify the use of materials, joining processes (fabrication), examination, inspection, testing, certification, and overpressure protection methods other than those allowed by this Division.

(h) Field assembly of vessels constructed to this Division may be performed as follows.

(1) The Manufacturer of the vessel completes the vessel in the field; completes the Form U-1, U-1A, or U-1P Manufacturer's Data Report; and stamps the vessel.

(2) The Manufacturer of parts of a vessel to be completed in the field by some other party stamps these parts in accordance with Code rules and supplies the Form U-2 or U-2A Manufacturer's Partial Data Report to the other party. The other party, who must hold a valid U Certificate of Authorization, makes the final assembly, required NDE, and final pressure test; completes the Form U-1, U-1A, or U-1P Manufacturer's Data Report; and stamps the vessel.

(3) The field portion of the work is completed by a holder of a valid U Certificate of Authorization other than the vessel Manufacturer. The Certificate Holder performing the field work is required to supply a Form U-2 or U-2A Manufacturer's Partial Data Report covering the portion of the work completed by his organization (including data on the pressure test if conducted by the Certificate Holder performing the field work) to the Manufacturer responsible for the Code vessel. The vessel Manufacturer applies his Certification Mark with the U Designator in the presence of a representative from his Inspection Agency and completes the Form U-1, U-1A, or U-1P Manufacturer's Data Report with his Inspector.

In all three alternatives, the party completing and signing the Form U-1, U-1A, or U-1P Manufacturer's Data Report assumes full Code responsibility for the vessel. In all three cases, each Manufacturer's Quality Control System shall describe the controls to assure compliance for each Certificate Holder.

(i) For some design analyses, both a chart or curve and a equation or tabular data are given. Use of the equation or tabular data may result in answers which are slightly different from the values obtained from the chart or curve. However, the difference, if any, is within practical accuracy and either method is acceptable.

U-3 STANDARDS REFERENCED BY THIS DIVISION

(a) Throughout this Division references are made to various standards, such as ASME standards, which cover pressure–temperature rating, dimensional, or procedural standards for pressure vessel parts. These standards, with the year of the acceptable edition, are listed in Table U-3.

(b) Rules for the use of these standards are stated elsewhere in this Division.

U-4 UNITS OF MEASUREMENT[5] (19)

(a) U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with requirements of this edition related to materials, fabrication, examination, inspection, testing, certification, and overpressure protection.

(b) A single system of units shall be used for all aspects of design except where otherwise permitted by this Division. When components are manufactured at different locations where local customary units are different than those used for the general design, the local units may be used for the design and documentation of that component, subject to the limitations given in (c). Similarly, for proprietary components or those uniquely associated with a system of units different than that used for the general design, the alternate units may be used for the design and documentation of that component, subject to the limitations given in (c).

(c) For any single equation, all variables shall be expressed in a single system of units. Calculations using any material data published in this Division or Section II, Part D (e.g., allowable stresses, physical properties, external pressure design factor B) shall be carried out in one of the standard units given in Table U-4-1. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations or any other calculations carried out in either U.S. Customary or SI units may be converted to other units.

(d) Production, measurement and test equipment, drawings, welding procedure specifications, welding procedure and performance qualifications, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis, fabrication documents, or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance and to ensure that dimensional consistency is maintained, shall be in accordance with the following:

(1) Conversion factors shall be accurate to at least four significant figures.

(2) The results of conversions of units shall be expressed to a minimum of three significant figures.

(e) Conversion of units, using the precision specified above, shall be performed to assure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in Nonmandatory Appendix GG, Guidance for the Use of U.S. Customary and SI Units in the ASME Boiler and Pressure Vessel Code. Whenever local customary units are used, the

Manufacturer shall provide the source of the conversion factors which shall be subject to verification and acceptance by the Authorized Inspector or Certified Individual.

(f) Dimensions shown in the text, tables, and figures, whether given as decimals or fractions, may be taken as decimals or fractions and do not imply any manufacturing precision or tolerance on the dimensions.

(g) Material that has been manufactured and certified to either the U.S. Customary or SI material specification (e.g., SA-516M) may be used regardless of the unit system used in design. Standard fittings (e.g., flanges, elbows, etc.) that have been certified to either U.S. Customary units or SI units may be used regardless of the units system used in design.

(h) All entries on a Manufacturer's Data Report and data for Code-required nameplate marking shall be in units consistent with the fabrication drawings for the component using U.S. Customary, SI, or local customary units. Units (either primary or alternative) may be shown parenthetically. Users of this Code are cautioned that the receiving jurisdiction should be contacted to ensure the units are acceptable.

U-5 TOLERANCES

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

(19)

Table U-3
Year of Acceptable Edition of Referenced Standards in This Division

Title	Number	Year
Pressure Relieving and Depressuring Systems	ANSI/API Std. 521	5th Ed., January 2007
Pipe Threads, General Purpose (Inch)	ANSI/ASME B1.20.1	Latest edition
Marking and Labeling Systems	ANSI/UL-969	Latest edition
Seat Tightness of Pressure Relief Valves	API Std. 527	2014, 4th Ed.
Minimum Design Loads and Associated Criteria for Buildings and Other Structures	ASCE/SEI 7	2016
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	Latest edition
Cast Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250	ASME B16.1	2015
Pipe Flanges and Flanged Fittings, NPS $^1/_2$ Through NPS 24 Metric/Inch Standard	ASME B16.5	2013 [Note (1)]
Factory-Made Wrought Buttwelding Fittings	ASME B16.9	Latest edition
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	Latest edition
Cast Copper Alloy Threaded Fittings, Classes 125 and 250	ASME B16.15	Latest edition
Metallic Gaskets for Pipe Flanges — Ring-Joint, Spiral– Wound, and Jacketed	ASME B16.20	Latest edition
Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves, Classes 150, 300, 600, 900, 1500, and 2500	ASME B16.24	2016
Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300	ASME B16.42	2016
Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard	ASME B16.47	2017
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2	Latest edition
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	Latest edition
Conformity Assessment Requirements	ASME CA-1	Latest edition
Guidelines for Pressure Boundary Bolted Flange Joint Assembly	ASME PCC-1	2013
Repair of Pressure Equipment and Piping	ASME PCC-2	2018
ASME Section VIII - Division 1 Example Problem Manual	ASME PTB-4	Latest edition
Pressure Relief Devices	ASME PTC 25	2014
Qualifications for Authorized Inspection	ASME QAI-1	Latest edition [Note (2)]
Standard Practice for Quantitative Measurement and Reporting of Hypoeutectoid Carbon and Low-Alloy Steel Phase Transformations	ASTM A1033	Latest edition
Standard Test Method for Flash Point by Tag Closed Tester	ASTM D56	Latest edition
Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester	ASTM D93	Latest edition
Standard Guide for Preparation of Metallographic Specimens	ASTM E3	2011
Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings	ASTM E125	1963 (R2008) [Note (3)]
Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness	ASTM E140	Latest edition

Table U-3
Year of Acceptable Edition of Referenced Standards in This Division (Cont'd)

Title	Number	Year
Standard Reference Radiographs for Heavy-Walled [2 to $4^1/_2$ in. (50.8 to 114 mm)] Steel Castings	ASTM E186	2015
Standard Test Method for Conducting Drop-Weight Test to Determine Nil– Ductility Transition Temperature of Ferritic Steels	ASTM E208	2006 (R2012) [Note (3)]
Standard Reference Radiographs for Heavy-Walled [$4^1/_2$ to 12 in. (114 to 305 mm)] Steel Castings	ASTM E280	2015
Standard Reference Radiographs for Steel Castings up to 2 in. (51 mm) in Thickness	ASTM E446	2015
Metallic Materials — Charpy Pendulum Impact Test Part 1: Test Method	ISO 148-1	2009
Metallic Materials — Charpy Pendulum Impact Test Part 2: Verification of Testing Machines	ISO 148-2	2008
Metallic Materials — Charpy Pendulum Impact Test Part 3: Preparation and Characterization of Charpy V-Notch Test Pieces for Indirect Verification of Pendulum Impact Machines	ISO 148-3	2008
Metric Standards		
Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal	ANSI/AWS A4.2M	2006
Metric Screw Thread — M Profile	ASME B1.13M	Latest edition
Metric Screw Thread — MJ Profile	ASME B1.21M	Latest edition
Metric Heavy Hex Screws	ASME B18.2.3.3M	Latest edition
Metric Hex Bolts	ASME B18.2.3.5M	Latest edition
Metric Heavy Hex Bolts	ASME B18.2.3.6M	Latest edition
Metric Fasteners for Use in Structural Applications	ASME B18.2.6M	Latest edition
Standard Test Method for Compressive Strength of Carbon and Graphite	ASTM C695	2015
Standard Terminology Relating to Manufactured Carbon and Graphite	ASTM C709	2009
Standard Practices for Force Verification of Testing Machines	ASTM E4	2016
Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods	ASTM E177	2014
Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method	ASTM E691	2016

NOTES:
(1) See UG-11(a)(2).
(2) See UG-91 and UG-117(a).
(3) R — Reaffirmed.

Table U-4-1
Standard Units for Use in Equations

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches ($in.^2$)	square millimeters (mm^2)
Volume	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Section modulus	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 ($in.^4$)	millimeters^4 (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (°R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi$\sqrt{in.}$)	MPa square root meters (MPa$\sqrt{m}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

SUBSECTION A
GENERAL REQUIREMENTS

PART UG
GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION AND ALL MATERIALS

UG-1 SCOPE

The requirements of Part UG are applicable to all pressure vessels and vessel parts and shall be used in conjunction with the specific requirements in Subsections B and C and the Mandatory Appendices that pertain to the method of fabrication and the material used.

MATERIALS

UG-4 GENERAL

(a) Material subject to stress due to pressure shall conform to one of the specifications given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including all applicable notes in the tables, and shall be limited to those that are permitted in the applicable Part of Subsection C, except as otherwise permitted in UG-9, UG-10, UG-11, UG-15, Part UCS, Part UIG, and the Mandatory Appendices. Material may be identified as meeting more than one material specification and/or grade, provided the material meets all requirements of the identified material specification(s) and/or grade(s) [see UG-23(a)].

(b) Material for nonpressure parts, such as skirts, supports, baffles, lugs, clips, and extended heat transfer surfaces, need not conform to the specifications for the material to which they are attached or to a material specification permitted in this Division, but if attached to the vessel by welding shall be of weldable quality [see UW-5(b)]. The allowable stress values for material not identified in accordance with UG-93 shall not exceed 80% of the maximum allowable stress value permitted for similar material in Subsection C.

(c) Material covered by specifications in Section II is not restricted as to the method of production unless so stated in the specification, and so long as the product complies with the requirements of the specification. (See UG-85.)

(d) Materials other than those allowed by the rules of this Division shall not be used. Data for new materials shall be submitted to and approved by the ASME Boiler and Pressure Vessel Committee on Materials in accordance with Section II, Part D, Mandatory Appendix 5.

(e) Materials outside the limits of size and/or thickness given in the title or scope clause of the specifications given in Section II, and permitted by the applicable part of Subsection C, may be used if the material is in compliance with the other requirements of the specification,[6] and no size or thickness limitation is given in the stress tables. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(f) It is recommended that the user or his designated agent assure himself that materials used for the construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life. See also informative and nonmandatory guidance regarding metallurgical phenomena in Section II, Part D, Nonmandatory Appendix A.

(g) When specifications, grades, classes, and types are referenced, and the material specification in Section II, Part A or Part B is a dual-unit specification (e.g., SA-516/SA-516M), the design values and rules shall be applicable to either the U.S. Customary version of the material specification or the SI unit version of the material specification. For example, when SA-516M Grade 485 is used in construction, the design values listed for its equivalent, SA-516 Grade 70, in either the U.S. Customary or metric Section II, Part D (as appropriate) shall be used.

(h) When the rules of this Division require the use of material physical properties, these properties shall be taken from the applicable tables in Section II, Part D,

Subpart 2. If the applicable tables in Section II, Part D, Subpart 2 do not contain these properties for a permitted material or do not list them within the required temperature range, the Manufacturer may use other authoritative sources for the needed information. The Manufacturer's Data Report shall note under "Remarks" the property values obtained and their source.

NOTE: If material physical properties are not listed, the Manufacturer is encouraged to bring the information to the attention of the ASME Committee on Materials (BPV Section II) so that the data can be added in Section II, Part D, Subpart 2.

UG-5 PLATE[7]

Plate used in the construction of pressure parts of pressure vessels shall conform to one of the specifications in Section II for which allowable stress values are given in the tables referenced in UG-23, except as otherwise provided in UG-4, UG-10, UG-11, and UG-15.

UG-6 FORGINGS

(a) Forged material may be used in pressure vessel construction, provided the material has been worked sufficiently to remove the coarse ingot structure. Specifications and maximum allowable stress values for acceptable forging materials are given in the tables referenced in UG-23. (See Part UF for forged vessels.)

(b) Forged rod or bar may only be used within the limitations of UG-14.

(c) Forgings certified to SA-105, SA-181, SA-182, SA-350, SA-403, and SA-420 may be used as tubesheets and hollow cylindrical forgings for pressure vessel shells that otherwise meet all the rules of this Division, provided that the following additional requirements are met:

(1) Forgings certified to SA-105 or SA-181 shall be subject to one of the austenitizing heat treatments permitted by these specifications.

(2) One tension test specimen shall be taken from each forging weighing more than 5,000 lb (2 250 kg). The largest obtainable tension test specimen as specified by the test methods referenced in the applicable specification shall be used. Except for upset-disk forgings, the longitudinal axis of the test specimen shall be taken parallel to the direction of major working of the forging. For upset-disk forgings, the longitudinal axis of the test specimen shall be taken in the tangential direction. When agreed to by the Manufacturer, and when not prohibited by the material specification, test specimens may be machined from specially forged test blocks meeting the provisions provided in SA-266 or other similar specifications for large forgings.

(3) For quenched and tempered forgings weighing more than 10,000 lb (4 500 kg) at the time of heat treatment, two tension test specimens shall be taken from each forging. These shall be offset 180 deg from each other, except that if the length of the forging, excluding test prolongations, exceeds 12 ft (3.7 m), then one specimen shall be taken from each end of the forging.

UG-7 CASTINGS

Cast material may be used in the construction of pressure vessels and vessel parts. Specifications and maximum allowable stress values for acceptable casting materials are given in the tables referenced in UG-23. These allowable stress values shall be multiplied by the applicable casting quality factor given in UG-24 for all materials except cast iron.

UG-8 PIPE AND TUBES

(a) Pipe and tubes of seamless or welded[8] construction conforming to one of the specifications given in Section II may be used for shells and other parts of pressure vessels. Allowable stress values for the materials used in pipe and tubes are given in the tables referenced in UG-23.

(b) Integrally finned tubes may be made from tubes that conform in every respect with one of the specifications given in Section II. These tubes may be used under the following conditions:

(1) The tubes, after finning, shall have a temper or condition that conforms to one of those provided in the governing specifications, or, when specified, they may be furnished in the "as-fabricated condition" where the finned portions of the tube are in the cold worked temper (as-finned) resulting from the finning operation, and the unfinned portions in the temper of the tube prior to finning.

(2) The maximum allowable stress value for the finned tube shall be that given in the tables referenced in UG-23 for the tube before finning except as permitted in (3) below.

(3) The maximum allowable stress value for a temper or condition that has a higher stress value than that of the tube before finning may be used, provided that qualifying mechanical property tests demonstrate that such a temper or condition is obtained and conforms to one of those provided in the governing specifications in Section II, and provided that allowable stress values have been established in the tables referenced in UG-23 for the tube material used. The qualifying mechanical property tests shall be made on specimens of finned tube from which the fins have been removed by machining. The frequency of tests shall be as required in the unfinned tube specification.

(4) The maximum allowable internal or external working pressure of the tube shall be based on the root diameter and the minimum wall of the finned section, or the outside diameter and wall of the unfinned section together with appropriate stress values, whichever results in the lower maximum allowable working pressure. Alternatively, the maximum allowable external pressure for tubes with integral fins may be established under the rules of Mandatory Appendix 23.

(5) In addition to the tests required by the governing specifications, each tube after finning shall be subjected to a pneumatic test or a hydrostatic test as indicated below. UG-90(c)(1)(-i) requirement for a visual inspection by the Inspector does not apply to either of these tests.

(-a) an internal pneumatic test of not less than 250 psi (1.7 MPa) for 5 sec without evidence of leakage. The test method shall permit easy visual detection of any leakage such as immersion of the tube under water or a pressure differential method.[9]

(-b) an individual tube hydrostatic test in accordance with UG-99 that permits complete examination of the tube for leakage.

UG-9 WELDING MATERIALS

Welding materials used for production shall comply with the requirements of this Division, those of Section IX, and the applicable qualified welding procedure specification. When the welding materials comply with one of the specifications in Section II, Part C, the marking or tagging of the material, containers, or packages as required by the applicable Section II specification may be accepted for identification in lieu of a Test Report or a Certificate of Compliance. When the welding materials do not comply with one of the specifications of Section II, the marking or tagging shall be identifiable with the welding materials set forth in the welding procedure specification, and may be accepted in lieu of a Test Report or a Certificate of Compliance.

UG-10 MATERIAL IDENTIFIED WITH OR PRODUCED TO A SPECIFICATION NOT PERMITTED BY THIS DIVISION, AND MATERIAL NOT FULLY IDENTIFIED

(a) Identified Material With Complete Certification From the Material Manufacturer. Material identified with a specification not permitted by this Division and identified to a single production lot as required by a permitted specification may be accepted as satisfying the requirements of a specification permitted by this Division, provided the following conditions are satisfied:

(1) Recertification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Recertification by the Vessel or Part Manufacturer

(-a) Documentation is provided to the Certificate Holder demonstrating that all applicable requirements (including, but not limited to, melting method, melting practice, deoxidation, chemical analysis, mechanical properties, quality, and heat treatment) of the specification permitted by this Division, to which the material is to be recertified, have been met.

(-b) The material has marking, acceptable to the Inspector, for identification to the documentation.

(-c) When the conformance of the material with the permitted specification has been established, the material shall be marked as required by the permitted specification.

(b) Material Identified With a Specification Not Permitted by This Division and Identified to a Particular Production Lot as Required by a Specification Permitted by This Division but Which Cannot Be Qualified Under (a). Any material for which the documentation required in (a) is not available may be accepted as satisfying the requirements of the specification permitted by this Division, provided that the conditions set forth below are satisfied.

(1) Recertification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Recertification by the Vessel or Part Manufacturer

(-a) When documentation demonstrating complete conformance to the chemical requirements is not available, chemical analyses are made on different pieces from the lot to establish a mean analysis that is to be accepted as representative of the lot. The pieces chosen for analysis shall be selected at random from the lot. The number of pieces selected shall be at least 10% of the number of pieces in the lot, but not less than three. For lots of three pieces or less, each piece shall be analyzed. Each individual analysis for an element shall conform to the limits for product analysis in the permitted specification, and the mean for each element shall conform to the heat analysis limits of that specification. Analyses need only be made for those elements required by the permitted specification (including its general specification); only those elements for which documentation is not available must be tested.

(-b) When documentation demonstrating complete conformance to the mechanical property requirements is not available, mechanical property tests are made in accordance with the requirements of the permitted specification, and the results of the tests conform to the specified requirements; only those properties for which documentation is not available must be tested.

(-c) When documentation demonstrating complete conformance to the heat treatment requirements is not available, the material is heat treated in accordance with those specification heat treatment requirements, either prior to or during fabrication. (See also UG-85.)

(-d) All other applicable requirements (including, but not limited to, melting method, melting practice, deoxidation, chemical analysis, mechanical properties, grain size, and quality) of the specification permitted by this Division, to which the material is to be recertified, have been demonstrated to have been met.

(-e) The material has marking, acceptable to the Inspector, for identification to the documentation.

(-f) When the conformance of the material with the permitted specification has been established, the material shall be marked as required by the permitted specification.

(c) Material Not Fully Identified. Material that cannot be qualified under the provisions of either (a) or (b), such as material not fully identified as required by the permitted specification or unidentified material, may be

accepted as satisfying the requirements of a specification permitted by this Division, provided that the conditions set forth below are satisfied.

(1) Qualification by an Organization Other Than the Vessel or Part Manufacturer. Not permitted.

(2) Qualification by the Vessel or Part Manufacturer

(-a) Each piece is tested to show that it meets the chemical composition for heat analysis and the mechanical properties requirements of the permitted specification. Chemical analyses need only be made for those elements required by the permitted specification (including its general specification). When the direction of final rolling or major work (as required by the material specification) is not known, tension test specimens shall be taken in each appropriate direction from each sampling location designated in the permitted specification. The results of all tests shall conform to the minimum requirements of the specification, but the tensile strength of only one of the specimens need conform to the maximum requirement.

(-b) The provision of (b)(2)(-c) above shall be met.

(-c) All other applicable requirements (including, but not limited to, melting method, melting practice, deoxidation, chemical analysis, mechanical properties, grain size, and quality) of the specification permitted by this Division, to which the material is to be recertified, have been demonstrated to have been met. If such verifiable evidence cannot be provided, recertification is not permitted.

(-d) When the identity of the material with the permitted specification has been established in accordance with (-a), (-b), and (-c) above, each piece (or bundle, etc., if permitted in the specification) shall be marked with a marking giving the permitted specification number and grade, type, or class, as applicable, and a serial number identifying the particular lot of material. A suitable report, clearly marked as being a "Report on Tests of Nonidentified Material," shall be completed and certified by the vessel or Part Manufacturer. This report, when accepted by the Inspector, shall constitute authority to use the material in lieu of material procured to the requirements of the permitted specification.

(19) UG-11 PREFABRICATED OR PREFORMED PRESSURE PARTS FURNISHED WITHOUT A CERTIFICATION MARK

(a) Prefabricated or preformed pressure parts for pressure vessels that are subject to stresses due to pressure and that are furnished by others or by the Manufacturer of the completed vessel shall conform to all applicable requirements of this Division except as permitted in (b), (c), (d), and (e) below. When the prefabricated or preformed parts are furnished with a nameplate that contains product identifying marks and the nameplate interferes with further fabrication or service, and where stamping on the material is prohibited, the Manufacturer of the completed vessel, with the concurrence of the Authorized Inspector, may remove the nameplate. The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report. The nameplate shall be destroyed. The rules of (b), (c), (d), and (e) below shall not be applied to welded shells or heads or to quick-actuating or quick-opening closures (see UG-35.2 and UG-35.3, respectively).

Parts furnished under the provisions of (b), (c), and (d) need not be manufactured by a Certificate Holder. However, the Manufacturer of the completed vessel or Certification Mark–stamped part shall ensure that parts furnished under the provisions of (b), (c), (d), and (e) meet all of the applicable Code requirements such as UCS-79(d), UNF-79(a), UHA-44(a), and UHT-79(a). Prefabricated or preformed pressure parts may be supplied as follows:

(1) cast, forged, rolled, or die formed non-standard pressure parts

(2) cast, forged, rolled, or die formed standard pressure parts that comply with an ASME product standard, either welded or nonwelded

(3) cast, forged, rolled, or die formed standard pressure parts that comply with a standard other than an ASME product standard, either welded or nonwelded

(b) Cast, Forged, Rolled, or Die Formed Non-standard Pressure Parts. Pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by casting, forging, rolling, or die forming may be supplied basically as materials. All such parts shall be made of materials permitted under this Division, and the manufacturer of the part shall furnish identification in accordance with UG-93. Such parts shall be marked with the name or trademark of the parts manufacturer and with such other markings as will serve to identify the particular parts with accompanying material identification. The Manufacturer of the completed vessel shall be satisfied that the part is suitable for the design conditions specified for the completed vessel in accordance with the rules of this Division.

(c) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts That Comply With an ASME Product Standard, Either Welded or Nonwelded

(1) These are pressure parts that comply with an ASME product standard accepted by reference in UG-44(a). The ASME product standard establishes the basis for the pressure–temperature rating and marking unless modified in UG-44(a).

(2) Flanges and flanged fittings may be used at the pressure–temperature ratings specified in the appropriate standard listed in this Division.

(3) Materials for standard pressure parts shall be as follows:

(-a) as permitted by this Division or

(-b) as specifically listed in the ASME product standard

(4) When welding is performed it shall meet the following:

(-a) the requirements of UW-26(a), UW-26(b), and UW-26(c) and UW-27 through UW-40, or;

(-b) the welding requirements of ASME specification SA-234.

(5) Standard pressure parts as identified in UG-11(c) do not require inspection, identification in accordance with UG-93(a) or UG-93(b), or Partial Data Reports, provided the requirements of UG-11(c) are met.

(6) If postweld heat treatment is required by the rules of this Division, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the vessel to be marked with the Certification Mark.

(7) If radiography or other volumetric examination is required by the rules of this Division, it may be performed at one of the following locations:

(-a) the location of the Manufacturer of the completed vessel

(-b) the location of the pressure parts manufacturer

(8) Parts made to an ASME product standard shall be marked as required by the ASME product standard.

(9) The Manufacturer of the completed vessels shall have the following responsibilities when using standard pressure parts that comply with an ASME product standard:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Division.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed vessel.

(-c) When volumetric examination is required by the rules of this Division, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer shall fulfill these responsibilities by obtaining, when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested. The documentation shall contain at a minimum:

(-a) material used

(-b) the pressure–temperature rating of the part

(-c) the basis for establishing the pressure–temperature rating

(d) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts That Comply With a Standard Other Than an ASME Product Standard, Either Welded or Nonwelded

(1) Standard pressure parts that are either welded or nonwelded and comply with a manufacturer's proprietary standard or a standard other than an ASME product standard may be supplied by

(-a) a Certificate Holder

(-b) a pressure parts manufacturer

(2) Parts of small size falling within this category for which it is impossible to obtain identified material or that may be stocked and for which identification in accordance with UG-93 cannot be obtained and are not customarily furnished, may be used for parts as described in UG-4(b).

(3) Materials for these parts shall be as permitted by this Division only.

(4) Requirements for welding and brazing are as follows:

(-a) When welding is performed, it shall meet the requirements of UW-26(a), UW-26(b), UW-26(c), and UW-27 through UW-40.

(-b) When brazing is performed, it shall meet the requirements of Part UB.

(5) Standard pressure parts as identified in (d) do not require inspection, identification in accordance with UG-93(a) or UG-93(b), or Partial Data Reports, provided the requirements of (d) are met.

(6) If postweld heat treatment is required by the rules of this Division, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the completed vessel.

(7) If radiography or other volumetric examination is required by the rules of this Division, it may be performed at one of the following locations:

(-a) the location of the Manufacturer of the completed vessel

(-b) the location of the parts Manufacturer

(-c) the location of the pressure parts manufacturer

(8) Marking for these parts shall be as follows:

(-a) with the name or trademark of the Certificate Holder or the pressure part manufacturer and any other markings as required by the proprietary standard or other standard used for the pressure part

(-b) with a permanent or temporary marking that will serve to identify the part with the Certificate Holder or the pressure parts manufacturer's written documentation of the particular items, and that defines the pressure–temperature rating of the part

(9) The Manufacturer of the completed vessels shall have the following responsibilities when using standard pressure parts:

(-a) Ensure that all standard pressure parts comply with applicable rules of this Division.

(-b) Ensure that all standard pressure parts are suitable for the design conditions of the completed vessel.

(-c) When volumetric examination is required by the rules of this Division, obtain the completed radiographs, properly identified, with a radiographic inspection report, and any other applicable volumetric examination report.

(10) The Manufacturer of the completed vessel shall fulfill these responsibilities by one of the following methods:

(-a) Obtain, when necessary, documentation as provided below, provide for retention of this documentation, and have such documentation available for examination by the Inspector when requested, or;

(-b) Perform an analysis of the pressure part in accordance with the rules of this Division. [See also U-2(g).] This analysis shall be included in the documentation and shall be made available for examination by the Inspector when requested.

(11) The documentation shall contain at a minimum:

(-a) material used

(-b) the pressure–temperature rating of the part

(-c) the basis for establishing the pressure–temperature rating

(-d) a written certification by the pressure parts manufacturer that all welding and brazing complies with Code requirements

(e) The Code recognizes that a Certificate Holder may fabricate parts in accordance with UG-11(d), and that are marked in accordance with UG-11(d)(8). In lieu of the requirement in UG-11(d)(4)(-a), the Certificate Holder may subcontract to an individual or organization not holding an ASME Certificate standard pressure parts that are fabricated to a standard other than an ASME product standard provided all the following conditions are met:

(1) The activities to be performed by the subcontractor are included within the Certificate Holder's Quality Control System.

(2) The Certificate Holder's Quality Control System provides for the following activities associated with subcontracting of welding operations, and these provisions shall be acceptable to the Manufacturer's Authorized Inspection Agency:

(-a) the welding processes permitted by this Division that are permitted to be subcontracted

(-b) welding operations

(-c) Authorized Inspection activities

(-d) placement of the Certificate Holder's marking in accordance with UG-11(d)(8)

(3) The Certificate Holder's Quality Control System provides for the requirements of UG-92 to be met at the subcontractor's facility.

(4) The Certificate Holder shall be responsible for reviewing and accepting the Quality Control Programs of the subcontractor.

(5) The Certificate Holder shall ensure that the subcontractor uses written procedures and welding operations that have been qualified as required by this Division.

(6) The Certificate Holder shall ensure that the subcontractor uses personnel that have been qualified as required by this Division.

(7) The Certificate Holder and the subcontractor shall describe in their Quality Control Systems the operational control of procedure and personnel qualifications of the subcontracted welding operations.

(8) The Certificate Holder shall be responsible for controlling the quality and ensuring that all materials and parts that are welded by subcontractors and submitted to the Inspector for acceptance, conform to all applicable requirements of this Division.

(9) The Certificate Holder shall describe in their Quality Control Systems the operational control for maintaining traceability of materials received from the subcontractor.

(10) The Certificate Holder shall receive approval for subcontracting from the Authorized Inspection Agency prior to commencing of activities.

UG-12 BOLTS AND STUDS

(a) Bolts and studs may be used for the attachment of removable parts. Specifications, supplementary rules, and maximum allowable stress values for acceptable bolting materials are given in the tables referenced in UG-23.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1^1/_2$ diameters in length.

Studs greater than eight diameters in length may have an unthreaded portion that has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1^1/_2$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion;

(3) a suitable transition shall be provided between the root diameter and the unthreaded portion; and

(4) particular consideration shall be given to any dynamic loadings.

UG-13 NUTS AND WASHERS

(a) Nuts shall conform to the requirements in the applicable Part of Subsection C (see UCS-11 and UNF-13). They shall engage the threads for the full depth of the nut.

(b) The use of washers is optional. When used, they shall be of wrought materials.

UG-14 RODS AND BARS (19)

(a) Rods and Bars Used for Pressure Parts. Rod and bar may be used in pressure vessel construction for pressure parts such as flange rings [see 2-2(d)], stiffening rings, frames for reinforced openings, stays and stay-bolts, and similar parts. Rod and bar materials shall conform to the requirements for bars or bolting in the applicable part of Subsection C.

(b) Parts Machined From Rod and Bar. Pressure parts such as hollow cylindrically shaped parts, heads, caps, flanges, elbows, return bends, tees, and header tees may be machined directly from rod or bar as provided in (1) through (4) below.

(1) Examination by the magnetic particle or liquid penetrant method in accordance with the requirements of Mandatory Appendix 6 or Mandatory Appendix 8 respectively, shall be as follows:

(-a) for flanges: the back of the flange and the outer surface of the hub

(-b) for heads, caps, elbows, return bends, tees, and header tees: all surfaces

(-c) for hollow, cylindrically shaped parts: no surface examination needed

(2) Parts may be machined from rod or bar having a hot-worked diameter not greater than 5.50 in. (140 mm), provided that the axial length of the part is approximately parallel to the metal flow lines of the stock.

(3) Parts may be machined from rod or bar having a hot-worked diameter greater than 5.50 in. (140 mm), but not greater than 8.00 in. (205 mm), provided the axial length of the part is approximately parallel to the metal flow lines of the stock, and the minimum required thickness of the component is calculated following the rules of this Division using 50% of the specified allowable stress.

(4) As an alternative to (3) above and for rod or bar having a hot-worked diameter greater than 8.00 in. (205 mm), parts may be machined from such rod or bar, if the following requirements are met:

(-a) The longitudinal axis of the part shall be parallel to the longitudinal axis of the rod or bar.

(-b) At least two transverse tension test specimens that have the same diameter shall be taken from each lot (as defined in the material specification) of rod or bar material.

(-1) The second specimen shall be taken at 90 deg around the perimeter from the first specimen.

(-2) The axis of the tension test specimen shall be located, as nearly as practicable, midway between the center thickness and the surface of the rod or bar.

(-3) Both specimens shall meet the mechanical property requirements of the material specification.

(-4) For Table UCS-23 materials, the reduction of area shall be not less than 30%.

(-c) Each rod or bar, before machining, shall be 100% ultrasonically examined perpendicular to the longitudinal axis by the straight beam technique in accordance with SA-388. The rod or bar shall be unacceptable if either of the following occurs:

(-1) The examination results show one or more indications accompanied by loss of back reflection larger than 60% of the reference back reflection.

(-2) The examination results show indications larger than 40% of the reference back reflection when accompanied by a 40% loss of back reflection.

(-d) For heads and the flat portion of caps, the examinations of (-c) shall also be performed in the axial direction.

(-e) Before welding, the cut surfaces of the part adjacent to the weld shall be examined by magnetic particle or liquid penetrant methods in accordance with Mandatory Appendix 6 or Mandatory Appendix 8, respectively.

UG-15 PRODUCT SPECIFICATION

When there is no material specification listed in Subsection C covering a particular wrought product of a grade, but there is an approved specification listed in Subsection C covering some other wrought product of that grade, the product for which there is no specification may be used provided:

(a) the chemical and physical properties, heat treating requirements, and requirements for deoxidation, or grain size requirements conform to the approved specification listed in Subsection C. The stress values for that specification given in the tables referenced in UG-23 shall be used.

(b) the manufacturing procedures, tolerances, tests, and marking are in accordance with a Section II specification covering the same product form of a similar material;

(c) for the case of welded tubing made of plate, sheet, or strip, without the addition of filler metal, the appropriate stress values are multiplied by a factor of 0.85;

(d) the product is not pipe or tubing fabricated by fusion welding with the addition of filler metal unless it is fabricated in accordance with the rules of this Division as a pressure part;

(e) mill test reports reference the specifications used in producing the material and in addition make reference to this paragraph.

DESIGN

UG-16 GENERAL (19)

(a) The design of pressure vessels and vessel parts shall conform to the general design requirements in the following paragraphs and in addition to the specific requirements for *Design* given in the applicable Parts of Subsections B and C As an alternative, the design rules of Mandatory Appendix 46 may be used.

(b) Minimum Thickness of Pressure-Retaining Components. Except for the special provisions listed below, the minimum thickness permitted for shells and heads, after forming and regardless of product form and material, shall be $^1/_{16}$ in. (1.5 mm) exclusive of any corrosion allowance. Exceptions are:

(1) the minimum thickness does not apply to heat transfer plates of plate-type heat exchangers;

(2) this minimum thickness does not apply to the inner pipe of double pipe heat exchangers nor to pipes and tubes that are enclosed and protected from mechanical damage by a shell, casing, or ducting, where such pipes

or tubes are NPS 6 (DN 150) and less. This exemption applies whether or not the outer pipe, shell, or protective element is constructed to Code rules. When the outer protective element is not provided by the Manufacturer as part of the vessel, the Manufacturer shall note this on the Manufacturer's Data Report, and the owner or his designated agent shall be responsible to assure that the required enclosures are installed prior to operation. Where pipes and tubes are fully enclosed, consideration shall be given to avoiding buildup of pressure within the protective chamber due to a tube/pipe leak. All other pressure parts of these heat exchangers that are constructed to Code rules must meet the $^1/_{16}$ in. (1.5 mm) minimum thickness requirements.

(3) the minimum thickness of shells and heads of unfired steam boilers shall be $^1/_4$ in. (6 mm) exclusive of any corrosion allowance;

(4) the minimum thickness of shells and heads used in compressed air service, steam service, and water service, made from materials listed in Table UCS-23, shall be $^3/_{32}$ in. (2.5 mm) exclusive of any corrosion allowance.

(5) this minimum thickness does not apply to the tubes in air cooled and cooling tower heat exchangers if all the following provisions are met:

(-a) the tubes shall not be used for lethal UW-2(a) service applications;

(-b) the tubes shall be protected by fins or other mechanical means;

(-c) the tube outside diameter shall be a minimum of $^3/_8$ in. (10 mm) and a maximum of $1^1/_2$ in. (38 mm);

(-d) the minimum thickness used shall not be less than that calculated by the formulas given in UG-27 or 1-1 and in no case less than 0.022 in. (0.5 mm).

(c) Plate Undertolerance

(1) Plate material shall not be ordered with a nominal thickness thinner than the design thickness.

(2) Plate material with an actual thickness less than the design thickness shall not be used unless the difference in thicknesses is less than the smaller of 0.01 in. (0.3 mm) or 6% of the design thickness [see UG-90(b)(6)].

(3) If plate material is ordered to a specification that allows an undertolerance greater than the smaller of 0.01 in. (0.3 mm) or 6% of the nominal thickness, the thickness of the plate ordered shall be increased, if required, so that the plate material will meet the requirement of (2) when used.

(d) Pipe Undertolerance. If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account except for nozzle wall reinforcement area requirements in accordance with UG-37 and UG-40. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable Tables in Subsection C.

(e) Corrosion Allowance in Design Formulas. The dimensional symbols used in all design formulas throughout this Division represent dimensions in the corroded condition.

(f) Examples showing the application of the design rules of this Division are contained in ASME PTB-4, ASME Section VIII, Division 1, Example Problem Manual.

UG-17 METHODS OF FABRICATION IN COMBINATION

A vessel may be designed and constructed by a combination of the methods of fabrication given in this Division, provided the rules applying to the respective methods of fabrication are followed and the vessel is limited to the service permitted by the method of fabrication having the most restrictive requirements (see UG-116).

UG-18 MATERIALS IN COMBINATION (19)

Except as specifically prohibited by other rules of this Division, a vessel may be designed and constructed of any combination of materials permitted in Subsection C, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

The requirements for the base metals, HAZs, and weld metal(s) of a weldment between metals having different impact testing requirements and acceptance criteria shall each be applied in accordance with the rules of this Division.

NOTE: Because of the different thermal coefficients of expansion of dissimilar materials, caution should be exercised in design and construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration and also because of metallurgical changes occurring at elevated temperatures. [See also *Galvanic Corrosion* in Section II, Part D, Nonmandatory Appendix A, A-440(c).]

UG-19 SPECIAL CONSTRUCTIONS

(a) Combination Units. A combination unit is a pressure vessel that consists of more than one independent or dependent pressure chamber, operating at the same or different pressures and temperatures. The parts separating each pressure chamber are the common elements. Each element, including the common elements, shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation (see 3-2). Only the chambers that come within the scope of this Division, U-1, need be constructed in compliance with its provisions. Also, see 9-1(c) for jacketed vessels.

(1) Common Element Design. It is permitted to design each common element for a differential pressure less than the maximum of the design pressures of its adjacent chambers (differential pressure design) or a mean metal temperature less than the maximum of the design temperatures of its adjacent chambers (mean metal

temperature design), or both, only when the vessel is to be installed in a system that controls the common element design conditions.

(2) Differential Pressure Design (Dependent Pressure Chamber). When differential pressure design is permitted, the common element design pressure shall be the maximum differential design pressure expected between the adjacent chambers. The common element and its corresponding differential pressure shall be indicated in the "Remarks" section of the Manufacturer's Data Report [see UG-120(b)(1) and UHX-19.3] and marked on the vessel [see UG-116(j)(1)(-a) and UHX-19.2.1(a)]. The differential pressure shall be controlled to ensure the common element design pressure is not exceeded.

(3) Mean Metal Temperature Design (Dependent Pressure Chamber). When mean metal temperature design is used, the maximum common element design temperature determined in accordance with UG-20(a) may be less than the greater of the maximum design temperatures of its adjacent chambers; however, it shall not be less than the lower of the maximum design temperatures of its adjacent chambers. The common element and its corresponding design temperature shall be indicated in the "Remarks" section of the Manufacturer's Data Report [see UG-120(b)(2) and UHX-19.3] and marked on the vessel [see UG-116(j)(1)(-b) and UHX-19.2.1(b)]. The fluid temperature, flow, and pressure, as required, shall be controlled to ensure the common element design temperature is not exceeded.

(b) Special Shapes. Vessels other than cylindrical and spherical and those for which no design rules are provided in this Division may be designed under the conditions set forth in U-2.

(c) When no design rules are given and the strength of a pressure vessel or vessel part cannot be calculated with a satisfactory assurance of accuracy, the maximum allowable working pressure of the completed vessel shall be established in accordance with the provisions of UG-101.

UG-20 DESIGN TEMPERATURE

(a) Maximum. Except as required in UW-2(d)(3), the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered (see 3-2). If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions. See also U-2(a).

NOTE: The user and Manufacturer are cautioned that certain fabrication details allowed by this Division may result in cracking at welds and associated heat-affected zones (HAZ) for vessels designed for use at elevated temperature. WRC Bulletin 470, "Recommendations for Design of Vessels for Elevated Temperature Service" has information that may prove helpful to the vessel designer. WRC Bulletin 470 contains recommended design details for use at elevated temperature service, which is for the purposes of this Division, when the allowable stresses in Section II, Part D are based on time-dependent properties. The use of these details does not relieve the Manufacturer of design responsibility with regard to consideration of stresses associated with both steady state conditions and transient events, such as startup, shutdown, intermittent operation, thermal cycling, etc., as defined by the user.

(b) Minimum. The minimum metal temperature used in design shall be the lowest expected in service except when lower temperatures are permitted by the rules of this Division[10] (see UG-116, UCS-66, and UCS-A-3). The minimum mean metal temperature shall be determined by the principles described in (a) above. Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling [except as permitted in (f)(3) below for vessels meeting the requirements of (f) below]. The MDMT marked on the nameplate shall correspond to a coincident pressure equal to the MAWP. When there are multiple MAWP's, the largest value shall be used to establish the MDMT marked on the nameplate. Additional MDMT's corresponding with other MAWP's may also be marked on the nameplate.[10]

(c) Design temperatures that exceed the temperature limit in the applicability column shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 are not permitted. In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

(e) Suggested methods for obtaining the operating temperature of vessel walls in service are given in Nonmandatory Appendix C.

(f) Impact testing per UG-84 is not mandatory for pressure vessel materials that satisfy all of the following:

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a) [see also Note (1) in Figure UCS-66.2], shall not exceed that given in (-a) or (-b) below:

(-a) $^1/_2$ in. (13 mm) for materials listed in Curve A of Figure UCS-66;

(-b) 1 in. (25 mm) for materials listed in Curve B, C, or D of Figure UCS-66.

(2) The completed vessel shall be hydrostatically tested per UG-99(b) or UG-99(c) or 27-4. Alternatively, the completed vessel may be pneumatically tested in accordance with 35-6.

(3) Design temperature is no warmer than 650°F (345°C) nor colder than −20°F (−29°C). Occasional operating temperatures colder than −20°F (−29°C) are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

UG-21 DESIGN PRESSURE[11]

Each element of a pressure vessel shall be designed for at least the most severe condition of coincident pressure (including coincident static head in the operating position) and temperature expected in normal operation. For this condition, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered [see UG-98 and 3-2]. See also U-2(a).

UG-22 LOADINGS

The loadings to be considered in designing a vessel shall include those from:

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions;

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of:

(1) internals (see Nonmandatory Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Nonmandatory Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion;

(i) abnormal pressures, such as those caused by deflagration;

(j) test pressure and coincident static head acting during the test (see UG-99).

(19) UG-23 MAXIMUM ALLOWABLE STRESS VALUES[12]

(a) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in Section II, Part D, Subpart 1. Section II, Part D is published as two separate publications. One publication contains values only in the 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. A listing of these materials is given in the following tables, which are included in Subsection C. For material identified as meeting more than one material specification and/or grade, the maximum allowable tensile stress value for either material specification and/or grade may be used provided all requirements and limitations for the material specification and grade are met for the maximum allowable tensile stress value chosen.

Table	Title
UCS-23	Carbon and Low Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other carbon steels)
UNF-23.1 through UNF-23.5	Nonferrous Metals (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1B for other nonferrous metals)
UHA-23	High Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A or Table 1B for other high alloy steels)
UCI-23	Maximum Allowable Stress Values in Tension for Cast Iron
UCD-23	Maximum Allowable Stress Values in Tension for Cast Ductile Iron
UHT-23	Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Subpart 1, Table 1A)
ULT-23	Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

(b) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined by the following procedure where

E = modulus of elasticity of material at design temperature. 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.)

R_o = outside radius of cylindrical shell or tube

t = the minimum required thickness of the cylindrical shell or tube

The joint efficiency for butt-welded joints shall be taken as unity.

The value of B shall be determined as follows.

Step 1. Using the selected values of t and R, calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

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 (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

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. If tabular values are used, the last (maximum) tabulated value shall be used. 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_o 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:

$$B = \frac{AE}{2}$$

If tabulated values are used, determine B as in Step 2 and apply it to the equation in Step 4.

Step 5. Compare the value of B determined in Step 3 or Step 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of t and R_o. 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 that is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

(c) The wall thickness of a vessel computed by these rules shall be determined such that, for any combination of loadings listed in UG-22 that induce primary stress and are expected to occur simultaneously during normal operation[13] of the vessel, the induced maximum general primary membrane stress does not exceed the maximum allowable stress value in tension (see UG-23), except as provided in (d) below. Except where limited by special rules, such as those for cast iron in flanged joints, the above loads shall not induce a combined maximum primary membrane stress plus primary bending stress across the thickness that exceeds $1\frac{1}{2}$ times[14] the maximum allowable stress value in tension (see UG-23). It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

The maximum allowable stress values that are to be used in the thickness calculations are to be taken from the tables at the temperature that is expected to be maintained in the metal under the conditions of loading being considered. Maximum stress values may be interpolated for intermediate temperatures.

(d) For the combination of earthquake loading, or wind loading with other loadings in UG-22, the wall thickness of a vessel computed by these rules shall be determined such that the general primary membrane stress shall not exceed 1.2 times the maximum allowable stress permitted in (a), (b), or (c) above. This rule is applicable to stresses caused by internal pressure, external pressure, and axial compressive load on a cylinder.[15]

Earthquake loading and wind loading need not be considered to act simultaneously.

(e) Localized discontinuity stresses [see (c) above] are calculated in Mandatory Appendix 1, 1-5(g) and 1-8(e), Part UHX, and Mandatory Appendix 5. The primary plus secondary stresses[14] at these discontinuities shall be limited to S_{PS}, where S_{PS} = 3S, and S is the maximum allowable stress of the material at temperature [see (a) above].

In lieu of using S_{PS} = 3S, a value of S_{PS} = 2S_Y may be used, where S_Y is the yield strength at temperature, provided the following are met:

(1) the allowable stress of material S is not governed by time-dependent properties as provided in Section II, Part D, Subpart 1, Table 1A or Table 1B;

(2) the room temperature ratio of the specified minimum yield strength to specified minimum tensile strength for the material does not exceed 0.7;

(3) the value for S_Y at temperature can be obtained from Section II, Part D, Subpart 1, Table Y-1.

(f) Maximum shear stress in restricted shear, such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without a reduction of area, shall be limited to 0.80 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

(g) Maximum bearing stress shall be limited to 1.60 times the values in Section II, Part D, Subpart 1, Table 1A, Table 1B, or Table 3.

UG-24 CASTINGS

(a) Quality Factors. A casting quality factor as specified below shall be applied to the allowable stress values for cast materials given in Subsection C except for castings

permitted by Part UCI. At a welded joint in a casting, only the lesser of the casting quality factor or the weld joint efficiency specified in UW-12 applies, but not both. NDE methods and acceptance standards are given in Mandatory Appendix 7.

(1) A factor not to exceed 80% shall be applied to static castings that are examined in accordance with the minimum requirements of the material specification. In addition to the minimum requirements of the material specification, all surfaces of centrifugal castings shall be machined after heat treatment to a finish not coarser than 250 μin. (6.3 μm) arithmetical average deviation, and a factor not to exceed 85% shall be applied.

(2) For nonferrous and ductile cast iron materials, a factor not to exceed 90% shall be applied if in addition to the minimum requirements of (1):

(-a) each casting is subjected to a thorough examination of all surfaces, particularly such as are exposed by machining or drilling, without revealing any defects;

(-b) at least three pilot castings[16] representing the first lot of five castings made from a new or altered design are sectioned or radiographed at all critical sections[17] without revealing any defects;

(-c) one additional casting taken at random from every subsequent lot of five is sectioned or radiographed at all critical sections without revealing any defects; and

(-d) all castings other than those that have been radiographed are examined at all critical sections by the magnetic particle or liquid penetrant methods in accordance with the requirements of Mandatory Appendix 7.

(3) For nonferrous and ductile cast iron materials, a factor not to exceed 90% may be used for a single casting that has been radiographed at all critical sections and found free of defects.

(4) For nonferrous and ductile cast iron materials, a factor not to exceed 90% may be used for a casting that has been machined to the extent that all critical sections are exposed for examination for the full wall thickness; as in tubesheets drilled with holes spaced no farther apart than the wall thickness of the casting. The examination afforded may be taken in lieu of destructive or radiographic testing required in (2)(-b) above.

(5) For carbon, low alloy, or high alloy steels, higher quality factors may be applied if in addition to the minimum requirements of (1) above, additional examinations are made as follows.

(-a) For centrifugal castings, a factor not to exceed 90% may be applied if the castings are examined by the magnetic particle or liquid penetrant methods in accordance with the requirements of Mandatory Appendix 7.

(-b) For static and centrifugal castings a factor not to exceed 100% may be applied if the castings are examined in accordance with all of the requirements of Mandatory Appendix 7.

(6) The following additional requirements apply when castings (including those permitted in UG-11) are to be used in vessels to contain lethal substances (UW-2).

(-a) Castings of cast iron (UCI-2) and cast ductile iron (UCD-2) are prohibited.

(-b) Each casting of nonferrous material permitted by this Division shall be radiographed at all critical sections[17] without revealing any defects. The quality factor for nonferrous castings for lethal service shall not exceed 90%.

(-c) Each casting of steel material permitted by this Division shall be examined per Mandatory Appendix 7 for severe service applications [7-3(b)]. The quality factor for lethal service shall not exceed 100%.

(b) Defects. Imperfections defined as unacceptable by either the material specification or by Mandatory Appendix 7, 7-3, whichever is more restrictive, are considered to be defects and shall be the basis for rejection of the casting. Where defects have been repaired by welding, the completed repair shall be subject to reexamination and, when required by either the rules of this Division or the requirements of the castings specification, the repaired casting shall be postweld heat treated and, to obtain a 90% or 100% quality factor, the repaired casting shall be stress relieved.

(c) Identification and Marking. Each casting to which a quality factor greater than 80% is applied shall be marked with the name, trademark, or other traceable identification of the manufacturer and the casting identification, including the casting quality factor and the material designation.

UG-25 CORROSION

(a) The user or his designated agent (see U-2) shall specify corrosion allowances other than those required by the rules of this Division. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report.

(b) Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection. (See Nonmandatory Appendix E.)

NOTE: When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

(c) Material added for these purposes need not be of the same thickness for all parts of the vessel if different rates of attack are expected for the various parts.

(d) No additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

(e) Telltale Holes. Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. Telltale holes shall not be used in vessels that are to contain lethal substances [see UW-2(a)], except as permitted by ULW-76 for vent

holes in layered construction. When telltale holes are provided, they shall have a diameter of $^1/_{16}$ in. to $^3/_{16}$ in. (1.5 mm to 5 mm)and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the opposite surface to that where deterioration is expected. [For telltale holes in clad or lined vessels, see UCL-25(b).]

(f) Openings for Drain. Vessels subject to corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel; or a pipe may be used extending inward from any other location to within $^1/_4$ in. (6 mm) of the lowest point.

UG-26 LININGS

Corrosion resistant or abrasion resistant linings, whether or not attached to the wall of a vessel, shall not be considered as contributing to the strength of the wall except as permitted in Part UCL (see Nonmandatory Appendix F).

UG-27 THICKNESS OF SHELLS UNDER INTERNAL PRESSURE

(a) The minimum required thickness of shells under internal pressure shall not be less than that computed by the following formulas,[18] except as permitted by Mandatory Appendix 1 or Mandatory Appendix 32. In addition, provision shall be made for any of the loadings listed in UG-22, when such loadings are expected. The provided thickness of the shells shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32.

(b) The symbols defined below are used in the formulas of this paragraph.

E = joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells, or the efficiency of ligaments between openings, whichever is less.
For welded vessels, use the efficiency specified in UW-12.
For ligaments between openings, use the efficiency calculated by the rules given in UG-53.

P = internal design pressure (see UG-21)

R = inside radius of the shell course under consideration,[19]

S = maximum allowable stress value (see UG-23 and the stress limitations specified in UG-24)

t = minimum required thickness of shell

(c) Cylindrical Shells. The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

(1) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385SE$, the following formulas shall apply:

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t} \tag{1}$$

(2) Longitudinal Stress (Circumferential Joints).[20] When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE + 0.4P} \quad \text{or} \quad P = \frac{2SEt}{R - 0.4t} \tag{2}$$

(d) Spherical Shells. When the thickness of the shell of a wholly spherical vessel does not exceed $0.356R$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t = \frac{PR}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{R + 0.2t} \tag{3}$$

(e) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(f) A stayed jacket shell that extends completely around a cylindrical or spherical vessel shall also meet the requirements of UG-47(c).

(g) Any reduction in thickness within a shell course or spherical shell shall be in accordance with UW-9.

UG-28 THICKNESS OF SHELLS AND TUBES UNDER EXTERNAL PRESSURE

(a) Rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells, with or without stiffening rings, tubes, and spherical shells. Three typical forms of cylindrical shells are shown in Figure UG-28. Charts used in determining minimum required thicknesses of these components are given in Section II, Part D, Subpart 3.

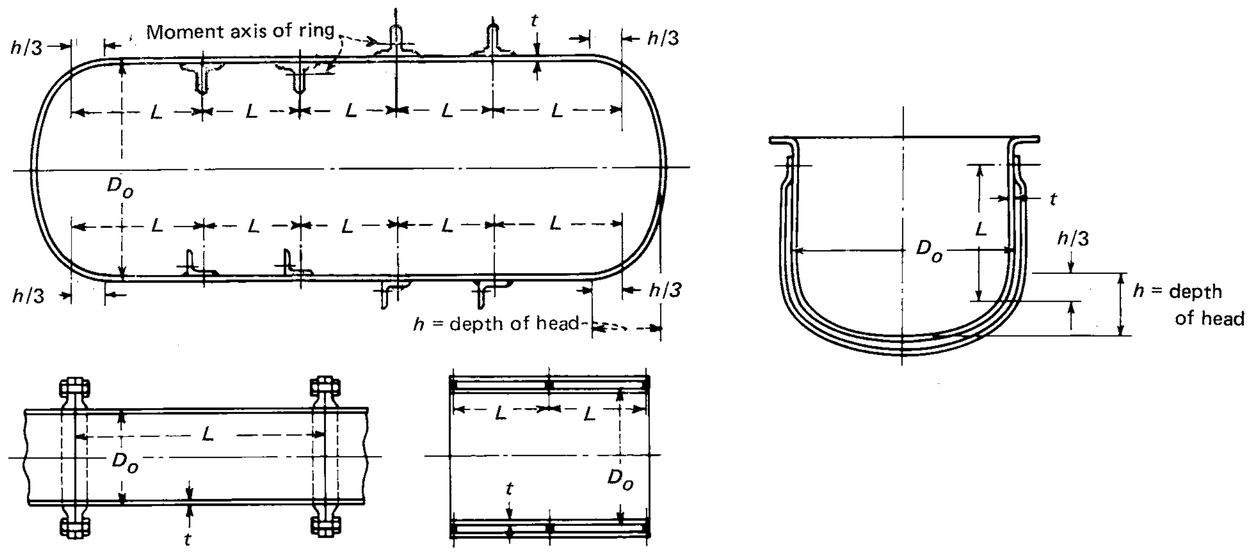
(b) The symbols defined below are used in the procedures of this paragraph:

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 (c)(2).

B = factor determined from the applicable material chart or table in Section II, Part D, Subpart 3 for maximum design metal temperature [see UG-20(c)]

D_o = outside diameter of cylindrical shell course or tube

Figure UG-28
Diagrammatic Representation of Variables for Design of Cylindrical Vessels Subjected to External Pressure



E = modulus of elasticity of material at design temperature. For external pressure design in accordance with this Section, 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.)

L = total length, in. (mm), of a tube between tubesheets, or design length of a vessel section between lines of support (see Figure UG-28.1). A line of support is:

(a) a circumferential line on a head (excluding conical heads) at one-third the depth of the head from the head tangent line as shown on Figure UG-28;

(b) a stiffening ring that meets the requirements of UG-29;

(c) a jacket closure of a jacketed vessel that meets the requirements of 9-5;

(d) a cone-to-cylinder junction or a knuckle-to-cylinder junction of a toriconical head or section that satisfies the moment of inertia requirement of 1-8.

P = external design pressure [see Note in (f)]

P_a = calculated value of maximum allowable external working pressure for the assumed value of t, [see Note in (f) below]

R_o = outside radius of spherical shell

t = minimum required thickness of cylindrical shell or tube, or spherical shell, in. (mm)

t_s = nominal thickness of cylindrical shell or tube, in. (mm)

(c) Cylindrical Shells and Tubes. The required minimum thickness of a cylindrical shell or tube under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure:

(1) Cylinders having D_o/t values ≥ 10:

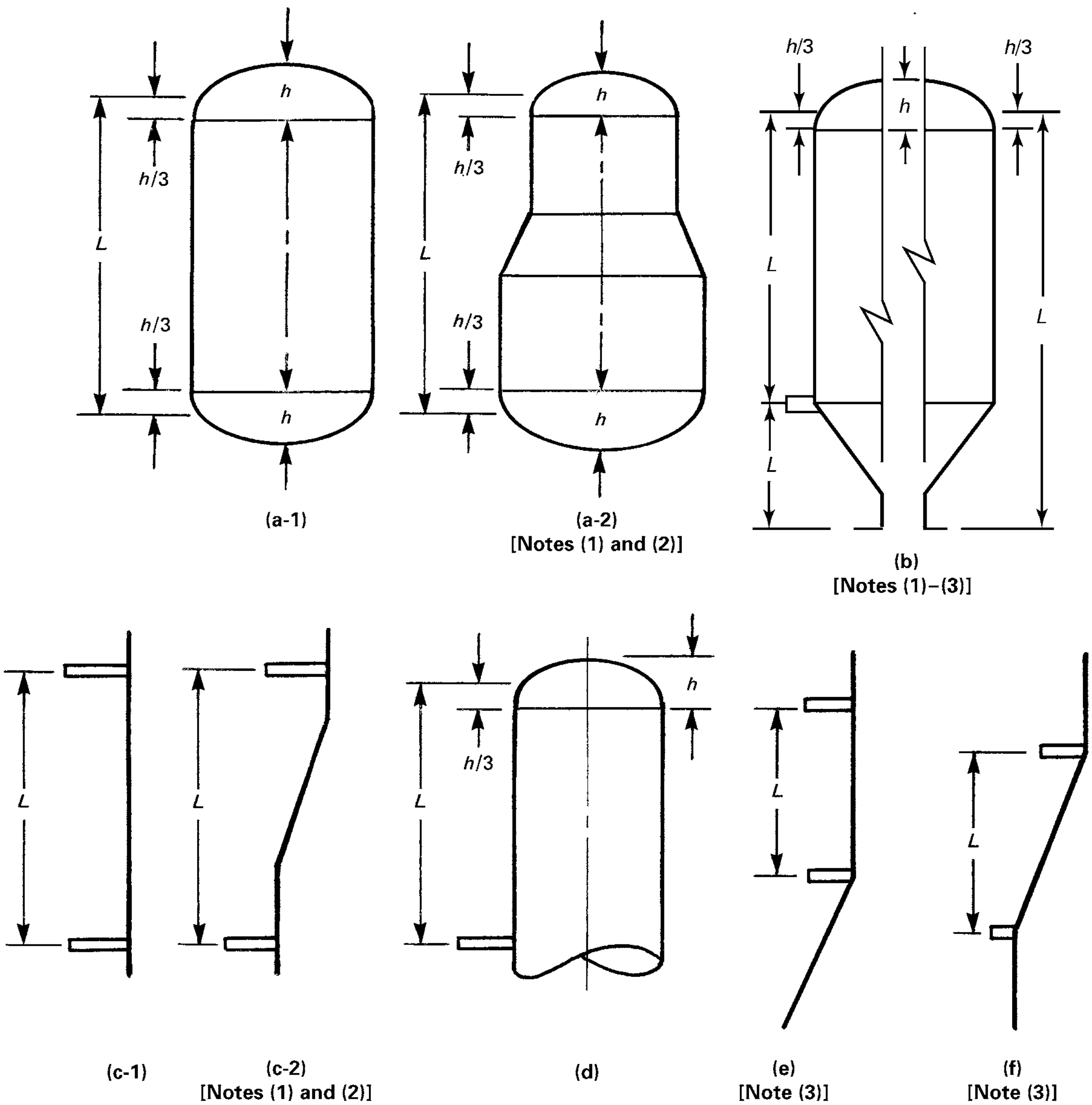
Step 1. Assume a value for t and determine the ratios L/D_o and D_o/t.

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 = 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; extrapolation is not permitted. 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 (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to

Figure UG-28.1
Diagrammatic Representation of Lines of Support for Design of Cylindrical Vessels Subjected to External Pressure



NOTES:

(1) When the cone-to-cylinder or the knuckle-to-cylinder junction is not a line of support, the required thickness of the cone, knuckle, or toriconical section shall not be less than the required thickness of the adjacent cylindrical shell. Also, the reinforcement requirement of 1-8 shall be satisfied when a knuckle is not provided at the cone-to-cylinder junction.

(2) Calculations shall be made using the diameter and corresponding thickness of each cylindrical section with dimension L as shown. Thicknesses of the transition sections are based on Note (1).

(3) When the cone-to-cylinder or the knuckle-to-cylinder junction is a line of support, the moment of inertia shall be provided in accordance with 1-8 [see UG-33(f)].

determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

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. If tabular values are used, the last (maximum) tabulated value shall be used. 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 factor B.

Step 6. Using this value of B, calculate the value of the maximum allowable external working 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:

$$P_a = \frac{2AE}{3(D_o/t)}$$

If tabular values are used, determine B as in Step 4 and apply it to the equation in Step 6.

Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 7 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.

(2) Cylinders having D_o/t values <10:

Step 1. Using the same procedure as given in (1), 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:

$$P_{a2} = \frac{2S}{D_o/t}\left[1 - \frac{1}{D_o/t}\right]$$

where S is the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced in UG-23, or 0.9 times the yield strength of the material at design temperature. Values of yield strength are obtained from the applicable external pressure chart as follows:

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

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 working 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.

(d) Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the following procedure:

Step 1. Assume a value for t and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R_o/t)}$$

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 (see UG-20). Interpolation may be made between lines for intermediate temperatures. If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine a B value that lies between two adjacent tabular values for a specific temperature. Such interpolation may also be used to determine a B value at an intermediate temperature that lies between two sets of tabular values, after first determining B values for each set of tabular values.

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. If tabular values are used, the last (maximum) tabulated value shall be used. For values at 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 working pressure P_a using the following equation:

$$P_a = \frac{B}{(R_o/t)}$$

Step 5. 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:

$$P_a = \frac{0.0625E}{(R_o/t)^2}$$

If tabulated values are used, determine B as in Step 2 and apply it to the equation in Step 4.

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.

(e) The external design pressure or maximum allowable external working pressure shall not be less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the vessel at any time.

(f) Vessels intended for service under external design pressures of 15 psi (103 kPa) and less [see U-1(c)(2)(-h)] may be stamped with the Certification Mark and Designator denoting compliance with the rules for external pressure, provided all the applicable rules of this Division are satisfied. When the Certification Mark is to be applied, the user or his designated agent shall specify the required maximum allowable external working pressure.[21] The vessel shall be designed and stamped with the maximum allowable external working pressure.

(g) When there is a longitudinal lap joint in a cylindrical shell or any lap joint in a spherical shell under external pressure, the thickness of the shell shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(h) Circumferential joints in cylindrical shells may be of any type permitted by the Code and shall be designed for the imposed loads.

(i) Those portions of pressure chambers of vessels that are subject to a collapsing pressure and that have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels that extend over only a portion of the circumference, shall be fully staybolted in accordance with the requirements of UG-47 through UG-50 or shall be proof tested in compliance with UG-101(p).

(j) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

UG-29 STIFFENING RINGS FOR CYLINDRICAL SHELLS UNDER EXTERNAL PRESSURE

(a) External stiffening rings shall be attached to the shell by welding or brazing [see UG-30]. Internal stiffening rings need not be attached to the shell when the rings are designed to carry the loads and adequate means of support is provided to hold the ring in place when subjected to external pressure loads. Segments of rings need not be attached when the requirements of (c) are met.

Except as exempted in (f) below, the available moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two formulas:

$$I_s = \left[D_o^2 L_s(t + A_s/L_s)A\right] /14$$

$$I_s' = \left[D_o^2 L_s(t + A_s/L_s)A\right] /10.9$$

where

I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I_s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I' = available moment of inertia of combined ring-shell cross section about its neutral axis parallel to the axis of the shell. The nominal shell thickness t_s shall be used and the width of shell that is taken as contributing to the moment of inertia of the combined section shall not be greater than $1.10\sqrt{D_o t_s}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring.

I_s' = required moment of inertia of the combined ring-shell cross section about its neutral axis parallel to the axis of the shell

CAUTION: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s [see U-2(g)].

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

A = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B, below, and the design temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor determined from the applicable chart or table in Section II, Part D, Subpart 3 for the material used for the stiffening ring [see UG-20(c)]

L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder. A line of support is:

(a) a stiffening ring that meets the requirements of this paragraph;

(b) a circumferential connection to a jacket for a jacketed section of a cylindrical shell;

(c) a circumferential line on a head at one-third the depth of the head from the head tangent line as shown on Figure UG-28;

(d) a cone-to-cylinder junction.

D_o, E, P, t, and t_s are as defined in UG-28(b).

The adequacy of the moment of inertia for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s. Then calculate factor B using the following equation:

$$B = \frac{3}{4}\left(\frac{PD_o}{t + A_s/L_s}\right)$$

Step 2. See below.

(a) If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine an A value that lies between two adjacent tabular values for a specific temperature. Linear interpolation may also be used to determine an A value at an intermediate temperature that lies between two sets of tabular values, after first determining A values for each set of tabular values. The value of A so determined is then applied in the equation for I_s or I_s' in Step 6(a) or Step 6(b).

(b) If material charts in Section II, Part D, Subpart 3 are used, enter the right-hand side of the applicable material chart for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, 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 formula $A = 2B/E$.

Step 6. See below.

(a) In those cases where only the stiffening ring is considered, compute the required moment of inertia from the formula for I_s given above.

(b) In those cases where the combined ring-shell is considered, compute the required moment of inertia from the formula for I_s' given above.

Step 7. See below.

(a) In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

(b) In those cases where the combined ring-shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring, Step 6(a) and Step 7(a) are considered. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, 6(b) and (b) are considered.

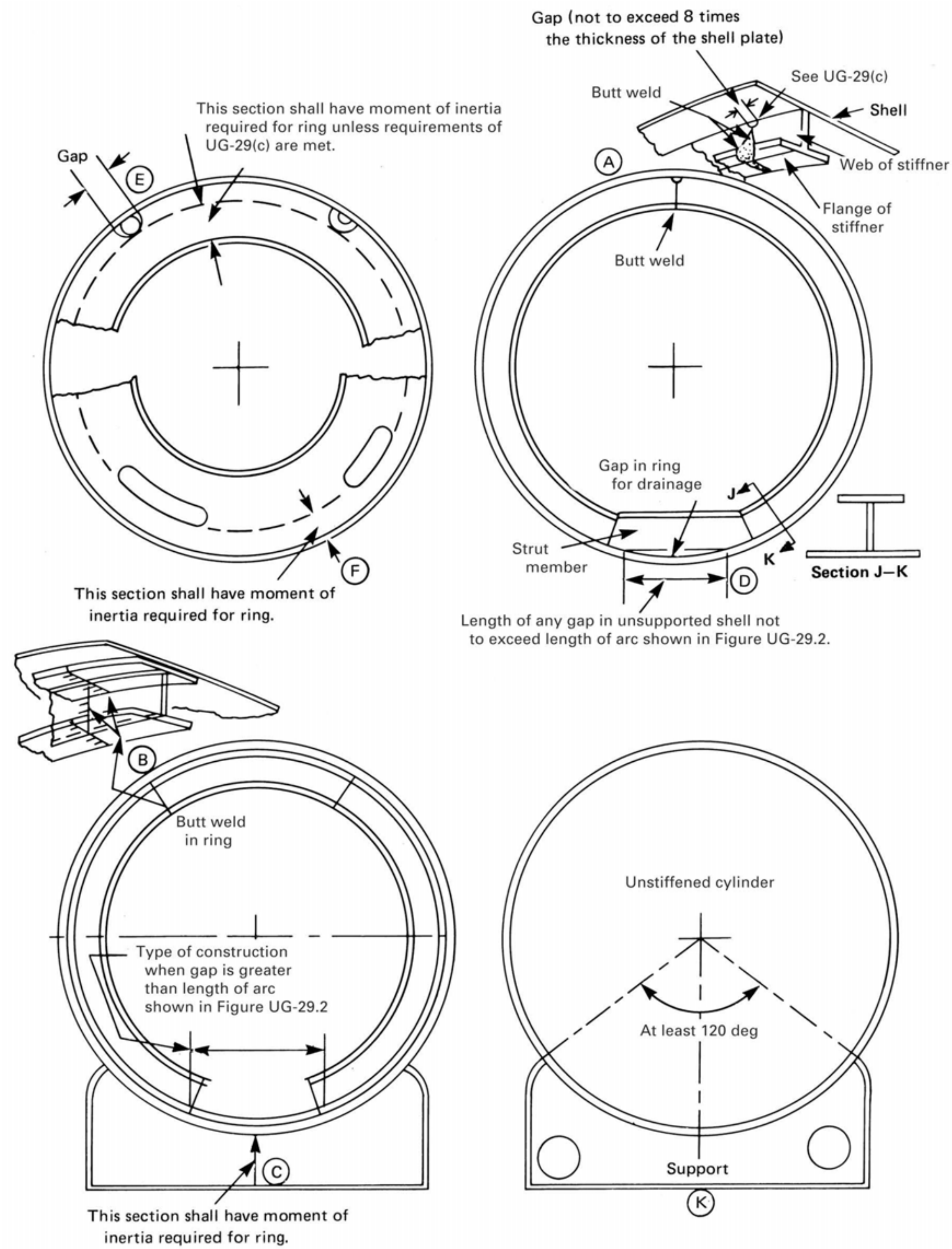
Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination that was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the actual moment of inertia of the ring or ring-shell combination, whichever is used, that ring section or combined section is satisfactory.

(b) Stiffening rings shall extend completely around the circumference of the cylinder except as permitted in (c) below. Any joints between the ends or sections of such rings, such as shown in Figure UG-29.1 (A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell as shown in Figure UG-29.1 (C) shall be made so that the required moment of inertia of the combined ring-shell section is maintained.

(c) Stiffening rings placed on the inside of a vessel may be arranged as shown in Figure UG-29.1 (E) and (F), provided that the required moment of inertia of the ring in (E) or of the combined ring-shell section in (F) is maintained within the sections indicated. Where the gap at (A) or (E) does not exceed eight times the thickness of the shell plate, the combined moment of inertia of the shell and stiffener may be used.

Figure UG-29.1
Various Arrangements of Stiffening Rings for Cylindrical Vessels Subjected to External Pressure



Any gap in that portion of a stiffening ring supporting the shell, such as shown in Figure UG-29.1 (D) and (E), shall not exceed the length of are given in Figure UG-29.2 unless additional reinforcement is provided as shown in Figure UG-29.1 (C) or unless the following conditions are met:

(1) only one unsupported shell arc is permitted per ring; and

(2) the length of the unsupported shell arc does not exceed 90 deg; and

(3) the unsupported arcs in adjacent stiffening rings are staggered 180 deg; and

(4) the dimension L defined in UG-28(b) is taken as the larger of the following: the distance between alternate stiffening rings, or the distance from the head tangent line to the second stiffening ring plus one-third of the head depth.

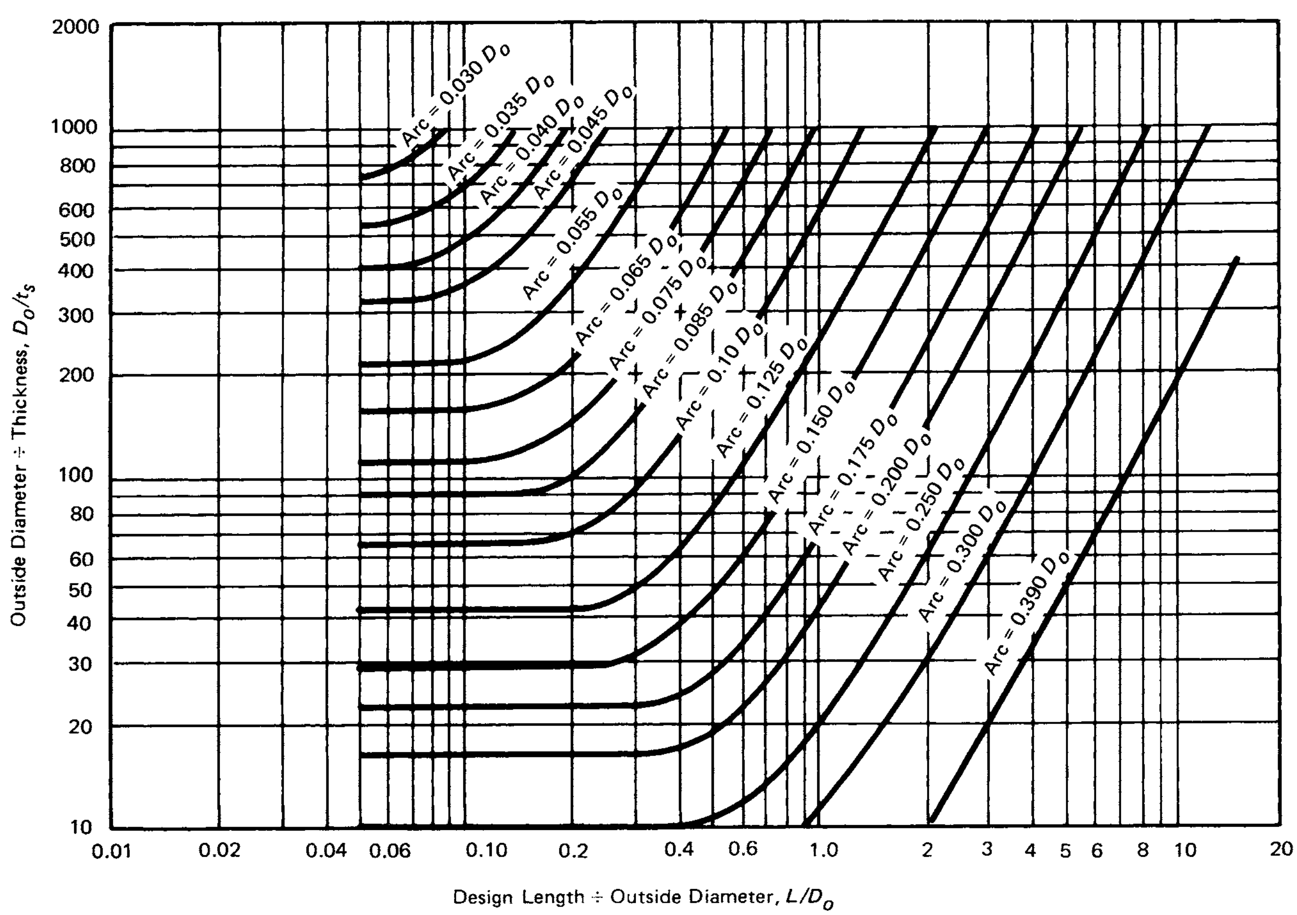
(d) When internal plane structures perpendicular to the longitudinal axis of the cylinder (such as bubble trays or baffle plates) are used in a vessel, they may also be considered to act as stiffening rings, provided they are designed to function as such.

(e) Any internal stays or supports used as stiffeners of the shell shall bear against the shell of the vessel through the medium of a substantially continuous ring.

NOTE: Attention is called to the objection to supporting vessels through the medium of legs or brackets, the arrangement of which may cause concentrated loads to be imposed on the shell. Vertical vessels should be supported through a substantial ring secured to the shell (see G-3). Horizontal vessels, unless supported at or close to the ends (heads) or at stiffening rings, should be supported through the medium of substantial members extending over at least one-third of the circumference, as shown at (K) in Figure UG-29.1.

Attention is called also to the hazard of imposing highly concentrated loads by the improper support of one vessel on another or by the hanging or supporting of heavy weights directly on the shell of the vessel. (See Nonmandatory Appendix G.)

Figure UG-29.2
Maximum Arc of Shell Left Unsupported Because of Gap in Stiffening Ring of Cylindrical Shell Under External Pressure



(f) When closure bars or other rings are attached to both the inner shell and outer jacket of a vessel, with pressure in the space between the jacket and inner shell, this construction has adequate inherent stiffness, and therefore the rules of this paragraph do not apply.

UG-30 ATTACHMENT OF STIFFENING RINGS

(a) Stiffening rings may be placed on the inside or outside of a vessel, and except for the configurations permitted by UG-29, shall be attached to the shell by welding or brazing. Brazing may be used if the vessel is not to be later stress relieved. The ring shall be essentially in contact with the shell and meet the rules in UG-29(b) and UG-29(c). Welding of stiffening rings shall comply with the requirements of this Division for the type of vessel under construction.

(b) Stiffening rings may be attached to the shell by continuous, intermittent, or a combination of continuous and intermittent welds or brazes. Some acceptable methods of attaching stiffening rings are illustrated in Figure UG-30.

(c) Intermittent welding shall be placed on both sides of the stiffener and may be either staggered or in-line. Length of individual fillet weld segments shall not be less than 2 in. (50 mm) and shall have a maximum clear spacing between toes of adjacent weld segments of $8t$ for external rings and $12t$ for internal rings where t is the shell thickness at the attachment. The total length of weld on each side of the stiffening ring shall be:

(1) not less than one-half the outside circumference of the vessel for rings on the outside; and

(2) not less than one-third the circumference of the vessel for rings on the inside.

(d) A continuous full penetration weld is permitted as shown in sketch (e) of Figure UG-30. Continuous fillet welding or brazing on one side of the stiffener with intermittent welding or brazing on the other side is permitted for sketches (a), (b), (c), and (d) of Figure UG-30 when the thickness t_w of the outstanding stiffening element [sketches (a) and (c)] or width w of the stiffening element mating to the shell [sketches (b) and (d)] is not more than 1 in. (25 mm). The weld segments shall be not less than 2 in. (50 mm) long and shall have a maximum clear spacing between toes of adjacent weld segments of $24t$.

(e) Strength of Attachment Welds. Stiffening ring attachment welds shall be sized to resist the full radial pressure load from the shell between stiffeners, and shear loads acting radially across the stiffener caused by external design loads carried by the stiffener (if any) and a computed radial shear equal to 2% of the stiffening ring's compressive load.

(1) The radial pressure load from shell, lb/in., is equal to PL_s.

(2) The radial shear load is equal to $0.01PL_sD_O$.

(3) P, L_s, and D_O are defined in UG-29.

(f) Minimum Size of Attachment Welds. The fillet weld leg size shall be not less than the smallest of the following:

(1) $^1/_4$ in. (6 mm);

(2) vessel thickness at the weld location;

(3) stiffener thickness at weld location.

UG-31 TUBES, AND PIPE WHEN USED AS TUBES OR SHELLS

(a) Internal Pressure. The required wall thickness for tubes and pipe under internal pressure shall be determined in accordance with the rules for shells in UG-27.

(b) External Pressure. The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with the rules in UG-28.

(c) The thickness as determined under (a) or (b) above shall be increased when necessary to meet the following requirements:

(1) Additional wall thickness should be provided when corrosion, erosion, or wear due to cleaning operations is expected.

(2) Where ends are threaded, additional wall thickness is to be provided in the amount of $0.8/n$ in. ($20/n$ mm) [where n equals the number of threads per inch (25.4 mm)].

NOTE: The requirements for rolling, expanding, or otherwise seating tubes in tube plates may require additional wall thickness and careful choice of materials because of possible relaxation due to differential expansion stresses.

UG-32 FORMED HEADS, AND SECTIONS, PRESSURE ON CONCAVE SIDE

(a) The minimum required thickness at the thinnest point after forming[22] of ellipsoidal, torispherical, hemispherical, conical, and toriconical heads under pressure on the concave side (plus heads) shall be computed by the appropriate formulas in this paragraph,[23] except as permitted by Mandatory Appendix 32. Heads with bolting flanges shall meet the requirements of UG-35.1. In addition, provision shall be made for any of the loadings listed in UG-22. The provided thickness of the heads shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32.

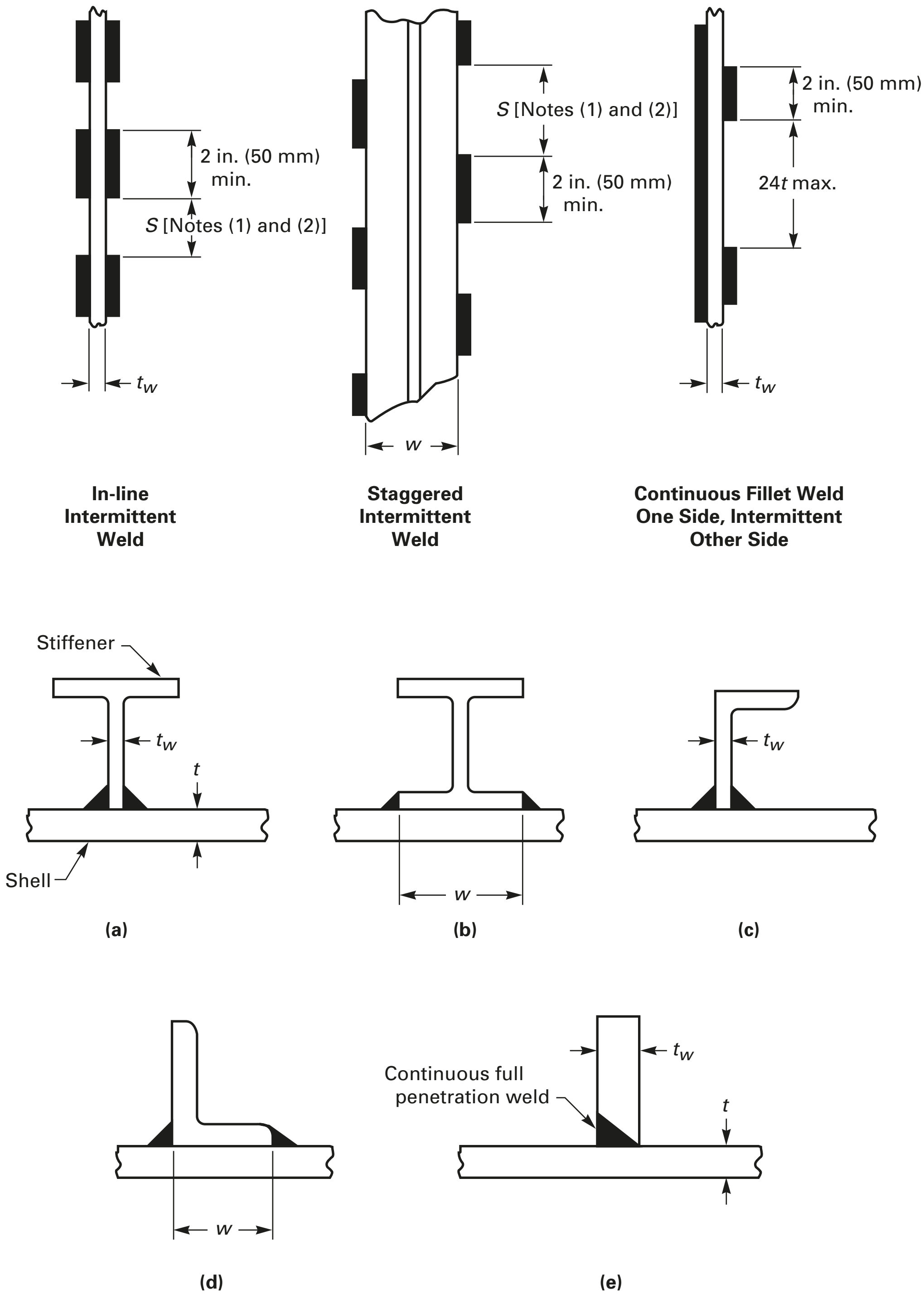
(b) The symbols defined below are used in the formulas of this paragraph:

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis

D_i = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone
 = $D - 2r(1 - \cos \alpha)$

E = lowest efficiency of any joint in the head; for hemispherical heads this includes head-to-shell joint; for welded vessels, use the efficiency specified in UW-12

Figure UG-30
Some Acceptable Methods of Attaching Stiffening Rings



NOTES:
(1) For external stiffeners, $S \le 8t$.
(2) For internal stiffeners, $S \le 12t$.

L = inside spherical or crown radius. The value of L for ellipsoidal heads shall be obtained from Table UG-37.
P = internal design pressure (see UG-21)
r = inside knuckle radius
S = maximum allowable stress value in tension as given in the tables referenced in UG-23, except as limited in UG-24 and (d) below.
t = minimum required thickness of head after forming
t_s = minimum specified thickness of head after forming, in. (mm). t_s shall be ≥ t
α = one-half of the included (apex) angle of the cone at the centerline of the head (see Figure 1-4)

(c) Ellipsoidal Heads With $t_s/L \geq 0.002$. The required thickness of a dished head of semiellipsoidal form, in which half the minor axis (inside depth of the head minus the skirt) equals one-fourth of the inside diameter of the head skirt, shall be determined by

$$t = \frac{PD}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{D + 0.2t} \tag{1}$$

NOTE: For ellipsoidal heads with $t_s/L < 0.002$, the rules of 1-4(f) shall also be met.

An acceptable approximation of a 2:1 ellipsoidal head is one with a knuckle radius of 0.17D and a spherical radius of 0.90D.

(d) Torispherical Heads With $t_s/L \geq 0.002$. The required thickness of a torispherical head for the case in which the knuckle radius is 6% of the inside crown radius and the inside crown radius equals the outside diameter of the skirt [see (i)] shall be determined by

$$t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t} \tag{2}$$

NOTE: For torispherical heads with $t_s/L < 0.002$, the rules of 1-4(f) shall also be met.

Torispherical heads made of materials having a specified minimum tensile strength exceeding 70,000 psi (485 MPa) shall be designed using a value of S equal to 20,000 psi (138 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material (see UG-23).

(e) Hemispherical Heads. When the thickness of a hemispherical head does not exceed 0.356L, or P does not exceed 0.665SE, the following formulas shall apply:

$$t = \frac{PL}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{L + 0.2t} \tag{3}$$

(f) Conical Heads and Sections (Without Transition Knuckle). The required thickness of conical heads or conical shell sections that have a half apex-angle α not greater than 30 deg shall be determined by

$$t = \frac{PD}{2\cos\alpha(SE - 0.6P)} \quad \text{or} \quad P = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha} \tag{4}$$

A reinforcing ring shall be provided when required by the rule in 1-5(d) and 1-5(e).

Conical heads or sections having a half apex-angle α greater than 30 deg without a transition knuckle shall comply with eq. (4) and 1-5(g).

(g) Toriconical Heads and Sections. The required thickness of the conical portion of a toriconical head or section, in which the knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness, shall be determined by eq. (f)(4) in (f) above, using D_i in place of D.

The required thickness of the knuckle shall be determined by eq. 1-4(d)(3) in which

$$L = \frac{D_i}{2\cos\alpha}$$

Toriconical heads or sections may be used when the angle $\alpha \leq 30$ deg and are mandatory for conical head designs when the angle α exceeds 30 deg, unless the design complies with 1-5(g).

(h) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of UG-47 for braced and stayed flat plates.

(i) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than 3 times the head thickness.

(j) A dished head with a reversed skirt may be used in a pressure vessel, provided the maximum allowable working pressure for the head is established in accordance with the requirements of UG-101.

(k) All formed heads, thicker than the shell and concave to pressure, intended for butt-welded attachment, shall have a skirt length sufficient to meet the requirements of Figure UW-13.1, when a tapered transition is required. All formed heads concave to pressure and intended for butt-welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same inside diameter.

(l) Heads concave to pressure, intended for attachment by brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints in Part UB.

(m) Any taper at a welded joint within a formed head shall be in accordance with UW-9. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of UW-13 for the respective type of joint shown therein.

(n) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by eq. UG-34(c)(2)(1), using C = 0.25.

(o) Openings in formed heads under internal pressure shall comply with the requirements of UG-36 through UG-46.

(p) A stayed jacket that completely covers a formed inner head or any of the types included in this paragraph shall also meet the requirements of UG-47(c).

UG-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

(a) General. The required thickness at the thinnest point after forming[22] of ellipsoidal, torispherical, hemispherical, toriconical, and conical heads and conical segments under pressure on the convex side (minus heads) shall be computed by the appropriate formulas given in this paragraph (see UG-16). Heads with bolting flanges shall meet the requirements of UG-35.1. In addition, provisions shall be made for any other loading given in UG-22. The required thickness for heads due to pressure on the convex side shall be determined as follows.

(1) For ellipsoidal and torispherical heads, the required thickness shall be the greater of the following:

(-a) the thickness computed by the procedure given in UG-32 for heads with pressure on the concave side (plus heads) using a design pressure 1.67 times the design pressure on the convex side, assuming a joint efficiency E = 1.00 for all cases; or

(-b) the thickness as computed by the appropriate procedure given in (d) or (e) below.

In determining the maximum allowable working pressure on the convex side of ellipsoidal or torispherical heads, reverse the procedures in (-a) and (-b) above, and use the smaller of the pressures obtained.

(2) For hemispherical heads, the required thickness shall be determined by the rules given in (c) below.

(3) For conical and toriconical heads and conical sections, the required thickness shall be determined by the rules given in (f) below.

(b) Nomenclature. The nomenclature defined below is used in this paragraph. Figure 1-4 shows principal dimensions of typical heads.

A, B, E, and P are as defined in UG-28(b)

D_o = outside diameter of the head skirt

$D_o/2h_o$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the outside diameter of the head skirt divided by twice the outside height of the head (see Table UG-33.1)

D_L = outside diameter at large end of conical section under consideration

D_s = outside diameter at small end of conical section under consideration

D_{ss} = outside diameter at small end of conical section under consideration

h_o = one-half of the length of the outside minor axis of the ellipsoidal head, or the outside height of the ellipsoidal head measured from the tangent line (head-bend line)

K_o = factor depending on the ellipsoidal head proportions $D_o/2h_o$ (see Table UG-33.1)

L_c = axial length of cone or conical section (see Figure UG-33.1).

L_e = equivalent length of conical head or Section between lines of support [see (g)]

R_o = for hemispherical heads, the outside radius
= for ellipsoidal heads, the equivalent outside spherical radius taken as K_oD_o
= for torispherical heads, the outside radius of the crown portion of the head

t = minimum required thickness of head after forming, in. (mm)

t_e = effective thickness of conical section
= $t \cos \alpha$

α = one-half the apex angle in conical heads and sections, deg

(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 UG-28(d) 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 formula:

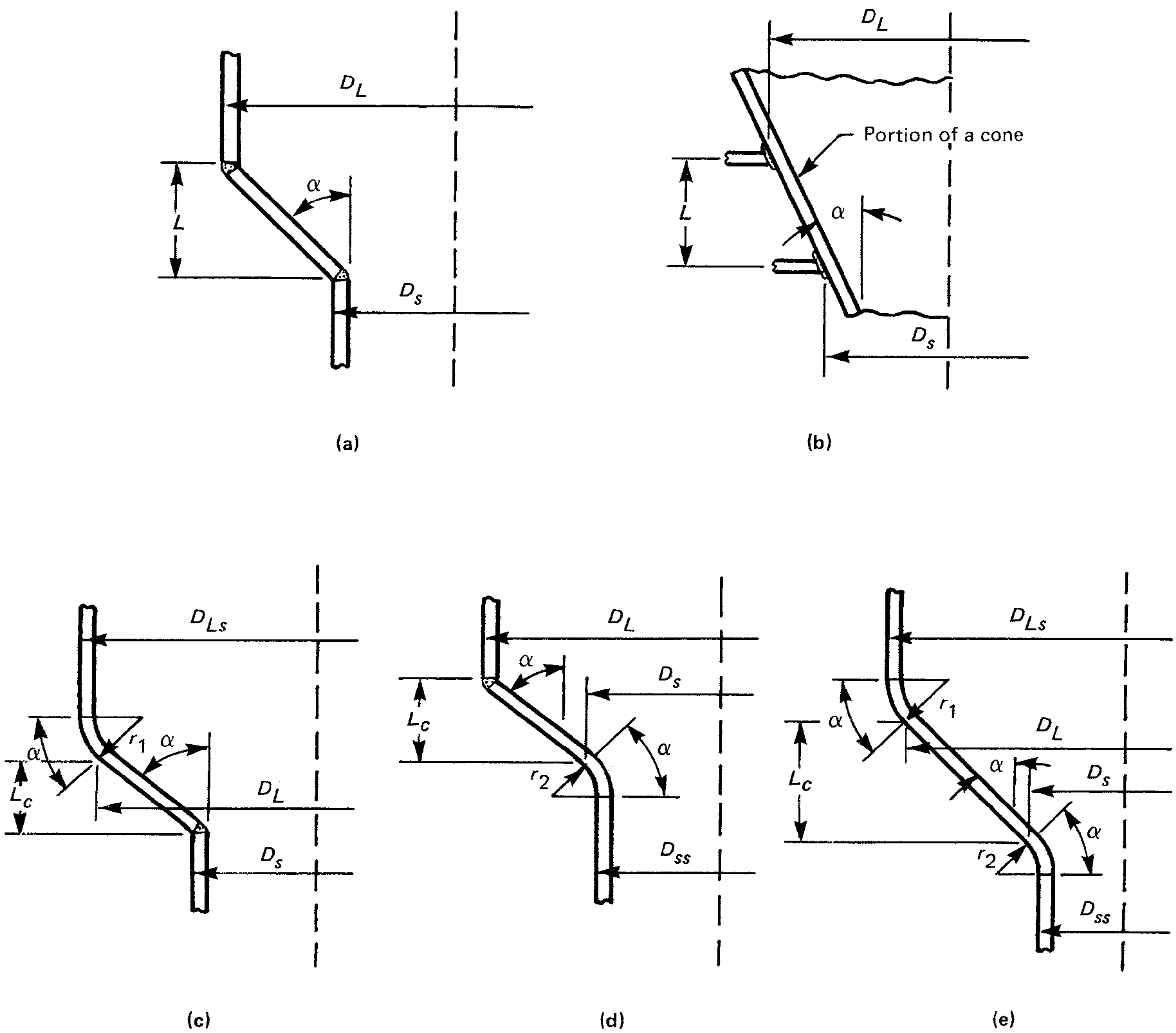
$$A = \frac{0.125}{R_o/t}$$

Table UG-33.1
Values of Spherical Radius Factor K_o for Ellipsoidal Head With Pressure on Convex Side

$D_o/2h_o$	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_o	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Interpolation permitted for intermediate values.

Figure UG-33.1
Length L_c of Some Typical Conical Sections for External Pressure



Step 2. Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in UG-28(d), Steps 2 through 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_o.

(f) Conical Heads and Sections. When the cone-to-cylinder junction is not a line-of-support, the required thickness of a conical head or section under pressure on the convex side, either seamless or of built-up construction with butt joints shall not be less than the required thickness of the adjacent cylindrical shell and, when a knuckle is not provided, the reinforcement requirement of 1-8 shall be satisfied (see Figure UG-28.1). When the cone-to-cylinder junction is a line-of-support, the required thickness shall be determined in accordance with the following subparagraphs.

(1) When α is equal to or less than 60 deg:

(-a) cones having D_L/t_e values ≥10:

Step 1. Assume a value for t_e and determine the ratios L_e/D_L and D_L/t_e.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at a value of L/D_o equivalent to the value of L_e/D_L determined in Step 1. For values of L_e/D_L greater than 50, enter the chart at a value of L_e/D_L = 50.

Step 3. Move horizontally to the line for the value of D_o/t equivalent to the value of D_L/t_e determined in Step 1. Interpolation may be made for intermediate values of D_L/t_e; extrapolation is not permitted. From this point of intersection move vertically downwards 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 (see UG-20). 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 factor B.

Step 6. Using this value of B, calculate the value of the maximum allowable external working pressure P_a using the following formula:

$$P_a = \frac{4B}{3(D_L/t_e)}$$

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 formula:

$$P_a = \frac{2AE}{3(D_L/t_e)}$$

Step 8. Compare the calculated value of P_a obtained in Step 6 or Step 7 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.

Step 9. Provide adequate moment of inertia and reinforcement at the cone-to-cylinder junction in accordance with 1-8. For a junction with a knuckle, the reinforcement calculation is not required, and the moment of inertia calculation may be performed either by considering the presence of the knuckle or by assuming the knuckle is not present whereby the cone is assumed to intersect the adjacent cylinder.

(-b) cones having D_L/t_e values <10:

Step 1. Using the same procedure as given in (-a) above, obtain the value of B. For values of D_L/t_e less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_L/t_e)^2}$$

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 formula:

$$P_{a1} = \left[\frac{2.167}{(D_L/t_e)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2S}{D_L/t_e}\left[1 - \frac{1}{D_L/t_e}\right]$$

where

S = the lesser of two times the maximum allowable stress value in tension at design metal temperature, from the applicable table referenced by UG-23, or 0.9 times the yield strength of the material at design temperature

Values of yield strength are obtained from the applicable external pressure chart as follows.

(a) For a given temperature curve, determine the B value that corresponds to the right hand side termination point of the curve.

(b) The yield strength is twice the B value obtained in (a) above.

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 working 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.

Step 5. Provide adequate moment of inertia and reinforcement at the cone-to-cylinder junction in accordance with 1-8. For a junction with a knuckle, the reinforcement calculation is not required, and the moment of inertia calculation may be performed either by considering the presence of the knuckle or by assuming the knuckle is not present whereby the cone is assumed to intersect the adjacent cylinder.

(2) When α of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest diameter of the cone (see UG-34).

(3) The thickness of an eccentric cone shall be taken as the greater of the two thicknesses obtained using both the smallest and largest α in the calculations.

(g) The required thickness of a conical part of a toriconical head or conical section having pressure on the convex side, either seamless or of built-up construction with butt joints within the conical part of a toriconical head or conical section, shall not be less than that determined from (f) above with the exception that L_e shall be determined as follows:

(1) For sketches (a) and (b) in Figure UG-33.1,

$$L_e = (L_c/2)(1 + D_s/D_L)$$

(2) For sketch (c) in Figure UG-33.1,

$$L_e = r_1 \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_{Ls}}\right)$$

(3) For sketch (d) in Figure UG-33.1,

$$L_e = r_2 \frac{D_{ss}}{D_L} \sin\alpha + \frac{L_c}{2}\left(\frac{D_L + D_s}{D_L}\right)$$

(4) For sketch (e) in Figure UG-33.1,

$$L_e = \left(r_1 + r_2 \frac{D_{ss}}{D_{Ls}}\right) \sin\alpha + \frac{L_c}{2}\frac{(D_L + D_s)}{D_{Ls}}$$

(h) When lap joints are used in formed head construction or for longitudinal joints in a conical head under external pressure, the thickness shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(i) The required length of skirt on heads convex to pressure shall comply with the provisions of UG-32(k) and UG-32(l) for heads concave to pressure.

(j) Openings in heads convex to pressure shall comply with the requirements of UG-36 through UG-46.

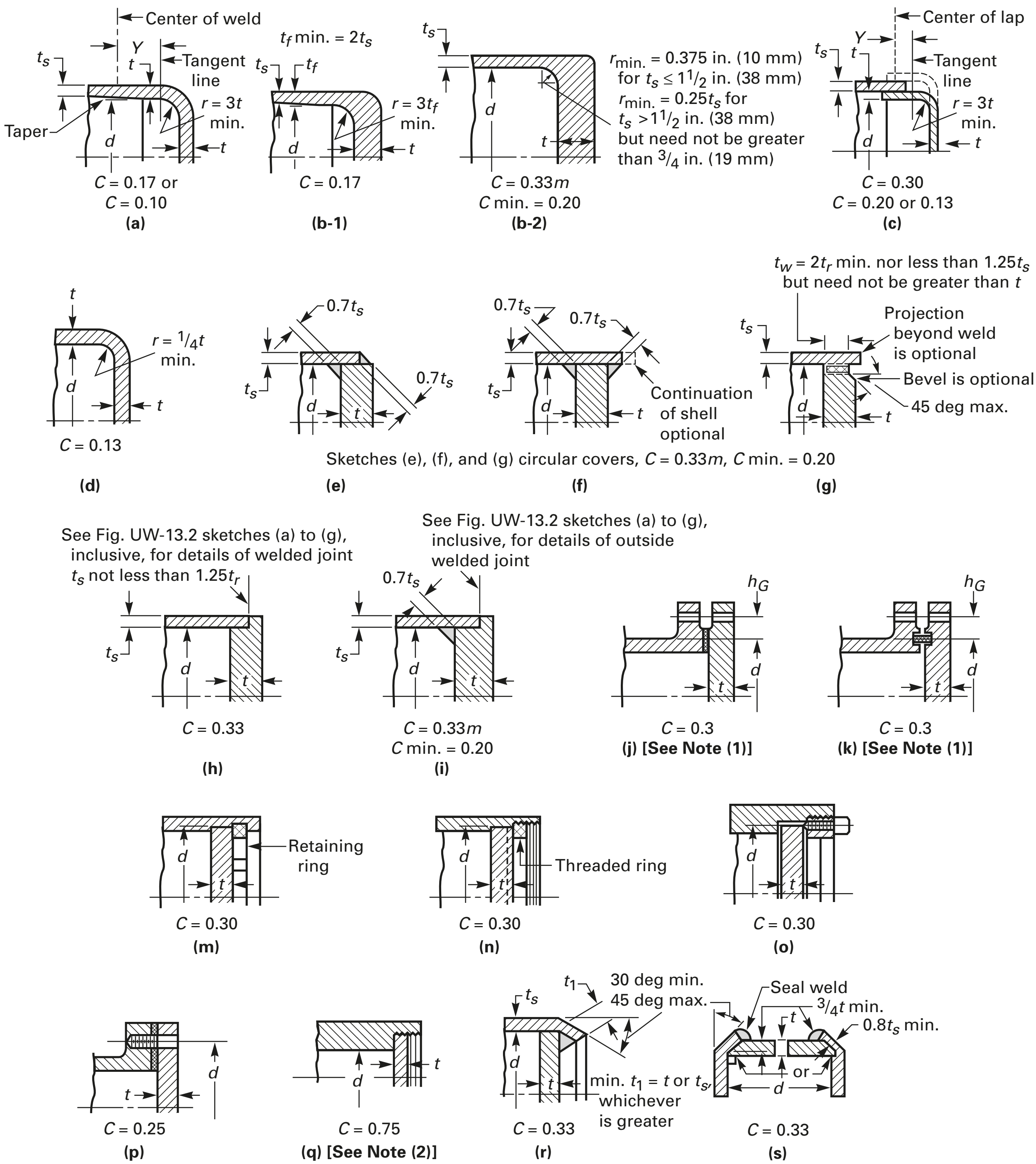
UG-34 UNSTAYED FLAT HEADS AND COVERS (19)

(a) The minimum thickness of unstayed flat heads, cover plates and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular[24] heads and covers. Some acceptable types of flat heads and covers are shown in Figure UG-34. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

(b) The symbols used in this paragraph and in Figure UG-34 are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d) below, dimensionless
D = long span of noncircular heads or covers measured perpendicular to short span
d = diameter, or short span, measured as indicated in Figure UG-34
E = joint efficiency, from Table UW-12, of any Category A weld as defined in UW-3(a)
h_G = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, as shown in Table 2-5.2
L = perimeter of noncircular bolted head measured along the centers of the bolt holes
m = the ratio t_r/t_s, dimensionless
P = internal design pressure (see UG-21)
r = inside corner radius on a head formed by flanging or forging
S = maximum allowable stress value in tension from applicable table of stress values referenced by UG-23
t = minimum required thickness of flat head or cover
t_1 = throat dimension of the closure weld, as indicated in Figure UG-34, sketch (r)
t_f = nominal thickness of the flange on a forged head, at the large end, as indicated in Figure UG-34, sketch (b)
t_h = nominal thickness of flat head or cover
t_r = required thickness of seamless shell, for pressure
t_s = nominal thickness of shell
t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Figure UG-34, sketch (g)
W = total bolt load given for circular heads for eqs. 2-5(e)(4) and 2-5(e)(5)
Y = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure UG-34, sketches (a) and (c), in. (mm)
Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span, as given in (c) below, dimensionless

Figure UG-34
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: The above sketches are diagrammatic only. Other designs that meet the requirements of UG-34 are acceptable.

NOTES:

(1) Use UG-34(c)(2) eq. (2) or UG-34(c)(3) eq. (5).

(2) When pipe threads are used, see Table UG-43.

(c) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements.[25]

(1) Circular blind flanges conforming to any of the flange standards listed in Table U-3 and further limited in UG-44(a) shall be acceptable for the diameters and pressure–temperature ratings in the respective standard when the blind flange is of the types shown in Figure UG-34, sketches (j) and (k).

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/SE} \tag{1}$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [sketches (j) and (k)] in which case the thickness shall be calculated by

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3} \tag{2}$$

When using eq. (2), the thickness t shall be calculated for both operating conditions and gasket seating, and the greater of the two values shall be used. For operating conditions, the value of P shall be the design pressure, and the values of S at the design temperature and W from eq. 2-5(e)(4) shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from eq. 2-5(e)(5) shall be used.

(3) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE} \tag{3}$$

where

$$Z = 3.4 - \frac{2.4d}{D} \tag{4}$$

with the limitation that Z need not be greater than two and one-half (2.5).

Equation (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [Figure UG-34, sketches (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/SE + 6Wh_G/SELd^2} \tag{5}$$

When using eq. (5), the thickness t shall be calculated in the same way as specified above for eq. (2)(2).

(d) For the types of construction shown in Figure UG-34, the minimum values of C to be used in eqs. (c)(2)(1), (c)(2)(2), (c)(3)(3), and (c)(3)(5) are:

(1) Sketch (a). C = 0.17 for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange, and where the welding meets all the requirements for circumferential joints given in Part UW.

C = 0.10 for circular heads, when the flange length for heads of the above design is not less than

$$Y = \left(1.1 - 0.8\frac{t_s^2}{t_h^2}\right)\sqrt{dt_h} \tag{6}$$

C = 0.10 for circular heads, when the flange length Y is less than the requirements in eq. (6) but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - Y/\sqrt{dt_h}} \tag{7}$$

for a length of at least $2\sqrt{dt_s}$.

When C = 0.10 is used, the taper shall be at least 1:3.

(2) Sketch (b-1). C = 0.17 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements for circumferential joints given in Part UW.

(3) Sketch (b-2). C = 0.33m but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than the following:

$$r_{min} = 0.375\text{ in. }(10\text{ mm})\text{ for } t_s \leq 1^1/_2\text{ in. }(38\text{ mm})$$

$$r_{min} = 0.25\,t_s \text{ for } t_s > 1^1/_2\text{ in. }(38\text{ mm})\text{ but need not be greater than } ^3/_4\text{ in. }(19\text{ mm})$$

The welding shall meet all the requirements for circumferential joints given in Part UW.

(4) Sketch (c). C = 0.13 for circular heads lap welded or brazed to the shell with corner radius not less than 3t and Y not less than required by eq. (1)(6) and the requirements of UW-13 are met.

C = 0.20 for circular and noncircular lap welded or brazed construction as above, but with no special requirement with regard to Y.

C = 0.30 for circular flanged plates screwed over the end of the vessel, with inside corner radius not less than 3t, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on a factor of safety of at least four, and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

(5) Sketch (d). C = 0.13 for integral flat circular heads when the dimension d does not exceed 24 in. (600 mm), the ratio of thickness of the head to the dimension d is not less than 0.05 or greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than $0.25t$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(6) Sketches (e), (f), and (g). $C = 0.33m$ but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

C = 0.33 for noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. The throat thickness of the fillet welds in sketches (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in sketch (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the sketch.

(7) Sketch (h). C = 0.33 for circular plates welded to the end of the shell when t_s is at least $1.25t_r$ and the weld details conform to the requirements of UW-13(e) and Figure UW-13.2, sketches (a) to (g) inclusive. See also UG-93(d)(3).

(8) Sketch (i). $C = 0.33m$ but not less than 0.20 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the outside weld conform to the requirements of UW-13(e) and Figure UW-13.2, sketches (a) to (g) inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b. See also UG-93(d)(3).

(9) Sketches (j) and (k). C = 0.3 for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that eq. (c)(2)(2) or (c)(3)(5) shall be used because of the extra moment applied to the cover by the bolting.

When the cover plate is grooved for a peripheral gasket, as shown in sketch (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

$$d\sqrt{1.9Wh_G/Sd^3}$$

for circular heads and covers, nor less than

$$d\sqrt{6Wh_G/SLd^2}$$

for noncircular heads and covers.

(10) Sketches (m), (n), and (o). C = 0.3 for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted with a factor of safety of at least four. Seal welding may be used, if desired.

(11) Sketch (p). C = 0.25 for circular and noncircular covers bolted with a full-face gasket, to shells, flanges or side plates.

(12) Sketch (q). C = 0.75 for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in. (300 mm); or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in. (300 mm); and when the design of the threaded joint, against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on a factor of safety of at least four. If a tapered pipe thread is used, the requirements of Table UG-43 shall also be met. Seal welding may be used, if desired.

(13) Sketch (r). C = 0.33 for circular plates having a dimension d not exceeding 18 in. (450 mm) inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

(14) Sketch (s). C = 0.33 for circular beveled plates having a diameter d not exceeding 18 in. (450 mm), inserted into a vessel, the end of which is crimped over at least 30 deg, but not more than 45 deg, and when the undercutting for seating leaves at least 80% of the shell thickness. The beveling shall be not less than 75% of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t_s/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = S/5d$ for Customary units ($P = 127S/d$ for SI units).

This construction is not permissible if machined from rolled plate.

UG-35 OTHER TYPES OF CLOSURES

UG-35.1 Dished Covers

Requirements for design of dished heads with bolting flanges are given in 1-6.

UG-35.2 Quick-Actuating Closures

(a) Definitions

(1) Quick-actuating closures are closures that are operated by an action that releases all holding elements.

(2) Holding elements are parts of the closure used to hold the cover to the vessel, and/or to provide the load required to seal the closure. Hinge pins or bolts may be used as holding elements.

(3) Locking elements are parts of the closure that prevent a reduction in the load on a holding element or prevent the release of a holding element. Locking elements may also be used as holding elements.

(4) The locking mechanism or locking device may consist of a combination of locking elements.

(b) General

(1) Quick-actuating closures shall be designed such that the locking elements are engaged prior to or upon application of pressure and remain engaged until the pressure is released.

(2) Quick-actuating closures shall be designed such that the failure of a single holding element while the vessel is pressurized (or contains a static head of liquid acting at the closure) will not

(-a) cause or allow the closure to be opened or leak; or

(-b) result in the failure of any locking element or other holding element; or

(-c) increase the stress in any other holding element by more than 50% above the allowable stress of the element

(3) Quick-actuating closures shall be designed and installed such that it may be determined by visual external observation that the holding elements are in satisfactory condition.

(4) Quick-actuating closures shall also be designed so that all locking elements can be verified to be fully engaged by visual observation or other means prior to the application of pressure to the vessel.

(5) When installed, all vessels having quick-actuating closures shall be provided with a pressure-indicating device visible from the operating area and suitable for detecting pressure at the closure.

(6) The use of a multilink component, such as a chain, is not permitted.

(7) When a quick-actuating closure is provided as a part, it shall be provided with a Partial Data Report as meeting the applicable requirements of this Division.

(8) Nonmandatory Appendix FF provides supplementary information for the Manufacturer of the pressure vessel and provides guidance on installation, operation, and maintenance for the owner and user.

(c) Specific Design Requirements

(1) Quick-actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism, and any closure that is other than manually operated, shall be so designed that when the vessel is installed the following conditions are met (see also Nonmandatory Appendix FF):

(-a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be applied in the vessel.

(-b) Pressure tending to force the closure open or discharge the vessel contents clear of the vessel shall be released before the closure can be fully opened for access.

(-c) In the event that compliance with (-a) and (-b) above is not inherent in the design of the closure and its holding elements, provisions shall be made so that devices to accomplish this can be added when the vessel is installed.

(2) The design rules of Mandatory Appendix 2 of this Division may not be applicable to the design of quick-actuating closures; see 2-1(e).

(3) The design shall consider the effects of cyclic and other loadings (see UG-22) and mechanical wear on the holding and locking elements and sealing surfaces.

(4) It is recognized that it is impractical to write requirements to cover the multiplicity of quick-actuating closures, or to prevent negligent operation or the circumventing of safety devices. Any device or devices that will provide the safeguards described in (1)(-a), (1)(-b), and (1)(-c) above will meet the intent of these rules.

(5) If clamps used in the design of quick-actuating closures meet the scope of Mandatory Appendix 24, then the requirements of Mandatory Appendix 24 shall also be met.

(6) The Manufacturer of a pressure vessel with a quick-actuating closure shall supply the user with an installation, operation, and maintenance manual that shall address the maintenance and operation of the closure. The manual should address the topics discussed in Nonmandatory Appendix FF. The intent is for this manual to stay with the owner or operator of the pressure vessel.

(d) Alternative Designs for Manually Operated Closures

(1) Quick-actuating closures that are held in position by a locking mechanism designed for manual operation shall be designed such that if an attempt is made to open the closure when the vessel is under pressure, the closure will leak prior to full disengagement of the locking elements and release of the closure. The design of the closure and vessel shall be such that any leakage shall be directed away from the normal position of the operator.

(2) Manually operated closures need not satisfy (c)(1)(-a), (c)(1)(-b), or (c)(1)(-c) above, but pressure vessels equipped with such closures shall be equipped with an audible or visible warning device that will warn the operator if pressure is applied to the vessel before the holding elements and locking elements are fully engaged in their intended position or if an attempt is made to disengage the locking mechanism before the pressure within the vessel is released.

(19) UG-35.3 Quick-Opening Closures

(a) Definitions

(1) Quick-opening closures are closures other than bolted flange joints as described in UG-44(a), 1-6, and Mandatory Appendix 2, and quick-actuating closures as described in UG-35.2. Closures utilizing a clamp design that meets the requirements of Mandatory Appendix 24 are exempt from the rules for quick-opening closures. Closures with multiple swing bolts are not considered quick-opening closures.

(2) Holding elements are parts of the closure used to hold the closure to the vessel, and/or to provide the load required to seal the closure. Hinge pins or bolts may be used as holding elements.

(b) General

(1) Quick-opening closures shall be designed such that the failure of a single holding element while the vessel is pressurized (or contains a static head of liquid acting at the closure) will not

(-a) cause or allow the closure to be opened or leak; or

(-b) increase the stress in any other holding element by more than 50% above the allowable stress of the element

(2) Quick-opening closures shall be designed and installed such that it can be determined by visual external observation that the holding elements are in satisfactory condition.

(3) All vessels having quick-opening closures shall have a pressure release device (e.g., vent valve, threaded plug) installed on the vessel that will relieve the pressure inside the vessel prior to opening the closure. Alternatively, if release of the product in the vessel could be dangerous to personnel or the environment, or could cause other safety issues, the provisions for pressure release need not be furnished when operating procedures are such that they can ensure there is no pressure in the vessel prior to opening the closure.

(4) When a quick-opening closure is provided as a part, it shall be provided with a Partial Data Report and shall meet the applicable requirements of this Division.

(5) Nonmandatory Appendix FF provides supplementary design information for the Manufacturer and provides guidance on installation, operation, and maintenance for the owner and user.

(c) Specific Design Requirements

(1) The design rules of Mandatory Appendix 2 of this Division may not be applicable to the design of quick-opening closures; see 2-1(e).

(2) The design shall consider the effects of cyclic and other loadings (see UG-22) and mechanical wear on the holding elements and the sealing surfaces.

(3) The Manufacturer of a pressure vessel with a quick-opening closure shall supply the user with an installation, operation, and maintenance manual that shall address the maintenance and operation of the closure. The manual should address the topics discussed in Nonmandatory Appendix FF. The intent is for this manual to stay with the owner or operator of the pressure vessel.

OPENINGS AND REINFORCEMENTS[26]

UG-36 OPENINGS IN PRESSURE VESSELS

(a) Shape of Opening [27]

(1) Openings in cylindrical or conical portions of vessels, or in formed heads, shall preferably be circular, elliptical, or obround.[28] When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(2) Openings may be of other shapes than those given in (1) above, and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy, or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in UG-101.

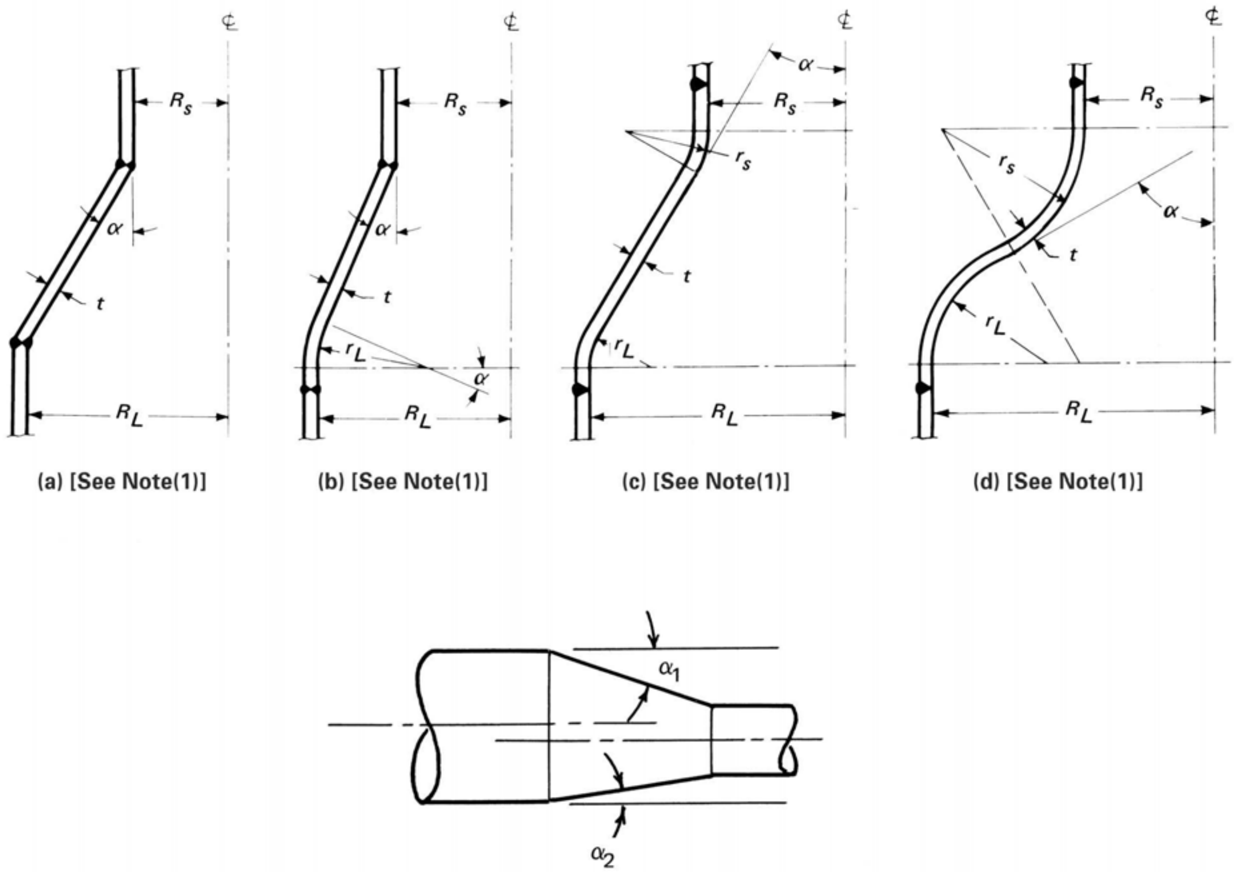
(b) Size of Openings

(1) Properly reinforced openings in cylindrical and conical shells are not limited as to size except with the following provisions for design. The rules in UG-36 through UG-43 apply to openings not exceeding the following: for vessels 60 in. (1 520 mm) inside diameter and less, one-half the vessel diameter, but not to exceed 20 in. (510 mm); for vessels over 60 in. (1 520 mm) inside diameter, one-third the vessel diameter, but not to exceed 40 in. (1 020 mm). (For conical shells, the inside shell diameter as used above is the cone diameter at the center of the opening.) For openings exceeding these limits, supplemental rules of 1-7 shall be satisfied in addition to the rules of this paragraph.

(2) Properly reinforced openings in formed heads and spherical shells are not limited in size. For an opening in an end closure, which is larger than one-half the inside diameter of the shell, one of the following alternatives to reinforcement may also be used:

(-a) a conical section as shown in Figure UG-36, sketch (a);

Figure UG-36
Large Head Openings — Reverse-Curve and Conical Shell-Reducer Sections



(a) [See Note(1)] (b) [See Note(1)] (c) [See Note(1)] (d) [See Note(1)]

(e) [See Note(2)]

NOTES:
(1) r_L shall not be less than the greater of $0.12(R_L + t)$ or $3t$: r_s has no dimensional requirement.
(2) $\alpha_1 > \alpha_2$; therefore, use α_1 in design equations.

(-b) a cone with a knuckle radius at the large end as shown in Figure UG-36, sketch (b);

(-c) a reverse curve section as shown in Figure UG-36, sketches (c) and (d); or

(-d) using a flare radius at the small end as shown in Figure UG-33.1, sketch (d).

The design shall comply with all the requirements of the rules for reducer sections [see (e) below] insofar as these rules are applicable.

(c) Strength and Design of Finished Openings

(1) All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, no metal added as corrosion allowance may be considered as reinforcement. The finished opening diameter is the diameter d as defined in UG-37 and in Figure UG-40.

(2) See below.

(-a) Openings in cylindrical or conical shells, or formed heads shall be reinforced to satisfy the requirements in UG-37 except as given in (3) below.

(-b) Openings in flat heads shall be reinforced as required by UG-39.

(3) Openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

(-a) welded, brazed, and flued connections meeting the applicable rules and with a finished opening not larger than:

(-1) $3^1/_2$ in. (89 mm) diameter — in vessel shells or heads with a required minimum thickness of $^3/_8$ in. (10 mm) or less;

(-2) $2^3/_8$ in. (60 mm) diameter — in vessel shells or heads over a required minimum thickness of $^3/_8$ in. (10 mm);

(-b) threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than 2$^3/_8$ in. (60 mm) diameter;

(-c) no two isolated unreinforced openings, in accordance with (-a) or (-b) above, shall have their centers closer to each other than the sum of their diameters;

(-d) no two unreinforced openings, in a cluster of three or more unreinforced openings in accordance with (-a) or (-b) above, shall have their centers closer to each other than the following:

for cylindrical or conical shells,

$$(1 + 1.5\cos\theta)(d_1 + d_2);$$

for doubly curved shells and formed or flat heads,

$$2.5(d_1 + d_2)$$

where

d_1, d_2 = the finished diameter of the two adjacent openings

θ = the angle between the line connecting the center of the openings and the longitudinal axis of the shell

The centerline of an unreinforced opening as defined in (-a) and (-b) above shall not be closer than its finished diameter to any material used for reinforcement of an adjacent reinforced opening.

(d) Openings Through Welded Joints. Additional provisions governing openings through welded joints are given in UW-14.

(e) Reducer Sections Under Internal Pressure

(1) The equations and rules of this paragraph apply to concentric reducer sections wherein all the longitudinal loads are transmitted wholly through the shell of the reducer. Where loads are transmitted in part or as a whole by other elements, e.g., inner shells, stays, or tubes, the rules of this paragraph do not apply.

(2) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable formula. In addition, provisions shall be made for any of the other loadings listed in UG-22, where such loadings are expected.

(3) The symbols defined in either UG-32(b) or below are used in this paragraph (see Figure UG-36).

t = minimum required thickness of the considered element of a reducer after forming

R_L = inside radius of larger cylinder

R_s = inside radius of smaller cylinder

r_L = inside radius of knuckle at larger cylinder

r_s = radius to the inside surface of flare at the small end

α = one-half of the included (apex) angle of a conical element

(4) Elements of a Reducer. A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of this paragraph are met.

(-a) Conical Shell Section. The required thickness of a conical shell section, or the allowable working pressure for such a section of given thickness, shall be determined by the equations given in UG-32(f).

(-b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of the appropriate equations and provisions of UG-32.

(5) Combination of Elements to Form a Reducer. When elements of (4) above, having different thicknesses are combined to form a reducer, the joints including the plate taper required by UW-9(c) shall lie entirely within the limits of the thinner element being joined.

(-a) A reducer may be a simple conical shell section, Figure UG-36, sketch (a), without knuckle, provided the half-apex angle α is not greater than 30 deg, except as provided for in 1-5(g). A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of 1-5.

(-b) A toriconical reducer, Figure UG-36, sketch (b), may be shaped as a portion of a toriconical head, UG-32(g), a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half-apex angle α is not greater than 30 deg, except as provided for in 1-5(g). A reinforcement ring shall be provided at the small end of the conical reducer element when required by the rules in 1-5.

(-c) Reverse curve reducers, Figure UG-36, sketches (c) and (d), may be shaped of elements other than those of (4) above. See U-2(g).

(f) Reducers Under External Pressure. The rules of UG-33(f) shall be followed, where applicable, in the design of reducers under external pressure.

(g) Oblique Conical Shell Sections Under Internal Pressure. A transition section reducer consisting of an oblique conical shell section may be used to join two cylindrical shell sections of different diameters and axes, provided the following requirements are used:

(1) The required thickness shall be determined by the equations given in UG-32(f).

(2) The angle α to be used shall be the largest included angle between the oblique cone and the attached cylindrical section [see Figure UG-36, sketch (e)] and shall not be greater than 30 deg, except as provided for in 1-5(g) (**19**)

(3) Diametrical dimensions to be used in the design equations shall be measured perpendicular to the axis of the cylinder to which the cone is attached.

(4) A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of 1-5.

UG-37 REINFORCEMENT REQUIRED FOR OPENINGS IN SHELLS AND FORMED HEADS

(a) Nomenclature. The symbols used in this paragraph are defined as follows:

A = total cross-sectional area of reinforcement required in the plane under consideration (see Figure UG-37.1) (includes consideration of nozzle area through shell if S_n/S_v < 1.0)

A_1 = area in excess thickness in the vessel wall available for reinforcement (see Figure UG-37.1) (includes consideration of nozzle area through shell if S_n/S_v < 1.0)

A_2 = area in excess thickness in the nozzle wall available for reinforcement (see Figure UG-37.1)

A_3 = area available for reinforcement when the nozzle extends inside the vessel wall (see Figure UG-37.1)

A_5 = cross-sectional area of material added as reinforcement (see Figure UG-37.1)

A_{41}, A_{42}, A_{43} = cross-sectional area of various welds available for reinforcement (see Figure UG-37.1)

c = corrosion allowance

D = inside shell diameter

D_p = outside diameter of reinforcing element (actual size of reinforcing element may exceed the limits of reinforcement established by UG-40; however, credit cannot be taken for any material outside these limits)

d = finished diameter of circular opening or finished dimension (chord length at midsurface of thickness excluding excess thickness available for reinforcement) of nonradial opening in the plane under consideration, in. (mm) [see Figures UG-37.1 and UG-40]

E = 1 (see definitions for t_r and t_{rn})

E_1 = 1 when an opening is in the solid plate or in a Category B butt joint; or
= 0.85 when an opening is located in an ERW or autogenously welded pipe or tube. If the ERW or autogenously welded joint is clearly identifiable and it can be shown that the opening does not pass through this weld joint, then E_1 may be determined using the other rules of this paragraph; or
= joint efficiency obtained from Table UW-12 when any part of the opening passes through any other welded joint

F = correction factor that compensates for the variation in internal pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Figure UG-37 may be used for integrally reinforced openings in cylindrical shells and cones. [See UW-16(c)(1).]

f_r = strength reduction factor, not greater than 1.0 [see UG-41(a)]

f_{r1} = S_n/S_v for nozzle wall inserted through the vessel wall
= 1.0 for nozzle wall abutting the vessel wall and for nozzles shown in Figure UG-40, sketch (j), (k), (n), and (o).

f_{r2} = S_n/S_v

f_{r3} = (lesser of S_n or S_p)/S_v

f_{r4} = S_p/S_v

h = distance nozzle projects beyond the inner surface of the vessel wall. (Extension of the nozzle beyond the inside surface of the vessel wall is not limited; however, for reinforcement calculations, credit shall not be taken for material outside the limits of reinforcement established by UG-40.)

K_1 = spherical radius factor (see definition of t_r and Table UG-37)

L = length of projection defining the thickened portion of integral reinforcement of a nozzle neck beyond the outside surface of the vessel wall [see Figure UG-40, sketch (e)]

P = internal design pressure (see UG-21), psi (MPa)

R = inside radius of the shell course under consideration

R_n = inside radius of the nozzle under consideration

S = allowable stress value in tension (see UG-23), psi (MPa). For welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85.

S_n = allowable stress in nozzle, psi (MPa) (see S above)

S_p = allowable stress in reinforcing element (plate), psi (MPa) (see S above)

S_v = allowable stress in vessel, psi (MPa) (see S above)

t = specified vessel wall thickness,[29] (not including forming allowances). For pipe it is the nominal thickness less manufacturing undertolerance allowed in the pipe specification.

t_e = thickness or height of reinforcing element (see Figure UG-40)

t_i = nominal thickness of internal projection of nozzle wall

t_n = nozzle wall thickness.[29] Except for pipe, this is the wall thickness not including forming allowances. For pipe, use the nominal thickness [see UG-16(d)].

t_r = required thickness of a seamless shell based on the circumferential stress, or of a formed head, computed by the rules of this Division for the designated pressure, using E = 1, and, for shells fabricated from welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85, except that

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by 1-4(d), using M = 1;

(b) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius K_1D, where D is the shell diameter and K_1 is given by Table UG-37.

t_{rn} = required thickness of a seamless nozzle wall, using E = 1, and, for nozzles fabricated from welded pipe or tubing, the allowable stress of the corresponding seamless product form. If there is no corresponding seamless product form, use the allowable stress for the welded product form divided by 0.85.

W = total load to be carried by attachment welds (see UG-41)

(b) General. The rules in this paragraph apply to all openings other than:

(1) small openings covered by UG-36(c)(3);

(2) openings in flat heads covered by UG-39;

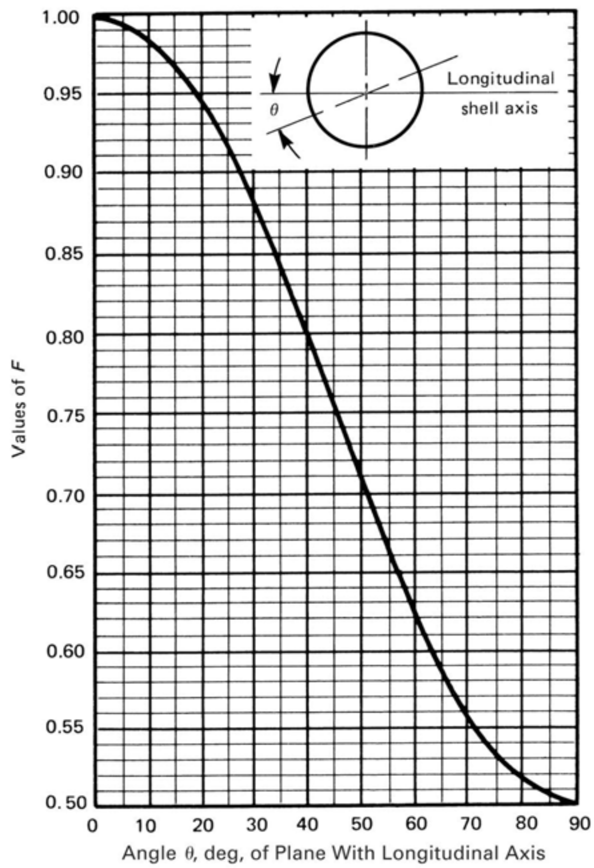
(3) openings designed as reducer sections covered by UG-36(e);

(4) large head openings covered by UG-36(b)(2);

(5) tube holes with ligaments between them conforming to the rules of UG-53.

Reinforcement shall be provided in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface. For a circular opening in a cylindrical shell, the plane containing the axis of the shell is the plane of greatest loading due to pressure. Not less than half the required reinforcement shall be on each side of the centerline of single openings.

Figure UG-37
Chart for Determining Value of *F*, as Required in UG-37



(c) Design for Internal Pressure. The total cross-sectional area of reinforcement A required in any given plane through the opening for a shell or formed head under internal pressure shall be not less than

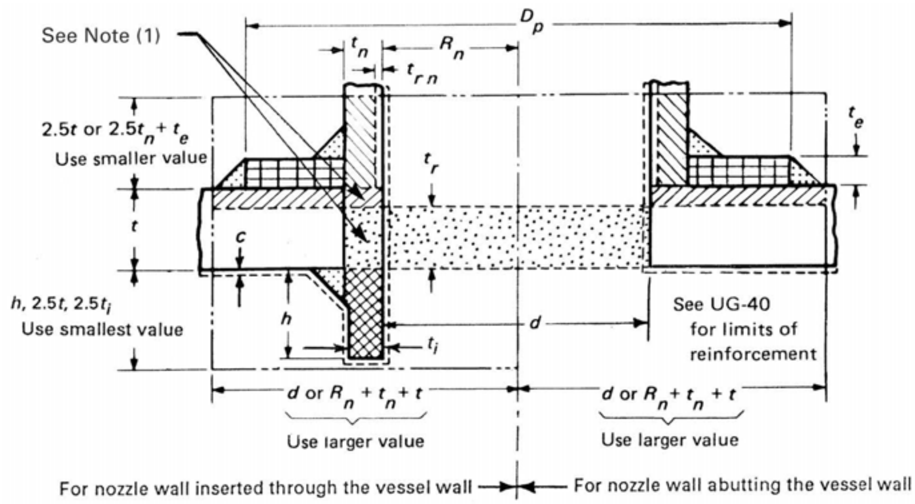
$$A = dt_rF + 2t_nt_rF\left(1 - f_{r1}\right)$$

(d) Design for External Pressure

(1) The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50% of that required in (c) above, where t_r is the wall thickness required by the rules for vessels under external pressure and the value of F shall be 1.0 in all external pressure reinforcement calculations.

(2) The reinforcement required for openings in each shell of a multiple-walled vessel shall comply with (1) above when the shell is subject to external pressure,

Figure UG-37.1
Nomenclature and Formulas for Reinforced Openings



Without Reinforcing Element

$= A = d\,t_r\,F + 2t_n\,t_r\,F(1 - f_{r1})$	Area required
$= A_1 \begin{cases} = d(E_1\,t - Ft_r) - 2t_n\,(E_1 t - Ft_r)\,(1 - f_{r1}) \\ = 2(t + t_n)(E_1 t - Ft_r) - 2t_n(E_1 t - Ft_r)(1 - f_{r1}) \end{cases}$	Area available in shell; use larger value
$= A_2 \begin{cases} = 5(t_n - t_{rn})\,f_{r2}t \\ = 5(t_n - t_{rn})\,f_{r2}t_n \end{cases}$	Area available in nozzle projecting outward; use smaller value
$= A_3 = 5t\,t_i\,f_{r2}$ $= 5t_i\,t_i\,f_{r2}$ $= 2h\,t_i\,f_{r2}$	Area available in inward nozzle; use smallest value
$= A_{41}$ = outward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in outward weld
$= A_{43}$ = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
If $A_1 + A_2 + A_3 + A_{41} + A_{43} \geqslant A$	Opening is adequately reinforced
If $A_1 + A_2 + A_3 + A_{41} + A_{43} < A$	Opening is not adequately reinforced so reinforcing elements must be added and/or thicknesses must be increased

With Reinforcing Element Added

A = same as A, above	Area required
A_1 = same as A_1, above	Area available
$A_2 \begin{cases} = 5(t_n - t_{rn})f_{r2}t \\ = 2(t_n - t_{rn})\,(2.5t_n + t_e)\,f_{r2} \end{cases}$	Area available in nozzle projecting outward; use smaller area
A_3 = same as A_3, above	Area available in inward nozzle
$= A_{41}$ = outward nozzle weld = $(\text{leg})^2 f_{r3}$	Area available in outward weld
$= A_{42}$ = outer element weld = $(\text{leg})^2 f_{r4}$	Area available in outer weld
$= A_{43}$ = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
$= A_5 = (D_p - d - 2t_n)\,t_e\;\;f_{r4}$ [Note (2)]	Area available in element
If $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geqslant A$	Opening is adequately reinforced

GENERAL NOTE: This figure illustrates a common nozzle configuration and is not intended to prohibit other configurations permitted by the Code.

NOTES:
(1) Includes consideration of these areas if S_n/S_v < 1.0 (both sides of centerline).
(2) This formula is applicable for a rectangular cross-sectional element that falls within the limits of reinforcement.

Table UG-37
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 NOTES:
(a) Equivalent spherical radius = K_1D; $D/2h$ = axis ratio.
(b) For definitions, see 1-4(b).
(c) Interpolation permitted for intermediate values.

and with (c) above when the shell is subject to internal pressure, regardless of whether or not there is a common nozzle secured to more than one shell by strength welds.

(e) Design for Alternate Internal and External Pressure. Reinforcement of vessels subject to alternate internal and external pressures shall meet the requirements of (c) above for internal pressure and of (d) above for external pressure.

(f) Details and equations for required area and available area are given in Figure UG-37.1.

(g) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one vent hole [maximum diameter $^7/_{16}$ in. (11 mm)] that may be tapped with straight or tapered threads. These vent holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

(h) Segmental reinforcing elements are allowed, provided the individual segments are joined by full penetration butt welds. These butt welds shall comply with all the applicable requirements of Part UW. Each segment of the reinforcing element shall have a vent hole as required by (g). Unless the provisions given below are satisfied, the area A_5 as defined in Figure UG-37.1 shall be multiplied by 0.75. The area A_5 does not require any reduction if one of the following is satisfied:

(1) Each butt weld is radiographed or ultrasonically examined to confirm full penetration, or

(2) For openings in cylinders, the weld is oriented at least 45 deg from the longitudinal axis of the cylinder.

(i) The reinforcement rules in this Division are applicable for internal or external pressure and do not address the requirements for openings under the action of externally applied loadings (such as pipe reactions). When externally applied loadings are to be considered, see U-2(g).

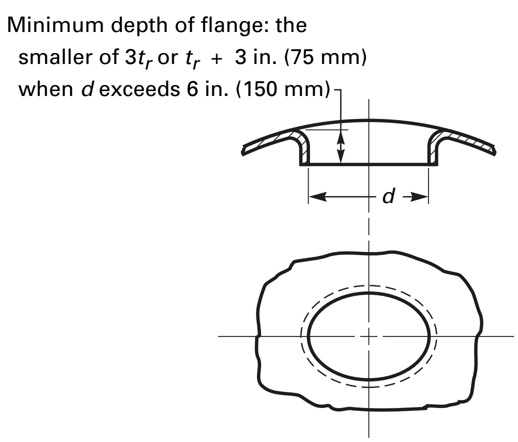
UG-38 FLUED OPENINGS IN SHELLS AND FORMED HEADS

(a) Flued openings in shells and formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in UG-37. The thickness of the flued flange shall also meet the requirements of UG-27 and/or UG-28, as applicable, where L as used in UG-28 is the minimum depth of flange as shown in Figure UG-38. The minimum thickness of the flued flange on a vessel subject to both internal and external pressure shall be the larger of the two thicknesses as determined above.

(b) The minimum depth of flange of a flued in opening exceeding 6 in. (150 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or (t_r + 3 in.) (for SI units, t_r + 75 mm), whichever is less, where t_r is the required shell or head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straightedge to the edge of the flanged opening (see Figure UG-38).

(c) There is no minimum depth of flange requirement for flued out openings.

Figure UG-38
Minimum Depth for Flange of Flued-In Openings



(d) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with UG-46(j).

(19) UG-39 REINFORCEMENT REQUIRED FOR OPENINGS IN FLAT HEADS AND COVERS

(a) General. The rules in this paragraph apply to all openings in flat heads except opening(s) that do not exceed the size and spacing limits in UG-36(c)(3) and do not exceed one-fourth the head diameter or shortest span. Electric immersion heater support plates (see 41-3) may be designed in accordance with the rules of this paragraph or Mandatory Appendix 41.

(b) Single and multiple openings in flat heads that have diameters equal to or less than one-half the head diameter may be reinforced as follows:

(1) Flat heads that have a single opening with a diameter that does not exceed one-half the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement for all planes through the center of the opening not less than that given by the formula

$$A = 0.5dt + tt_n\left(1 - f_{r1}\right)$$

where d, t_n, and f_{r1} are defined in UG-37 and t in UG-34.

(2) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced individually as required by (1) above when the spacing between any pair of adjacent openings is equal to or greater than twice the average diameter of the pair.

When spacing between adjacent openings is less than twice but equal to or more than $1\frac{1}{4}$ the average diameter of the pair, the required reinforcement for each opening in the pair, as determined by (1) above, shall be summed together and then distributed such that 50% of the sum is located between the two openings. Spacings of less than $1\frac{1}{4}$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

(3) Referencing Figure UG-39, sketch (a), the ligament between two adjacent openings (U_1, U_2, or U_3) shall not be less than one-quarter of the diameter of the smaller of the two openings in the pair. The radial distance between the inner edge of the opening (U_4, U_5, or U_6) and the dimension d as shown in Figure UG-34 and Figure UG-39, sketch (a) shall not be less than one-quarter of the diameter of that one opening.

(c) Flat heads that have an opening with a diameter that exceeds one-half the head diameter or shortest span, as defined in UG-34, shall be designed as follows:

(1) When the opening is a single, circular centrally located opening in a circular flat head, the head shall be designed according to Mandatory Appendix 14 and related factors in Mandatory Appendix 2. The head-to-shell junction may be integral, as shown in Figure UG-34, sketches (a), (b-1), (b-2), (d), and (g). The head may also be attached by a butt weld or a full-penetration corner weld similar to the joints shown in Figure UW-13.2, sketches (a), (b), (c), (d), (e), or (f). The large centrally located opening may have a nozzle that is integrally formed or integrally attached by a full penetration weld or may be plain without an attached nozzle or hub. The head thickness does not have to be calculated by UG-34 rules. The thickness that satisfies all the requirements of Mandatory Appendix 14 meets the requirements of the Code.

(2) Opening(s) may be located in the rim space surrounding the central opening. See Figure UG-39, sketch (b). Such openings may be reinforced by area replacement in accordance with the formula in (b)(1) above using as a required head thickness the thickness that satisfies rules of Mandatory Appendix 14. Multiple rim openings shall meet spacing rules of (b)(2) and (b)(3) above. Alternatively, the head thickness that meets the rules of Mandatory Appendix 14 may be increased by multiplying it by the square root of two (1.414) if only a single opening is placed in the rim space or if spacing p between two such openings is twice or more than their average diameter. For spacing less than twice their average diameter, the thickness that satisfies Mandatory Appendix 14 shall be divided by the square root of efficiency factor e, where e is defined in (e)(2) below.

The rim opening(s) shall not be larger in diameter than one-quarter the differences in head diameter less central opening diameter. The minimum ligament width U shall not be less than one-quarter the diameter of the smaller of the two openings in the pair. A minimum ligament width of one-quarter the diameter of the rim opening applies to ligaments designated as U_2, U_4, U_3, and U_5 in Figure UG-39, sketch (b).

(3) When the large opening is any other type than that described in (1) above, there are no specific rules given. Consequently, the requirements of U-2(g) shall be met.

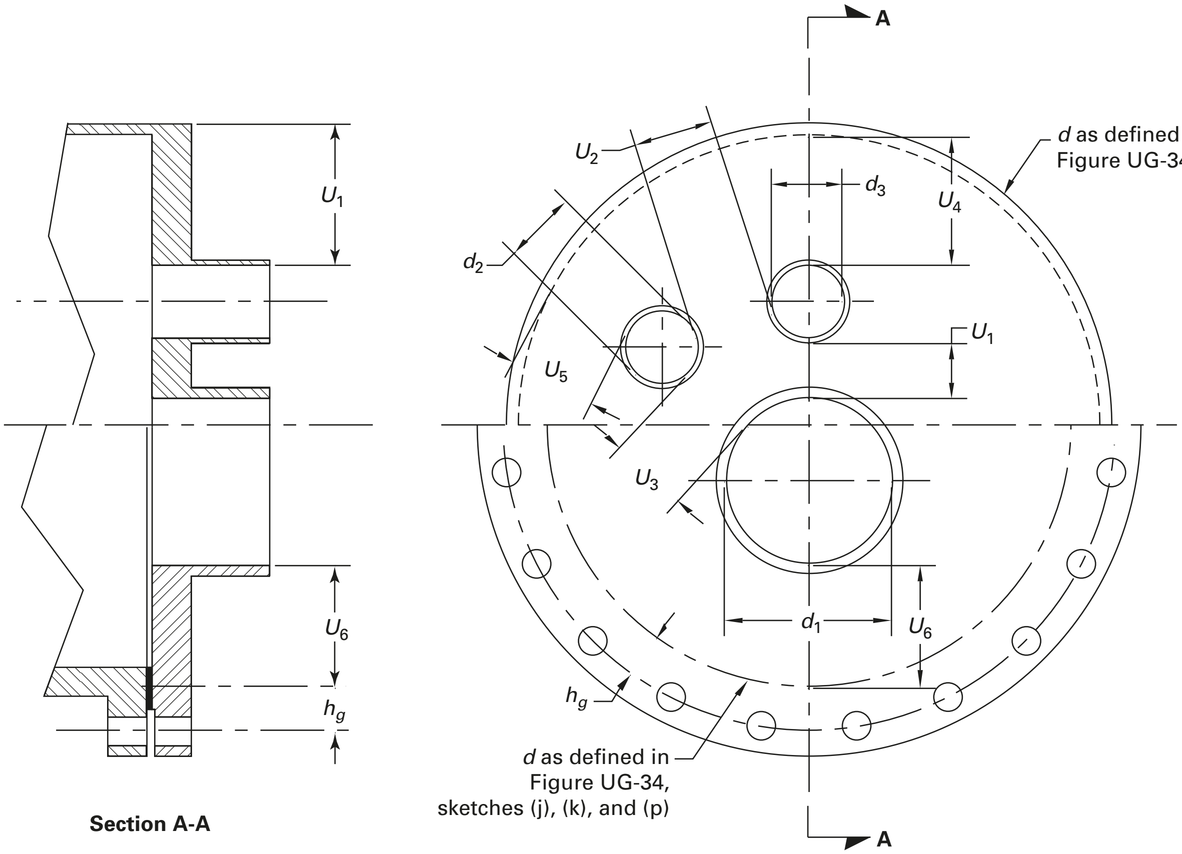
(d) As an alternative to (b)(1) above, the thickness of flat heads and covers with a single opening with a diameter that does not exceed one-half the head diameter may be increased to provide the necessary reinforcement as follows:

(1) In eq. UG-34(c)(2)(1) or eq. UG-34(c)(3)(3), use $2C$ or 0.75 in place of C, whichever is the lesser; except that, for sketches (b-1), (b-2), (e), (f), (g), and (i) of Figure UG-34, use $2C$ or 0.50, whichever is the lesser.

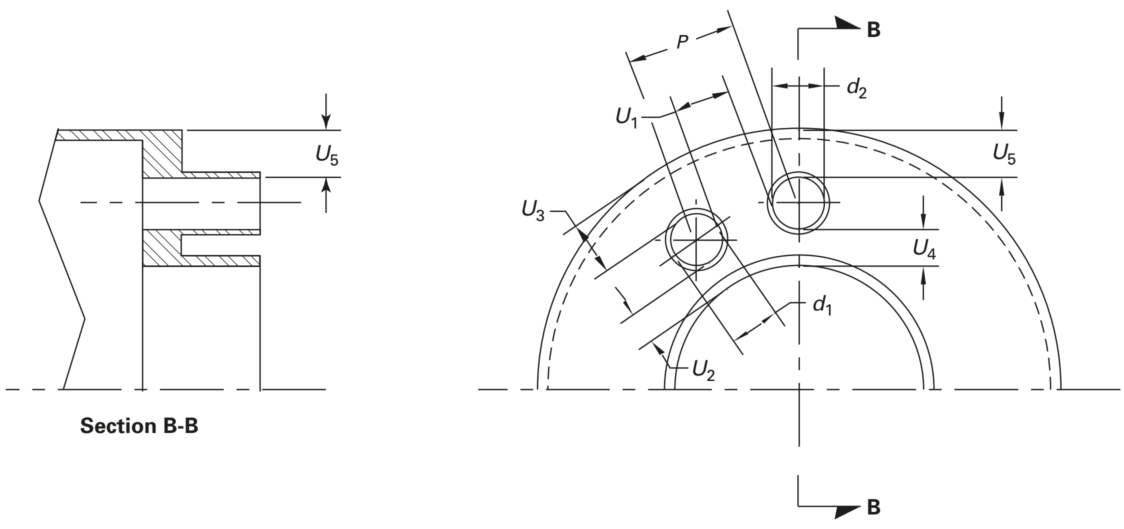
(2) In eq. UG-34(c)(2)(2) or eq. UG-34(c)(3)(5), double the quantity under the square root sign.

(19)

Figure UG-39
Openings in Flat Heads and Covers



(a)



(b)

Legend:

p = spacing, center-to-center, between openings
U_1, U_2,... = ligament width
$(d_1 + d_2)/2$ = average diameter of pair of openings

(e) Multiple openings none of which have diameters exceeding one-half the head diameter and no pair having an average diameter greater than one-quarter the head diameter may be reinforced as follows:

(1) When the spacing between a pair of adjacent openings is equal to or greater than twice the average diameter of the pair, and this is so for all opening pairs, the head thickness may be determined by rules in (d) above.

(2) When the spacing between adjacent openings in a pair is less than twice but equal to or greater than $1\frac{1}{4}$ the average diameter of the pair, the required head thickness shall be that determined by (d) above multiplied by a factor h, where

$$h = \sqrt{0.5 / e}$$

$$e = \left[(p - d_{\text{ave}})/p\right]_{\text{smallest}}$$

where

d_{ave} = average diameter of the same two adjacent openings

e = smallest ligament efficiency of adjacent opening pairs in the head

p = center-to-center spacing of two adjacent openings

(3) Spacings of less than $1\frac{1}{4}$ the average diameter of adjacent openings shall be treated by rules of U-2(g).

(4) In no case shall the width of ligament between two adjacent openings be less than one-quarter the diameter of the smaller of the two openings in the pair.

(5) The width of ligament between the edge of any one opening and the edge of the flat head (such as U_3 or U_5 in Figure UG-39) shall not be less than one-quarter the diameter of that one opening.

(19) UG-40 LIMITS OF REINFORCEMENT

(a) The boundaries of the cross sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal must be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane (see Figure UG-37.1). Figure UG-40 depicts thicknesses t, t_e, and t_n, or t_i and diameter d used in establishing the limits of reinforcement. All dimensions are in the corroded condition; for nomenclature, see UG-37(a).

(b) The limits of reinforcement, measured parallel to the vessel wall, shall be at a distance, on each side of the axis of the opening, equal to the greater of the following:

(1) the diameter d of the finished opening;

(2) the inside radius, R_n, of the nozzle plus the vessel wall thickness t, plus the nozzle wall thickness t_n.

(c) The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the smaller of the following:

(1) $2\frac{1}{2}$ times the vessel wall thickness t;

(2) $2\frac{1}{2}$ times the nozzle wall thickness t_n plus the thickness t_e as defined in Figure UG-40.

(d) Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

(1) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. the area in the vessel wall available as reinforcement is the larger of the values of A_1 given by the equations in Figure UG-37.1.

(2) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the smaller of the values of A_2 given by the equations in Figure UG-37.1.

All metal in the nozzle wall extending inside the vessel wall A_3 may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening:

(3) metal in attachment welds A_4 and metal added as reinforcement A_5.

(e) With the exception of studding outlet type flanges and the straight hubs of forged nozzle flanges [see UG-44(a)(10)], bolted flange material within the limits of reinforcement shall not be considered to have reinforcing value. With the exception of material within an integral hub, no material in a tubesheet or flat head shall be credited as reinforcement for an opening in an adjacent shell or head.

UG-41 STRENGTH OF REINFORCEMENT

(a) Material used for reinforcement shall have an allowable stress value equal to or greater than that of the material in the vessel wall, except that when such material is not available, lower strength material may be used, provided the area of reinforcement is increased in inverse proportion to the ratio of the allowable stress values of the two materials to compensate for the lower allowable stress value of the reinforcement. No credit may be taken for the additional strength of any reinforcement having a higher allowable stress value than that of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the

Figure UG-40
Some Representative Configurations Describing the Reinforcement Dimension t_e and the Opening Dimension d

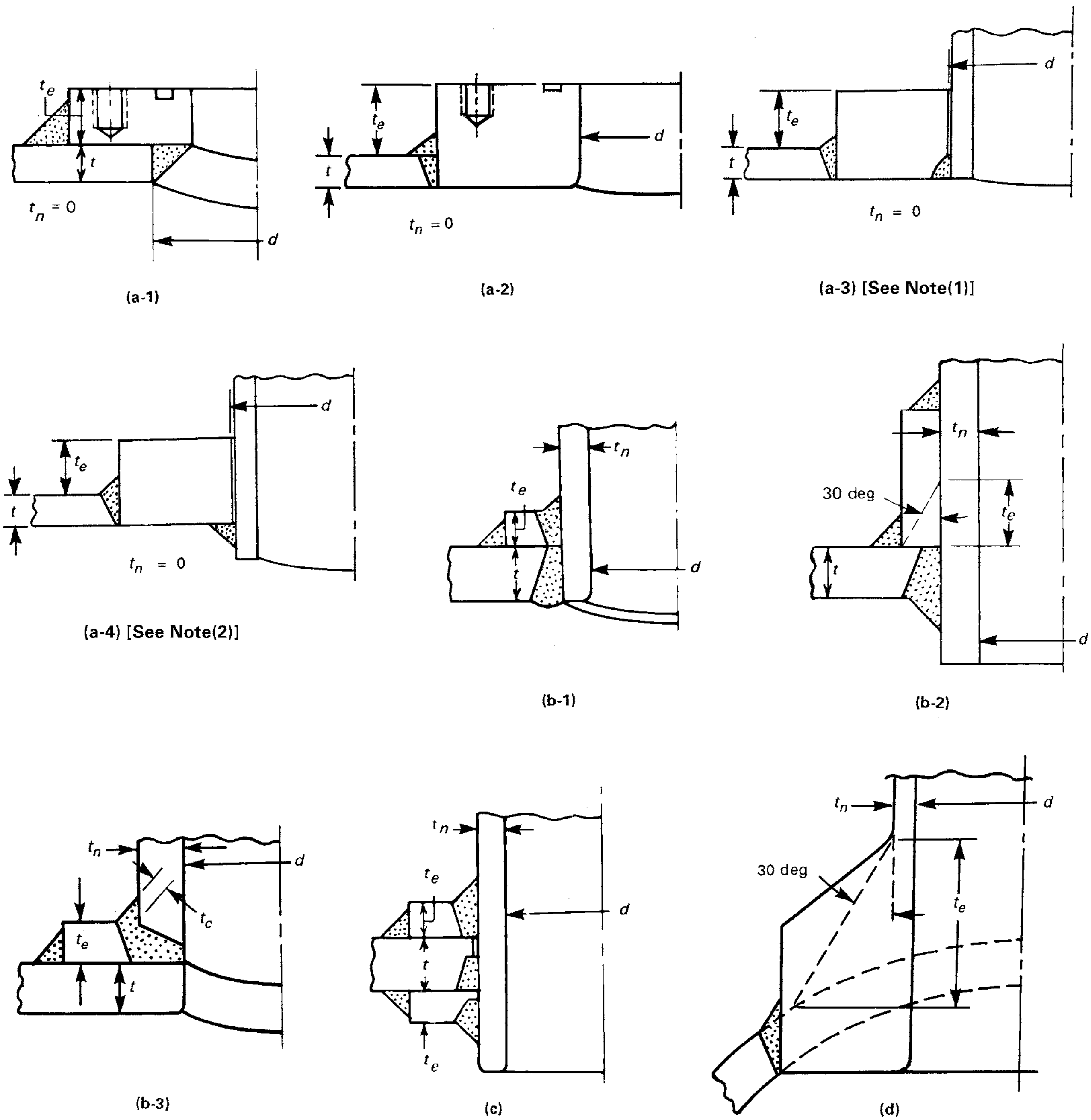
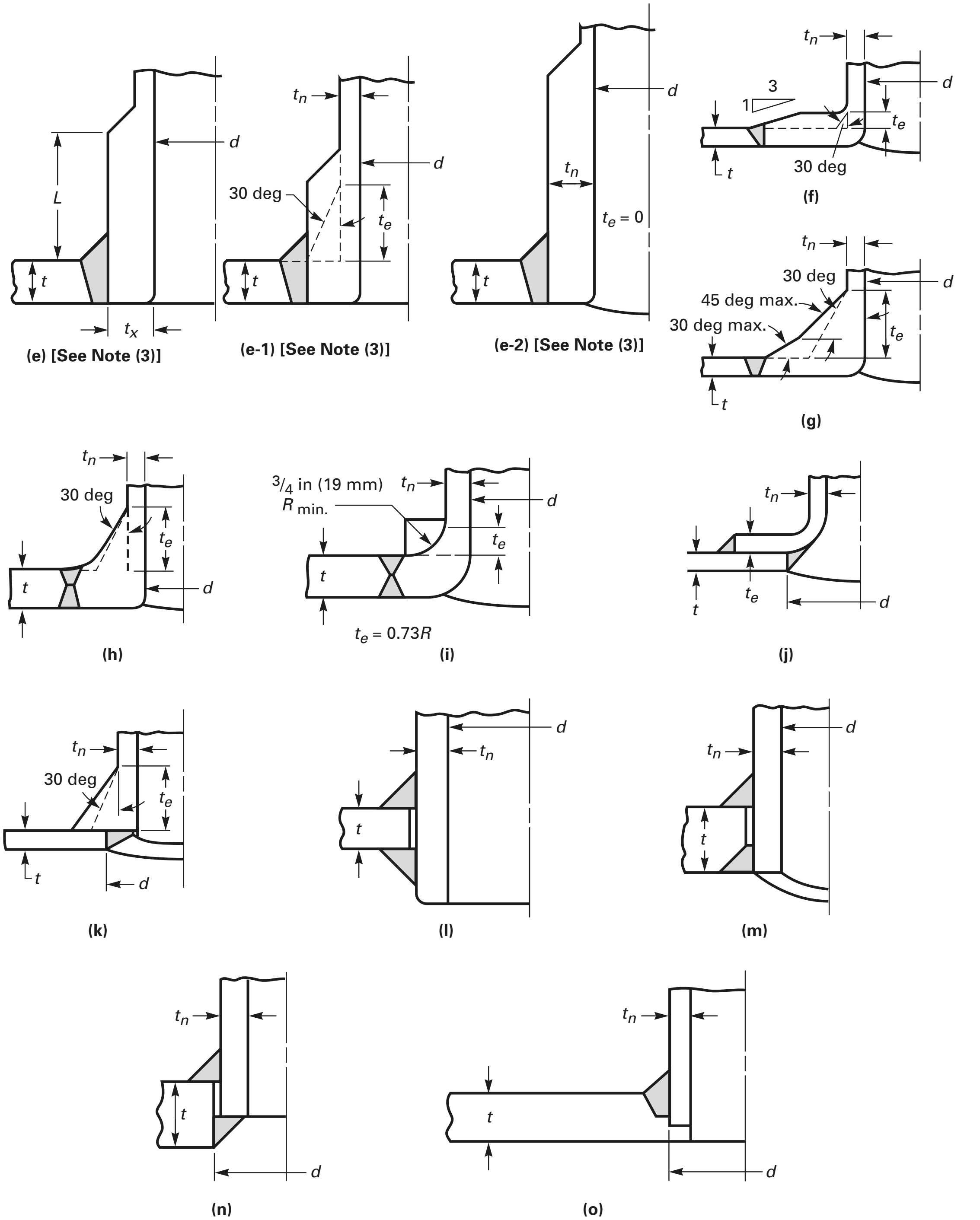


Figure UG-40
Some Representative Configurations Describing the Reinforcement Dimension t_e and the Opening Dimension d (Cont'd)



NOTES:

(1) See Figure UW-16.1, sketch (v-2) for limitations.

(2) See Figure UW-16.1, sketch (w-2) for limitations.

(3) If $L < 2.5t_x$, use sketch (e-1); if $L \geq 2.5t_x$, use sketch (e-2).

vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

(b) On each side of the plane defined in UG-40(a), the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the smaller of:

(1) the strength in tension of the cross section of the element or elements of reinforcement being considered (see $W_{1\text{-}1}$, $W_{2\text{-}2}$, and $W_{3\text{-}3}$ of Figure UG-41.1 for examples);

(2) the strength in tension of the area defined in UG-37 less the strength in tension of the reinforcing area that is integral in the vessel wall as permitted by UG-40(d)(1) (see W of Figure UG-41.1 for examples);

(3) for welded attachments, see UW-15 for exemptions to strength calculations.

(c) The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in UG-40. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening that passes through the center of the semicircular end of the opening.

(d) For detailed requirements for welded and brazed reinforcement see the appropriate paragraphs in the Parts devoted to these subjects (see UW-15 and UB-19).

UG-42 REINFORCEMENT OF MULTIPLE OPENINGS

(See UG-39 for multiple openings in flat heads.)

(a) When any two openings are spaced such that their limits of reinforcement overlap [see Figure UG-42, sketch (a)], the two openings shall be reinforced in the plane connecting the centers, in accordance with the rules of UG-37, UG-38, UG-40, and UG-41 with a combined reinforcement that has an area not less than the sum of the areas required for each opening. No portion of the cross section is to be considered as applying to more than one opening, nor to be considered more than once in a combined area.

(1) The available area of the head or shell between openings having an overlap area shall be proportioned between the two openings by the ratio of their diameters.

(2) For cylinders and cones, if the area of reinforcement between the two openings is less than 50% of the total required for the two openings, the supplemental rules of 1-7(a) and 1-7(c) shall be used.

(3) A series of openings all on the same centerline shall be treated as successive pairs of openings.

(b) When more than two openings are spaced as in (a) above [see Figure UG-42, sketch (b)], and are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall be $1^1/_3$ times their average diameter, and the area of reinforcement between any two openings shall be at least equal to 50% of the total required for the two openings. If the distance between centers of two such openings is less than $1^1/_3$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings. Such openings must be reinforced as described in (c) below.

(c) Alternatively, any number of adjacent openings, in any arrangement, may be reinforced by using an assumed opening enclosing all such openings. The limits for reinforcement of the assumed opening shall be those given in UG-40(b)(1) and UG-40(c)(1). The nozzle walls of the actual openings shall not be considered to have reinforcing value. For cylinders and cones, when the diameter of the assumed opening exceeds the limits in UG-36(b)(1), the supplemental rules of 1-7(a) and 1-7(c) shall also be used.

(d) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in UW-9(c).

(e) When a series of two or more openings in a cylindrical or conical shell are arranged in a regular pattern, reinforcement of the openings may be provided per the rules of ligaments in UG-53.

UG-43 METHODS OF ATTACHMENT OF PIPE AND NOZZLE NECKS TO VESSEL WALLS

(a) General. Nozzles may be attached to the shell or head of a vessel by any of the methods of attachment given in this paragraph, except as limited in UG-36.

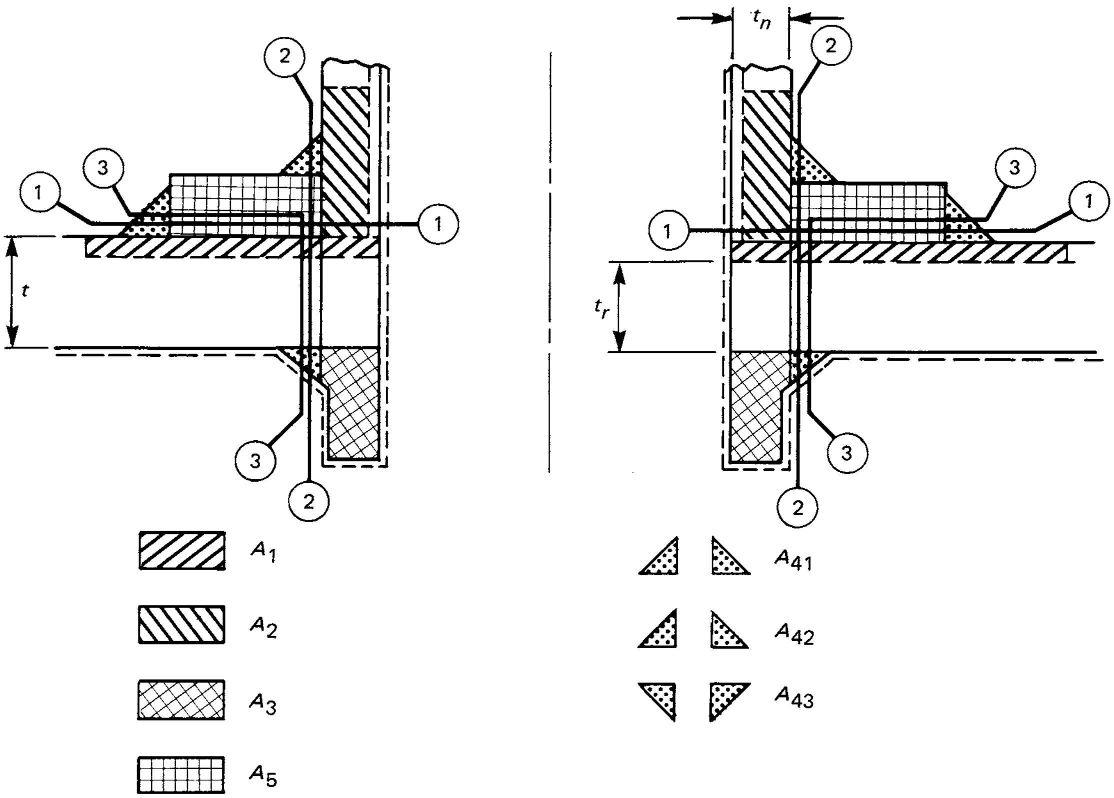
(b) Welded Connections. Attachment by welding shall be in accordance with the requirements of UW-15 and UW-16.

(c) Brazed Connections. Attachment by brazing shall be in accordance with the requirements of UB-17 through UB-19.

(d) Studded Connections. Connections may be made by means of studs. The vessel shall have a flat surface machined on the shell, or on a built-up pad, or on a properly attached plate or fitting. The distance from the inside surface of the vessel to the bottom of a drilled hole to be tapped shall not be less than the corrosion allowance plus one-fourth of the minimum required wall thickness. Weld metal may be added to the inside surface of the vessel to maintain this distance (see UW-42). The tapped holes shall also conform to the requirements of (g) below. Studded connections shall meet the requirements for reinforcement in UG-36 through UG-42.

(e) Threaded Connections. Pipes, tubes, and other threaded connections that conform to the ASME Standard for Pipe Threads, General Purpose, Inch (ASME B1.20.1) may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table UG-43 after allowance has been made for curvature of the vessel wall. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided. A built-up pad or a

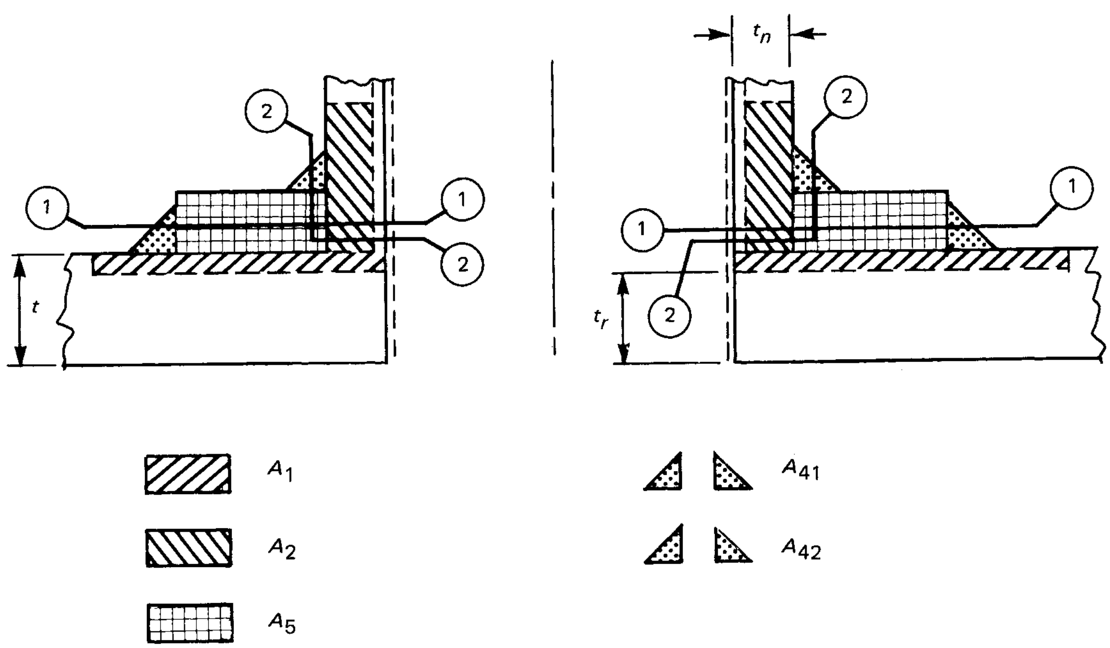
Figure UG-41.1
Nozzle Attachment Weld Loads and Weld Strength Paths to Be Considered



W = total weld load [UG-41(b)(2)]
$= [A - A_1 + 2t_n f_{r1}(E_1 t - F t_r)]S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
$= (A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
$= (A_2 + A_3 + A_{41} + A_{43} + 2t_n t f_{r1})S_v$
$W_{3\text{-}3}$ = weld load for strength path 3-3 [UG-41(b)(1)]
$= (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2t_n t f_{r1})S_v$

(a) Depicts Typical Nozzle Detail With Neck Inserted Through the Vessel Wall

Figure UG-41.1
Nozzle Attachment Weld Loads and Weld Strength Paths to Be Considered (Cont'd)



W = total weld load [UG-41(b)(2)]
= $(A - A_1)S_v$
$W_{1\text{-}1}$ = weld load for strength path 1-1 [UG-41(b)(1)]
= $(A_2 + A_5 + A_{41} + A_{42})S_v$
$W_{2\text{-}2}$ = weld load for strength path 2-2 [UG-41(b)(1)]
= $(A_2 + A_{41})S_v$

(b) Depicts Typical Nozzle Detail With Neck Abutting the Vessel Wall

GENERAL NOTES:
(a) Areas A_1, A_2, A_3, A_5, and A_{4i} are modified by f_{rx} factors.
(b) Nomenclature is the same as in UG-37 and Figure UG-37.1.

properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table UG-43, or to furnish reinforcement when required.

Threaded connections larger than 4 in. pipe size (DN 100) shall not be used in vessels that contain liquids having a flash point below 110°F (43°C), or flammable vapors, or flammable liquids at temperatures above that at which they boil under atmospheric pressure.

Threaded connections larger than 3 in. pipe size (DN 80) shall not be used when the maximum allowable working pressure exceeds 125 psi (0.8 MPa), except that this 3 in. pipe size (DN 80) restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes, or to integrally forged openings in vessel heads meeting the requirement of UF-43.

(f) Expanded Connections. A pipe, tube, or forging may be attached to the wall of a vessel by inserting through an unreinforced opening and expanding into the shell, provided the diameter is not greater than 2 in. pipe size (DN 50). A pipe, tube, or forging not exceeding 6 in. (150 mm) in outside diameter may be attached to the wall of a vessel by inserting through a reinforced opening and expanding into the shell.

Such connections shall be:

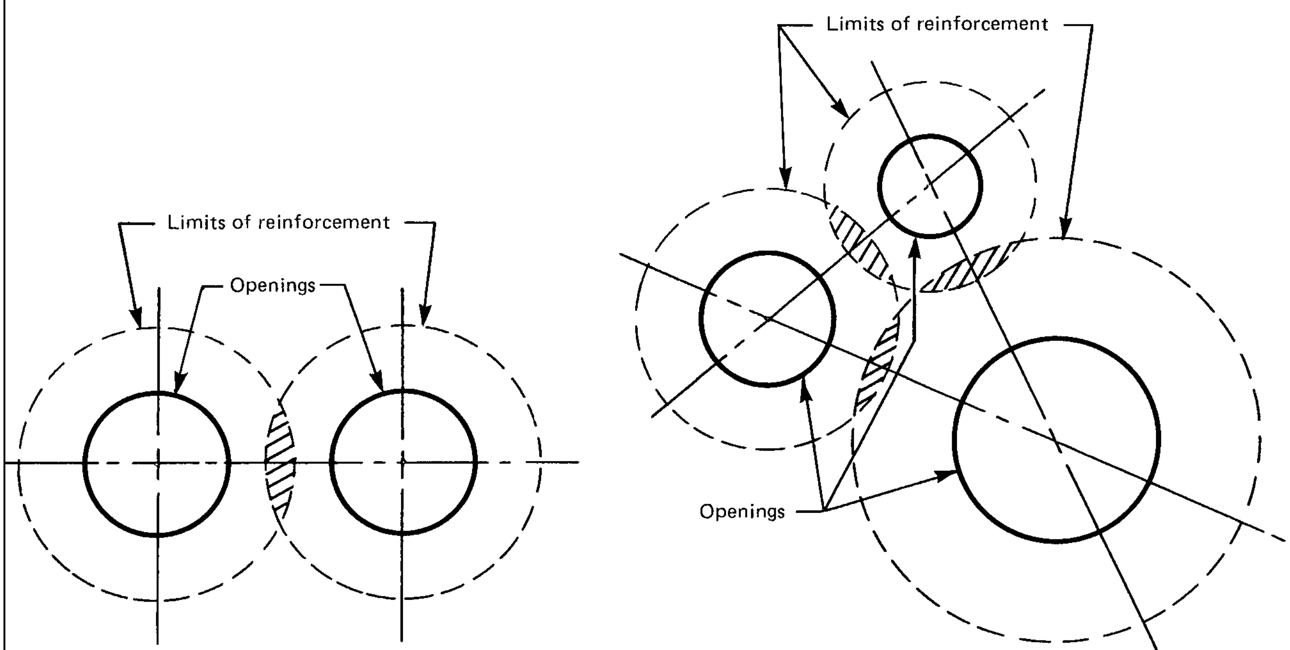
(1) firmly rolled in and beaded; or

(2) rolled in, beaded, and seal-welded around the edge of the bead; or

(3) expanded and flared not less than $^1/_8$ in. (3 mm) over the diameter of the hole; or

(4) rolled, flared, and welded; or

Figure UG-42
Examples of Multiple Openings



(a) Two Openings Spaced With Limits of Reinforcement Overlapping

(b) More Than Two Openings Spaced With Limits of Reinforcement Overlapping

Table UG-43
Minimum Number of Pipe Threads for Connections

Size of Pipe Connection, NPS (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
$^1/_2$ and $^3/_4$ (DN 15 and 20)	6	0.43 (11.0)
1, $1^1/_4$, and $1^1/_2$ (DN 25, 32, and 40)	7	0.61 (15)
2 (DN 50)	8	0.70 (18)
$2^1/_2$ and 3 (DN 65 and 80)	8	1.0 (25)
4–6 (DN 100–150)	10	1.25 (32)
8 (DN 200)	12	1.5 (38)
10 (DN 250)	13	1.62 (41)
12 (DN 300)	14	1.75 (45)

(5) rolled and welded without flaring or beading, provided:

(-a) the ends extend at least $\frac{1}{4}$ in. (6 mm), but no more than $\frac{3}{8}$ in. (10 mm), through the shell;

(-b) the throat of the weld is at least $\frac{3}{16}$ in. (5 mm), but no more than $\frac{5}{16}$ in. (8 mm).

When the tube or pipe does not exceed $1\frac{1}{2}$ in. (38 mm) in outside diameter, the shell may be chamfered or recessed to a depth at least equal to the thickness of the tube or pipe and the tube or pipe may be rolled into place and welded. In no case shall the end of the tube or pipe extend more than $\frac{3}{8}$ in. (10 mm) beyond the shell.

Grooving of shell openings in which tubes and pipe are to be rolled or expanded is permissible.

Expanded connections shall not be used as a method of attachment to vessels used for the processing or storage of flammable and/or noxious gases and liquids unless the connections are seal-welded.

(g) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75d_s \times \frac{\text{maximum allowable stress value of stud material at design temperature}}{\text{maximum allowable stress value of tapped material at design temperature}}$$

in which d_s is the nominal diameter of the stud, except that the thread engagement need not exceed $1\frac{1}{2}d_s$.

(19) UG-44 FLANGES AND PIPE FITTINGS

(a) The following standards covering flanges and pipe fittings are acceptable for use under this Division in accordance with the requirements of UG-11. Pressure–temperature ratings shall be in accordance with the appropriate standard except that the pressure–temperature ratings for ASME B16.9 and ASME B16.11 fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including the maximum allowable stress for the material. The thickness tolerance of the ASME standards shall apply.

(1) ASME B16.1, Gray Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250. Permitted only for pressure vessel parts used on pressure vessels constructed in accordance with Part UCI of this Division.

(2) ASME B16.5, Pipe Flanges and Flanged Fittings [see UG-11(a)(2)]

(3) ASME B16.9, Factory-Made Wrought Buttwelding Fittings

(4) ASME B16.11, Forged Fittings, Socket-Welding and Threaded

(5) ASME B16.15, Cast Bronze Threaded Fittings, Classes 125 and 250

(6) ASME B16.20, Metallic Gaskets for Pipe Flanges — Ring-Joint, Spiral-Wound, and Jacketed

(7) ASME B16.24, Cast Copper Alloy Pipe Flanges and Flanged Fittings, Class 150, 300, 400, 600, 900, 1500, and 2500

(8) ASME B16.42, Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300

(9) ASME B16.47, Large Diameter Steel Flanges, NPS 26 Through NPS 60

(10) A forged nozzle flange may use the ASME B16.5/B16.47 pressure–temperature ratings for the flange material being used, provided all of the following are met:

(-a) For ASME B16.5 applications, the forged nozzle flange shall meet all dimensional requirements of a flanged fitting given in ASME B16.5 with the exception of the inside diameter. The inside diameter of the forged nozzle flange shall not exceed the inside diameter of the same size lap joint flange given in ASME B16.5. For ASME B16.47 applications, the inside diameter shall not exceed the weld hub diameter A given in the ASME B16.47 tables.

(-b) For ASME B16.5 applications, the outside diameter of the forged nozzle neck shall be at least equal to the hub diameter of the same size and class ASME B16.5 lap joint flange. For ASME B16.47 applications, the outside diameter of the hub shall at least equal the X diameter given in the ASME B16.47 tables. Larger hub diameters shall be limited to nut stop diameter dimensions. See Figure 2-4, sketches (12) and (12a).

(b) External loads (forces and bending moments) may be evaluated for flanged joints with welding neck flanges chosen in accordance with (a)(2), (a)(9), and (a)(10), using the following requirements:

(1) The vessel MAWP (corrected for the static pressure acting on the flange) at the design temperature cannot exceed the pressure–temperature rating of the flange.

(2) The actual assembly bolt load (see Nonmandatory Appendix S) shall comply with ASME PCC-1, Nonmandatory Appendix O.

(3) The bolt material shall have an allowable stress equal to or greater than SA-193 B8 Cl. 2 at the specified bolt size and temperature.

(4) The combination of vessel MAWP (corrected for the static pressure acting on the flange) with external moment and external axial force shall satisfy the following equation (the units of the variables in this equation shall be consistent with the pressure rating):

$$16M_E + 4F_EG \leq \pi G^3\left[\left(P_R - P_D\right) + F_MP_R\right]$$

where

F_E = external tensile axial force
F_M = moment factor, in accordance with Table UG-44-1
G = gasket reaction diameter
M_E = external moment
P_D = vessel MAWP (corrected for static pressure acting on the flange) at design temperature
P_R = flange pressure rating at design temperature

UG-45 NOZZLE NECK THICKNESS

The minimum wall thickness of nozzle necks shall be determined as given below.

For access openings and openings used only for inspection:

$$t_{\text{UG-45}} = t_a$$

For other nozzles:

Determine t_b.

$$t_b = \min\left[t_{b3}, \max\left(t_{b1}, t_{b2}\right)\right]$$

$$t_{\text{UG-45}} = \max\left(t_a, t_b\right)$$

where

t_a = minimum neck thickness required for internal and external pressure using UG-27 and UG-28 (plus corrosion and threading allowance), as applicable. The effects of external forces and moments from supplemental loads (see UG-22) shall be considered. Shear stresses caused by UG-22 loadings shall not exceed 70% of the allowable tensile stress for the nozzle material.

t_{b1} = for vessels under internal pressure, the thickness (plus corrosion allowance) required for pressure (assuming E = 1.0) for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16(b).

t_{b2} = for vessels under external pressure, the thickness (plus corrosion allowance) obtained by using the external design pressure as an equivalent internal design pressure (assuming E = 1.0) in the formula for the shell or head at the location where the nozzle neck or other connection attaches to the vessel but in no case less than the minimum thickness specified for the material in UG-16(b).

t_{b3} = the thickness given in Table UG-45 plus the thickness added for corrosion allowance.

$t_{UG\text{-}45}$ = minimum wall thickness of nozzle necks

UG-46 INSPECTION OPENINGS[30]

(a) All pressure vessels for use with compressed air and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion (see UG-25), except as permitted otherwise in this paragraph, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

Compressed air as used in this paragraph is not intended to include air that has had moisture removed to provide an atmospheric dew point of −50°F (-46°C) or less.

Inspection openings may be omitted in vessels covered in (b), and in heat exchangers where the construction does not permit access to the shell side, such as fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers with Configuration a, b, or c as shown in Figure UHX-12.1 or Figure UHX-14.2. When inspection openings are not provided, the Manufacturer's Data Report shall include one of the following notations under "Remarks":

(1) "UG-46(b)" when telltale holes are used in lieu of inspection openings;

Table UG-44-1 Moment Factor, F_M (19)

Standard	Size Range	Flange Pressure Rating Class: 150	300	600	900	1500	2500
ASME B16.5	≤NPS 12	1.2	0.5	0.5	0.5	0.5	0.5
	>NPS 12 and ≤NPS 24	1.2	0.5	0.5	0.3	0.3	...
ASME B16.47							
Series A	All	0.6	0.1	0.1	0.1	...	...
Series B	<NPS 48	[Note (1)]	[Note (1)]	0.13	0.13	...	...
	≥NPS 48	0.1	[Note (2)]	...	...	...	...

GENERAL NOTES:
(a) The combinations of size ranges and flange pressure classes for which this Table gives no moment factor value are outside the scope of this Table.
(b) The designer should consider reducing the moment factor if the loading is primarily sustained in nature and the bolted flange joint operates at a temperature where gasket creep/relaxation will be significant.

NOTES:
(1) F_M = [0.1 + (48 − NPS)]/56.
(2) F_M = 0.1, except for NPS 60, Class 300, in which case F_M = 0.03.

Table UG-45
Nozzle Minimum Thickness Requirements

Nominal Size	Minimum Wall Thickness [See UG-16(d)] in.	mm
NPS $^1/_8$ (DN 6)	0.060	1.51
NPS $^1/_4$ (DN 8)	0.077	1.96
NPS $^3/_8$ (DN 10)	0.080	2.02
NPS $^1/_2$ (DN 15)	0.095	2.42
NPS $^3/_4$ (DN 20)	0.099	2.51
NPS 1 (DN 25)	0.116	2.96
NPS $1^1/_4$ (DN 32)	0.123	3.12
NPS $1^1/_2$ (DN 40)	0.127	3.22
NPS 2 (DN 50)	0.135	3.42
NPS $2^1/_2$ (DN 65)	0.178	4.52
NPS 3 (DN 80)	0.189	4.80
NPS $3^1/_2$ (DN 90)	0.198	5.02
NPS 4 (DN 100)	0.207	5.27
NPS 5 (DN 125)	0.226	5.73
NPS 6 (DN 150)	0.245	6.22
NPS 8 (DN 200)	0.282	7.16
NPS 10 (DN 250)	0.319	8.11
≥ NPS 12 (DN 300)	0.328	8.34

GENERAL NOTE: For nozzles having a specified outside diameter not equal to the outside diameter of an equivalent standard NPS (DN) size, the NPS (DN) size chosen from the table shall be one having an equivalent outside diameter larger than the nozzle outside diameter.

(2) "UG-46(a)" when inspection openings are omitted in fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers with Configuration a, b, or c as shown in Figure UHX-12.1 or Figure UHX-14.2;

(3) "UG-46(c)", "UG-46(d)", or "UG-46(e)" when provision for inspection is made in accordance with one of these paragraphs;

(4) the statement "for noncorrosive service."

(b) When provided with telltale holes complying with the provisions of UG-25, inspection openings as required in (a) above may be omitted in vessels not over 36 in. (900 mm) I.D. that are subject only to corrosion, provided that the holes are spaced one hole per 10 ft^2 (0.9 m^2) (or fraction thereof) of internal vessel surface area where corrosion is expected with a minimum of four uniformly spaced holes per vessel. This provision does not apply to vessels for compressed air.

(c) Vessels over 12 in. (300 mm) I.D. under air pressure that also contain, as an inherent requirement of their operation, other substances that will prevent corrosion need not have openings for inspection only, provided the vessel contains suitable openings through which inspection can be made conveniently, and provided such openings are equivalent in size and number to the requirements for inspection openings in (f) below.

(d) For vessels 12 in. (300 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS $^3/_4$ (DN 20).

(e) Vessels less than 16 in. (400 mm) and over 12 in. (300 mm) I.D. shall have at least two handholes or two threaded pipe plug inspection openings of not less than NPS $1^1/_2$ (DN 40) except as permitted by the following: when vessels less than 16 in. (400 mm) and over 12 in. (300 mm) I.D. are to be installed so that inspection cannot be made without removing the vessel from the assembly, openings for inspection only may be omitted, provided there are at least two removable pipe connections of not less than NPS $1^1/_2$ (DN 40).

(f) Vessels that require access or inspection openings shall be equipped as follows.[31]

(1) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) I.D. shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS $1^1/_2$ (DN 40).

(2) All vessels 18 in. (450 mm) to 36 in. (900 mm), inclusive, I.D. shall have a manhole or at least two handholes or two plugged, threaded inspection openings of not less than NPS 2 (DN 50).

(3) All vessels over 36 in. (900 mm) I.D. shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. × 6 in. (100 mm × 150 mm) or two equal openings of equivalent area.

(4) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(5) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings, provided they are equal at least to the size of the required inspection openings.

(6) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings, provided it is of such size and location as to afford at least an equal view of the interior.

(7) Flanged and/or threaded connections from which piping, instruments, or similar attachments can be removed may be used in place of the required inspection openings, provided that:

(-a) the connections are at least equal to the size of the required openings; and

(-b) the connections are sized and located to afford at least an equal view of the interior as the required inspection openings.

(g) When inspection or access openings are required, they shall comply at least with the following requirements:

(1) An elliptical or obround manhole shall be not less than 12 in. × 16 in. (300 mm × 400 mm). A circular manhole shall be not less than 16 in. (400 mm) I.D.

(2) A handhole opening shall be not less than 2 in. × 3 in. (50 mm × 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

(h) All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Division for openings.

(i) When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed in this Division for that material. The thread shall be a standard taper pipe thread except that a straight thread of at least equal strength may be used if other sealing means to prevent leakage are provided.

(j) Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $^{11}/_{16}$ in. (17 mm).

BRACED AND STAYED SURFACES

UG-47 BRACED AND STAYED SURFACES

(a) The minimum thickness and maximum allowable working pressure for braced and stayed flat plates and those parts that, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced, shall be calculated by the following equations:

$$t = p\sqrt{\frac{P}{SC}} \tag{1}$$

$$P = \frac{t^2 SC}{p^2} \tag{2}$$

where

C = 2.1 for welded stays or stays screwed through plates not over $^{7}/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.2 for welded stays or stays screwed through plates over $^{7}/_{16}$ in. (11 mm) in thickness with ends riveted over
= 2.5 for stays screwed through plates and fitted with single nuts outside of plate, or with inside and outside nuts, omitting washers; and for stays screwed into plates as shown in Figure UG-47, sketch (b)
= 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates or made a taper fit and having the heads formed on the stays before installing them, and not riveted over, said heads being made to have a true bearing on the plate
= 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than 0.4p and thickness not less than t

P = internal design pressure (see UG-21)

p = maximum pitch. The maximum pitch is the greatest distance between any set of parallel straight lines passing through the centers of staybolts in adjacent rows. Each of the three parallel sets running in the horizontal, the vertical, and the inclined planes shall be considered.

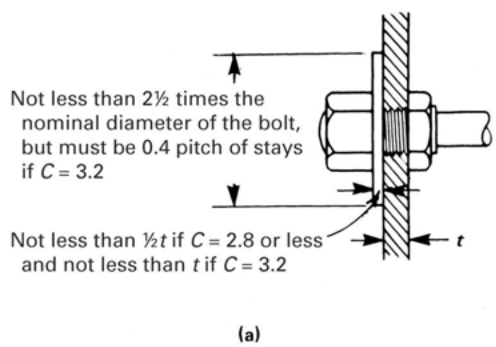
S = maximum allowable stress value in tension (see UG-23)

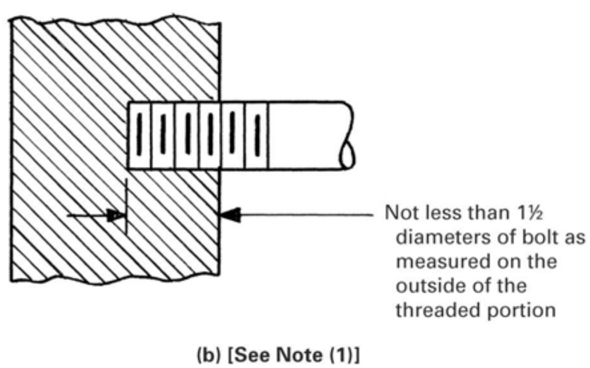
t = minimum thickness of plate

(b) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be $^{5}/_{16}$ in. (8 mm) except for welded construction covered by UW-19 or Mandatory Appendix 17.

(c) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given in (a) above, and shall also meet the applicable requirements

Figure UG-47
Acceptable Proportions for Ends of Stays





NOTE:
(1) See UG-83.

for shells or heads in UG-27(c) and UG-27(d) and UG-32. In addition, where any nozzle or other opening penetrates the cylindrical or spherical vessel, or completely covered head, and the jacket, the vessel or formed head shall be designed in accordance with UG-37(d)(2).

(d) When two plates are connected by stays and but one of these plates requires staying, the value of C shall be governed by the thickness of the plate requiring staying.

(e) Acceptable proportions for the ends of through stays with washers are indicated in Figure UG-47, sketch (a). See UG-83.

(f) The maximum pitch shall be $8^1/_2$ in. (220 mm), except that for welded-in staybolts the pitch may be greater, provided it does not exceed 15 times the diameter of the staybolt. See UW-19(a) for plate thicknesses greater than $^3/_4$ in. (19 mm).

(g) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

UG-48 STAYBOLTS

(a) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(b) The ends of steel stays upset for threading shall be fully annealed.

(c) Requirements for welded-in staybolts are given in UW-19.

UG-49 LOCATION OF STAYBOLTS

(a) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

UG-50 DIMENSIONS OF STAYBOLTS

(a) The required area of a staybolt at its minimum cross section[32] and exclusive of any allowance for corrosion shall be obtained by dividing the load on the staybolt computed in accordance with (b) below by the allowable stress value for the material used, as given inSubsection C, and multiplying the result by 1.10.

(b) Load Carried by Stays. The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable working pressure.

(c) Stays made of parts joined by welding shall be checked for strength using a joint efficiency of 60% for the weld.

LIGAMENTS

UG-53 LIGAMENTS

(a) The symbols used in the equations and charts of this paragraph are defined as follows:

d = diameter of tube holes
n = number of tube holes in length p_1
p = longitudinal pitch of tube holes
p_1 = unit length of ligament
p' = diagonal pitch of tube holes
s = longitudinal dimension of diagonal pitch
= $p' \cos \theta$
θ = angle of diagonal with longitudinal line, deg

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures UG-53.1 through UG-53.3, the efficiency of the ligaments between the tube holes shall be determined as follows:

(1) When the pitch of the tube holes on every row is equal (see Figure UG-53.1), the formula is

$$\frac{p-d}{p} = \text{efficiency of ligament}$$

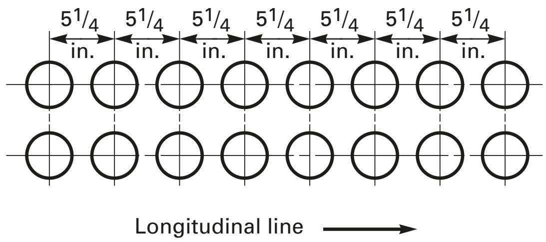
(2) When the pitch of tube holes on any one row is unequal (as in Figures UG-53.2 and UG-53.3), the formula is

$$\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}$$

(c) When the adjacent longitudinal rows are drilled as described in (b) above, diagonal and circumferential ligaments shall also be examined. The least equivalent longitudinal efficiency shall be used to determine the minimum required thickness and the maximum allowable working pressure.

(d) When a cylindrical shell is drilled for holes so as to form diagonal ligaments, as shown in Figure UG-53.4, the efficiency of these ligaments shall be determined by Figures UG-53.5 and UG-53.6. Figure UG-53.5 is used to determine the efficiency of longitudinal and diagonal ligaments with limiting boundaries where the condition of equal efficiency of diagonal and longitudinal ligaments form one boundary and the condition of equal efficiency of diagonal and circumferential ligaments form the other boundary. Figure UG-53.6 is used for determining the equivalent longitudinal efficiency of diagonal ligaments. This efficiency is used in the equations for setting the minimum required thickness and the maximum allowable working pressure.

Figure UG-53.1
Example of Tube Spacing With Pitch of Holes Equal in Every Row



GENERAL NOTE: $5^1/_4$ in. = 133 mm.

(e) Figure UG-53.5 is used when either or both longitudinal and circumferential ligaments exist with diagonal ligaments. To use Figure UG-53.5, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next find the vertical line in the diagram corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p_1. Then project this point horizontally to the left, and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The minimum shell thickness and the maximum allowable working pressure shall be based on the ligament that has the lower efficiency.

(f) Figure UG-53.6 is used for holes which are not in line, placed longitudinally along a cylindrical shell. The diagram may be used for pairs of holes for all planes between the longitudinal plane and the circumferential plane. To use Figure UG-53.6, determine the angle θ between the longitudinal shell axis and the line between the centers of the openings, θ, and compute the value of p'/d. Find the vertical line in the diagram corresponding to the value of θ and follow this line vertically to the line representing the value of p'/d. Then project this point horizontally to the left, and read the equivalent longitudinal efficiency of the diagonal ligament. This equivalent longitudinal efficiency is used to determine the minimum required thickness and the maximum allowable working pressure.

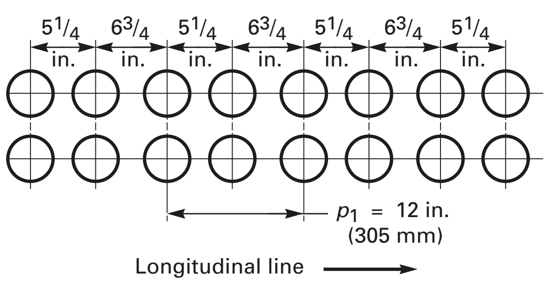
(g) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable working pressure is based.

(h) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both:[33]

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the inside diameter of the shell exceeds 60 in. (1 520 mm), the length shall be taken as 60 in. (1 520 mm) in applying this rule.

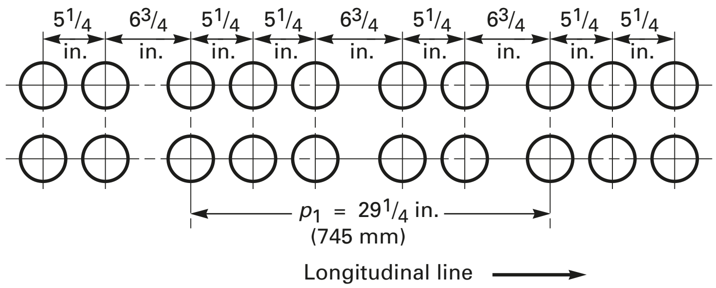
(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable working pressure is based. When

Figure UG-53.2
Example of Tube Spacing With Pitch of Holes Unequal in Every Second Row



GENERAL NOTE: $5^1/_4$ in. = 135 mm; $6^3/_4$ in. = 170 mm.

Figure UG-53.3
Example of Tube Spacing With Pitch of Holes Varying in Every Second and Third Row



GENERAL NOTE: $5^1/_4$ in. = 135 mm; $6^3/_4$ in. = 170 mm.

the inside radius of the shell exceeds 30 in. (760 mm), the length shall be taken as 30 in. (760 mm) in applying this rule.

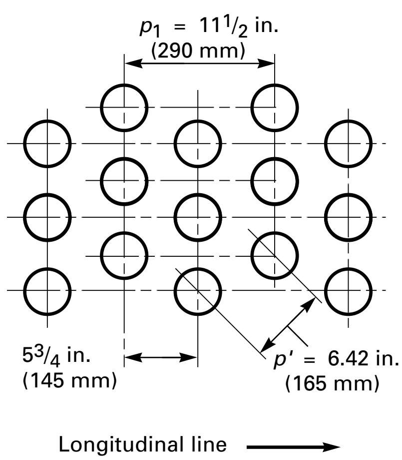
(i) When ligaments occur in cylindrical shells made from welded pipe or tubes, and their calculated efficiency is less than 85% (longitudinal) or 50% (circumferential), the efficiency to be used in the equations of UG-27 is the calculated ligament efficiency. In this case, the appropriate stress value in tension (see UG-23) may be multiplied by the factor 1.18.

UG-54 SUPPORTS

(a) All vessels shall be so supported and the supporting members shall be arranged and/or attached to the vessel wall in such a way as to provide for the maximum imposed loadings (see UG-22 and UG-82).

(b) Nonmandatory Appendix G contains suggested rules for the design of supports.

Figure UG-53.4
Example of Tube Spacing With Tube Holes on Diagonal Lines



UG-55 LUGS FOR PLATFORMS, LADDERS, AND OTHER ATTACHMENTS TO VESSEL WALLS

(a) Lugs or clips may be welded, brazed, or bolted to the outside or inside of the vessel to support ladders, platforms, piping, motor or machinery mounts, and attachment of insulating jackets (see UG-22). The material of the lugs or clips shall be in accordance with UG-4.

(b) External piping connected to a pressure vessel shall be installed so as not to overstress the vessel wall (see UG-22 and UG-82).

(c) Nonmandatory Appendix G provides guidance on the design of attachments.

FABRICATION

UG-75 GENERAL

The fabrication of pressure vessels and vessel parts shall conform to the general fabrication requirements in the following paragraphs and to the specific requirements for ULW-75 given in the applicable Parts of Subsections B and C.

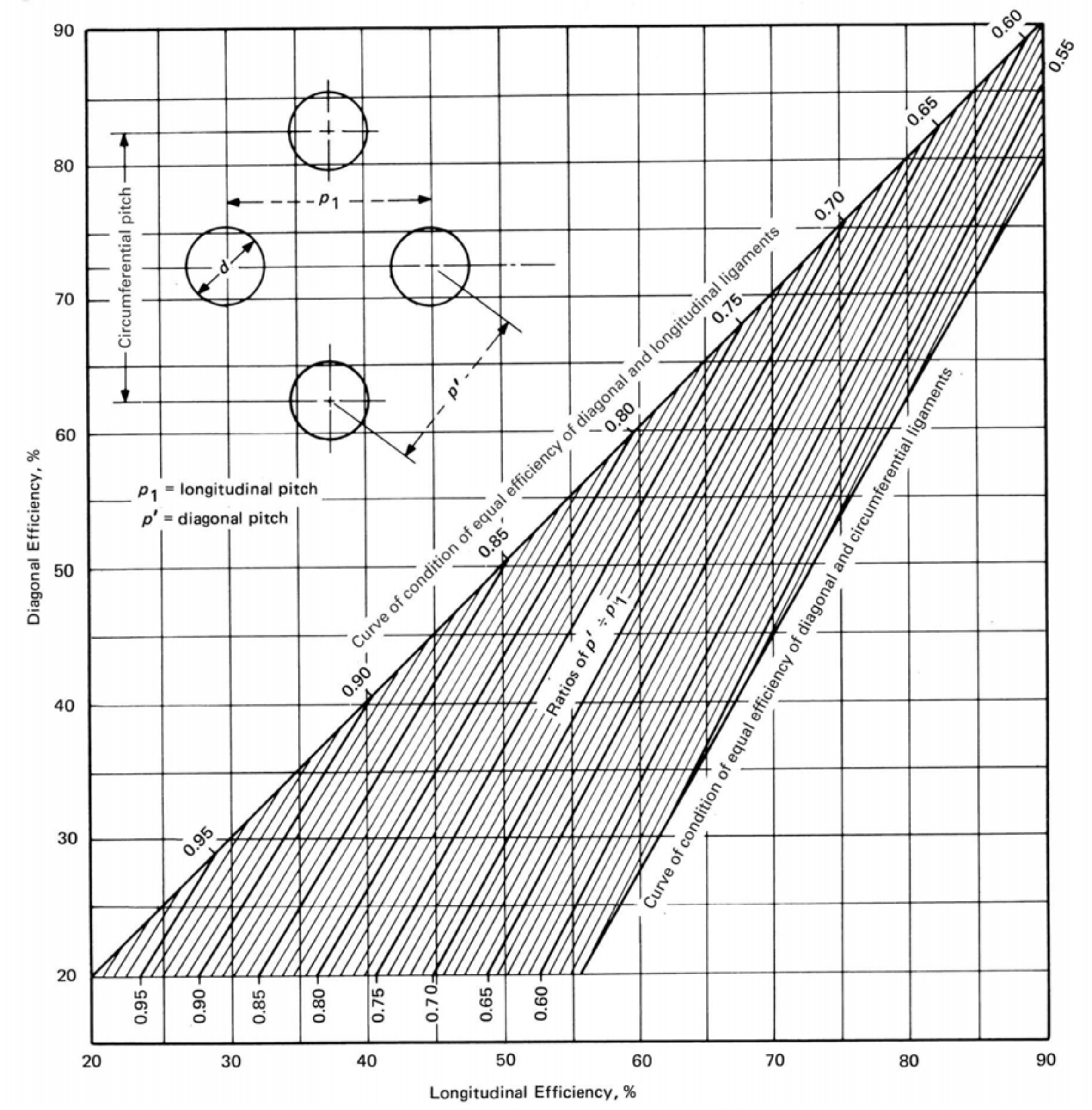
UG-76 CUTTING PLATES AND OTHER STOCK

(a) Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, grinding, or by oxygen or arc cutting. After oxygen or arc cutting, all slag and detrimental discoloration of material which has been molten shall be removed by mechanical means prior to further fabrication or use.

(b) Ends of nozzles or manhole necks which are to remain unwelded in the completed vessel may be cut by shearing, provided sufficient additional material is removed by any other method that produces a smooth finish.

(c) Exposed inside edges shall be chamfered or rounded.

Figure UG-53.5
Diagram for Determining the Efficiency of Longitudinal and Diagonal Ligaments Between Openings in Cylindrical Shells



GENERAL NOTES:

(a) Equations are provided for the user's option in (b), (c), and (d) below. The use of these equations is permitted for values beyond those provided by Figure UG-53.5.

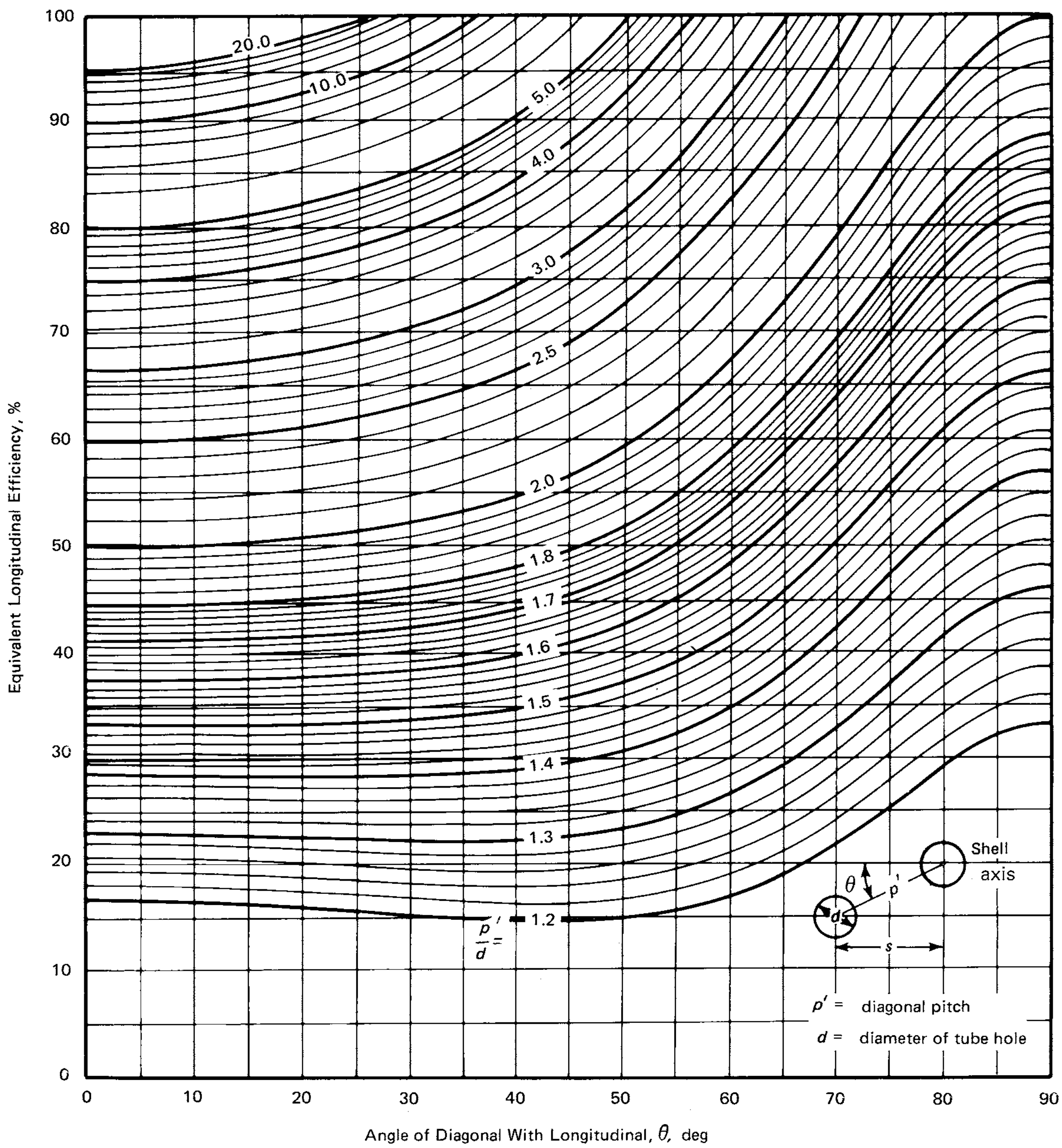
(b) Diagonal efficiency, $\% = \dfrac{J + 0.25 - \left(1 - 0.01E_{\text{long.}}\right)\sqrt{0.75 + J}}{0.00375 + 0.005J}$, where $J = (p'/p_1)^2$

(c) Curve of condition of equal efficiency of diagonal and circumferential ligaments, diagonal efficiency,

$\% = \dfrac{200M + 100 - 2\left(100 - E_{\text{long.}}\right)\sqrt{1 + M}}{(1 + M)}$, where $M = [(100 - E_{\text{long.}})/(200 - 0.5E_{\text{long.}})]^2$

(d) Longitudinal efficiency, $\% = E_{\text{long.}} = [(p_1 - d)/p_1]\ 100$

Figure UG-53.6
Diagram for Determining Equivalent Longitudinal Efficiency of Diagonal Ligaments Between Openings in Cylindrical Shells



GENERAL NOTE: The equation below is provided for the user's option. The use of the equation is prohibited beyond the range of the abscissa and ordinate shown.

$$\text{Equivalent longitudinal efficiency, \%} = \frac{\sec^2\theta + 1 - \left(\dfrac{\sec\theta}{p'/d}\right)\sqrt{3 + \sec^2\theta}}{0.015 + 0.005\sec^2\theta}$$

UG-77 MATERIAL IDENTIFICATION (SEE UG-85)

(a) Material for pressure parts preferably should be laid out so that when the vessel is completed, one complete set of the original identification markings required by UG-94 will be plainly visible. The pressure vessel Manufacturer shall maintain traceability of the material to the original identification markings by one or more of the following methods: accurate transfer of the original identification markings to a location where the markings will be visible on the completed vessel; identification by a coded marking traceable to the original required marking; or recording the required markings using methods such as material tabulations or as-built sketches that ensure identification of each piece of material during fabrication and subsequent identification in the completed vessel. Such transfers of markings shall be made prior to cutting except that the Manufacturer may transfer markings immediately after cutting, provided the control of these transfers is described in his written Quality Control System (see 10-6). Except as indicated in (b) below, material may be marked by any method acceptable to the Inspector. The Inspector need not witness the transfer of the marks but shall satisfy himself that it has been correctly done (see UHT-86).

(b) Where the service conditions prohibit die-stamping for material identification, and when so specified by the user, the materials manufacturer shall mark the required data on the plates in a manner which will allow positive identification upon delivery. The markings must be recorded so that each plate will be positively identified in its position in the completed vessel to the satisfaction of the Inspector. Transfer of markings for material that is to be divided shall be done as in (a) above.

(c) When material is formed into shapes by anyone other than the Manufacturer of the completed pressure vessel, and the original markings as required by the applicable material specification are unavoidably cut out, or the material is divided into two or more parts, the manufacturer of the shape shall either:

(1) transfer the original identification markings to another location on the shape; or

(2) provide for identification by the use of a coded marking traceable to the original required marking, using a marking method agreed upon and described in the Quality Control System of the Manufacturer of the completed pressure vessel.

Identification in accordance with UG-93, in conjunction with the above modified marking requirements, shall be considered sufficient to identify these shapes. Manufacturer's Partial Data Reports and parts stamping are not a requirement unless there has been fabrication to the shapes that include welding, except as exempted by UG-11.

UG-78 REPAIR OF DEFECTS IN MATERIALS

Defects in material may be repaired, provided acceptance by the Inspector is first obtained for the method and extent of repairs. Defective material that cannot be satisfactorily repaired shall be rejected.

UG-79 FORMING PRESSURE PARTS

(a) Limits are provided on cold working of all carbon and low alloy steels, nonferrous alloys, high alloy steels, and ferritic steels with tensile properties enhanced by heat treatment [see UCS-79(d), UNF-79(a), UHA-44(a), and UHT-79(a)]. Forming strains or extreme fiber elongation shall be determined by the equations in Table UG-79-1.

(b) If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical vessels shall first be shaped to the proper curvature by preliminary rolling or forming in order to avoid having objectionable flat spots along the completed joints (see UG-80).

(c) When the vessel shell section, heads, or other pressure boundary parts are cold formed by other than the manufacturer of the vessel, the required certification for the part shall indicate whether or not the part has been heat treated (see UCS-79, UHA-44, UNF-79, and UHT-79).

(d) A reduction in weld thickness due to a forming operation is acceptable, provided all of the following conditions are met:

(1) Prior to the forming operation, the weld(s) are verified to comply with UW-35(a) through UW-35(d) by the Manufacturer and the Inspector.

(2) The reduced weld thickness, at any point, shall not be less than the design thickness of the component.

(3) The reduction in thickness shall not exceed $^1/_{32}$ in. (1 mm) or 10% of the nominal thickness of the adjoining surface, whichever is less.

Table UG-79-1
Equations for Calculating Forming Strains

Type of Part Being Formed	Forming Strain
Cylinders formed from plate	$\varepsilon_f = \left(\frac{50t}{R_f}\right)\left(1 - \frac{R_f}{R_o}\right)$
For double curvature (e.g., heads)	$\varepsilon_f = \left(\frac{75t}{R_f}\right)\left(1 - \frac{R_f}{R_o}\right)$
Tube and pipe bends	$\varepsilon_f = \frac{100r}{R}$

GENERAL NOTE:
ε_f = calculated forming strain or extreme fiber elongation
R = nominal bending radius to centerline of pipe or tube
R_f = final mean radius
R_o = original mean radius, equal to infinity for a flat plate
r = nominal outside radius of pipe or tube
t = nominal thickness of the plate, pipe, or tube before forming

UG-80 PERMISSIBLE OUT-OF-ROUNDNESS OF CYLINDRICAL, CONICAL, AND SPHERICAL SHELLS

(a) Internal Pressure. The shell of a completed vessel shall be substantially round and shall meet the following requirements:

(1) The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (see Figure UG-80.2).

(2) When the cross section passes through an opening or within 1 I.D. of the opening measured from the center of the opening, the permissible difference in inside diameters given above may be increased by 2% of the inside diameter of the opening. When the cross section passes through any other location normal to the axis of the vessel, including head-to-shell junctions, the difference in diameters shall not exceed 1%.

For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

(b) External Pressure. The shell of a completed vessel to operate under external pressure shall meet the following requirements at any cross section:

(1) The out-of-roundness limitations prescribed in (a)(1) and (a)(2) above.

(2) The maximum plus-or-minus deviation from the true circular form, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation e obtained from Figure UG-80.1. Use $e = 1.0t$ or $e = 0.2t$, respectively, for points falling above or below these curves. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending upon where the measurements are taken) and a chord length equal to twice the arc length obtained from Figure UG-29.2. The values of L and D_o in Figures UG-29.2 and UG-80.1 shall be determined as follows:

(-a) for cylinders, L and D_o as defined in UG-28(b);

(-b) for cones and conical sections, L and D_o values to be used in the figures are given below in terms of the definitions given in UG-33(b). In all cases below,

$$L_e = 0.5L\left(1 + D_s/D_L\right)$$

(-1) at the large diameter end,

$$L = L_e$$

$$D_o = D_L$$

(-2) at the small diameter end,

$$L = L_e\left(D_L/D_s\right)$$

$$D_o = D_s$$

(-3) at the midlength diameter,

$$L = L_e[2D_L/(D_L + D_s)]$$

$$D_o = 0.5\left(D_L + D_s\right)$$

(-4) at any cross section having an outside diameter of D_x,

$$L = L_e(D_L/D_x)$$

$$D_o = D_x$$

(-c) for spheres, L is one-half of the outside diameter D_o.

(3) For cylinders and spheres, the value of t shall be determined as follows:

(-a) For vessels with butt joints, t is the nominal plate thickness less corrosion allowance.

(-b) For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is

$$t + e$$

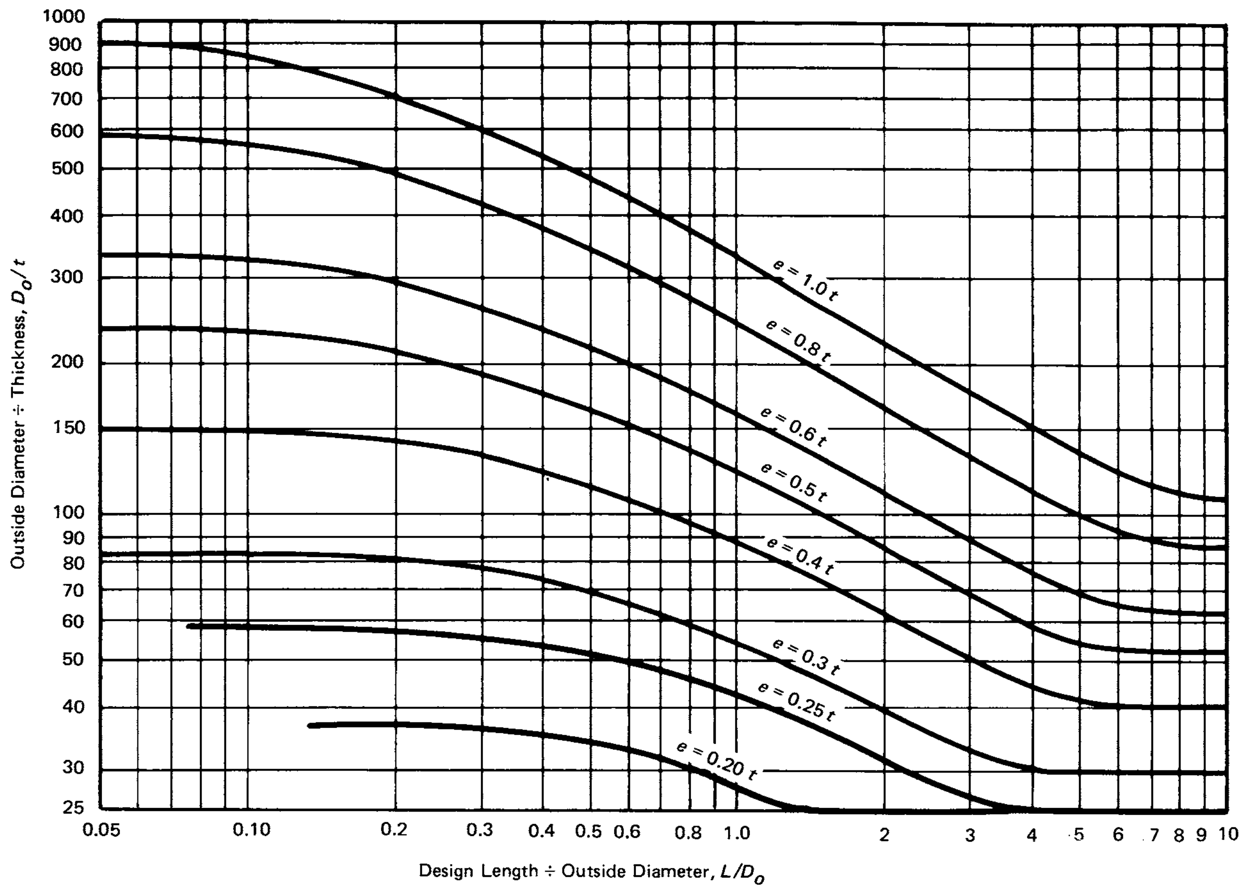
(-c) Where the shell at any cross section is made of plates having different thicknesses, t is the nominal thickness of the thinnest plate less corrosion allowance.

(4) For cones and conical sections, the value of t shall be determined as in (3) above, except that t in (3)(-a), (3)(-b), and (3)(-c) shall be replaced by t_e as defined in UG-33(b).

(5) The requirements of (2) above shall be met in any plane normal to the axis of revolution for cylinders and cones and in the plane of any great circle for spheres. For cones and conical sections, a check shall be made at locations (2)(-b)(-1), (2)(-b)(-2), and (2)(-b)(-3) above and such other locations as may be necessary to satisfy manufacturers and inspectors that requirements are met.

(6) Measurements shall be taken on the surface of the base metal and not on welds or other raised parts of the material.

Figure UG-80.1
Maximum Permissible Deviation From a Circular Form e for Vessels Under External Pressure

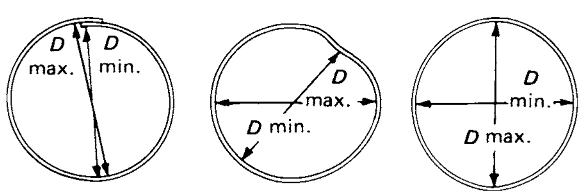


(7) The dimensions of a completed vessel may be brought within the requirements of this paragraph by any process which will not impair the strength of the material.

(8) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

(9) If the nominal thickness of plate used for a cylindrical vessel exceeds the minimum thickness required by UG-28 for the external design pressure, and if such excess thickness is not required for corrosion allowance or loadings causing compressive forces, the maximum permissible deviation e determined for the nominal plate thickness used may be increased by the ratio of factor B for the nominal plate thickness used divided by factor B for the minimum required plate thickness; and the chord length for measuring e_{max} shall be determined by D_o/t for the nominal plate thickness used.

Figure UG-80.2
Example of Differences Between Maximum and Minimum Inside Diameters in Cylindrical, Conical, and Spherical Shells



(c) Vessels and components fabricated of pipe or tube under internal or external pressure may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.

UG-81 TOLERANCE FOR FORMED HEADS

(a) The inner surface of a torispherical, toriconical, hemispherical, or ellipsoidal head shall not deviate outside of 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 the nominal inside diameter of the vessel shell at point of attachment. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than that specified.

(b) Hemispherical heads or any spherical portion of a torispherical or ellipsoidal head designed for external pressure shall, in addition to satisfying (a) above, meet the tolerances specified for spheres in UG-80(b) using a value of 0.5 for L/D_o.

(c) Measurements for determining the deviations specified in (a) above shall be taken from the surface of the base metal and not from welds.

(d) The skirts of heads shall be sufficiently true to round so that the difference between the maximum and minimum inside diameters shall not exceed 1% of the nominal diameter.

(e) When the skirt of any unstayed formed head is machined to make a driving fit into or over a shell, the thickness shall not be reduced to less than 90% of that required for a blank head (see UW-13) or the thickness of the shell at the point of attachment. When so machined, the transition from the machined thickness to the original thickness of the head shall not be abrupt but shall be tapered for a distance of at least three times the difference between the thicknesses.

UG-82 LUGS AND FITTING ATTACHMENTS

All lugs, brackets, saddle type nozzles, manhole frames, reinforcement around openings, and other appurtenances shall be formed and fitted to conform reasonably to the curvature of the shell or surface to which they are attached.

(a) When pressure parts, such as saddle type nozzles, manhole frames, and reinforcement around openings, extend over pressure-retaining welds, such welds shall be ground flush for the portion of the weld to be covered.

(b) When nonpressure parts, such as lugs, brackets, and support legs and saddles, extend over pressure-retaining welds, such welds shall be ground flush as described in (a) above, or such parts shall be notched or coped to clear those welds.

UG-83 HOLES FOR SCREW STAYS

Holes for screw stays shall be drilled full size or punched not to exceed $\frac{1}{4}$ in. (6 mm) less than full diameter of the hole for plates over $\frac{5}{16}$ in. (8 mm) in thickness and $\frac{1}{8}$ in. (3 mm) less than the full diameter of the hole for plates not exceeding $\frac{5}{16}$ in. (8 mm) in thickness, and then drilled or reamed to the full diameter. The holes shall be tapped fair and true with a full thread.

UG-84 CHARPY IMPACT TESTS

(a) General. Charpy V-notch impact tests in accordance with the provisions of this paragraph shall be made on weldments and all materials for shells, heads, nozzles, and other vessel parts subject to stress due to pressure for which impact tests are required by the rules in Subsection C.

(b) Test Procedures

(1) Impact test procedures and apparatus shall conform to the applicable paragraphs of SA-370 or ISO 148 (Parts 1, 2, and 3).

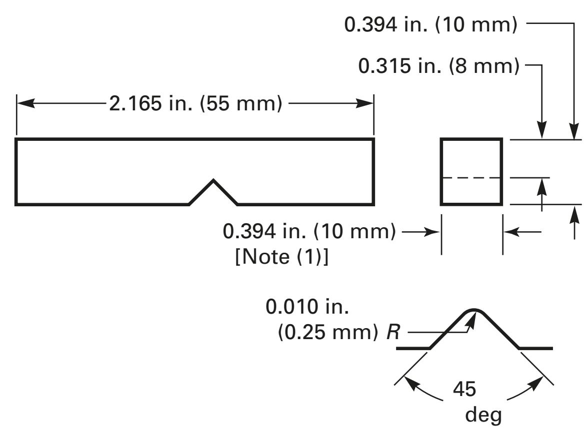
(2) Unless permitted by Table UG-84.4, impact test temperature shall not be warmer than the minimum design metal temperature [see UG-20(b)]. The test temperature may be colder than the minimum specified in the material specification of Section II.

(c) Test Specimens

(1) Each set of impact test specimens shall consist of three specimens.

(2) The impact test specimens shall be of the Charpy V-notch type and shall conform in all respects to Figure UG-84. The standard (10 mm × 10 mm) specimens, when obtainable, shall be used for nominal thicknesses of $\frac{7}{16}$ in. (11 mm) or greater, except as otherwise permitted in (-a) below.

Figure UG-84
Simple Beam Impact Test Specimens (Charpy Type Test)



NOTE:
(1) See UG-84(c) for thickness of reduced-size specimen.

(-a) For materials that normally have absorbed energy in excess of 180 ft-lbf (240 J) when tested using full size (10 mm × 10 mm) specimens at the specified testing temperature, subsize (10 mm × 6.7 mm) specimens may be used in lieu of full size specimens. However, when this option is used, the acceptance value shall be 75 ft-lbf (100 J) minimum for each specimen and the lateral expansion in mils (mm) shall be reported.

(3) For material from which full size (10 mm × 10 mm) specimens cannot be obtained, either due to the material shape or thickness, the specimens shall be either the largest possible standard subsize specimens obtainable or specimens of full material nominal thickness which may be machined to remove surface irregularities. [The test temperature criteria of (5)(-b) below shall apply for Table UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) when the width along the notch is less than 80% of the material nominal thickness.] Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. Toughness tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm).

(4) See below.

(-a) Except for materials produced and impact tested in accordance with the requirements in the specifications listed in General Note (c) of Figure UG-84.1, the applicable minimum energy requirement for all specimen sizes for Table UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) shall be that shown in Figure UG-84.1, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size (10 mm × 10 mm) specimen, except as otherwise provided in (2)(-a) above.

(-b) The applicable minimum lateral expansion opposite the notch for all specimen sizes for Table UCS-23 materials, having a specified minimum tensile strength of 95,000 psi (655 MPa) or more, shall be as required in UHT-6(a)(3) and UHT-6(a)(4). For UHT materials, all requirements of UHT-6(a)(3) and UHT-6(a)(4) shall apply. For Table UHA-23 materials, all requirements of UHA-51 shall apply.

(5) For all Charpy impact tests the following test temperature criteria shall be observed:

(-a) For Materials of Nominal Thickness Equal to or Greater Than 0.394 in. (10 mm). Where the largest obtainable Charpy V-notch specimen has a width along the notch of at least 0.315 in. (8 mm), the Charpy test using such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature.[34] Where the largest possible test specimen has a width along the notch less than 0.315 in. (8 mm), the test shall be conducted at a temperature lower than the minimum design metal temperature[34] by the amount shown in Table UG-84.2 for that specimen width. [This latter requirement does not apply when the option of (2)(-a) above is used.]

(-b) For Materials of Nominal Thickness Less Than 0.394 in. (10 mm). Where the largest obtainable Charpy V-notch specimen has a width along the notch of at least 80% of the material nominal thickness, the Charpy test of such a specimen shall be conducted at a temperature not warmer than the minimum design metal temperature.[34]

Where the largest possible test specimen has a width along the notch of less than 80% of the material nominal thickness, the test, for Table UCS-23 materials having specified minimum tensile strength of less than 95,000 psi (655 MPa), shall be conducted at a temperature lower than the minimum design metal temperature[34] by an amount equal to the difference (referring to Table UG-84.2) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested. [This latter requirement does not apply when the option of (2)(-a) above is used.] For Table UCS-23 materials having a specified minimum tensile strength of 95,000 psi (655 MPa) and over, for Table UHT-23 materials, and for Table UHA-23 materials, the test shall be conducted at a temperature not warmer than the minimum design temperature.

(6) When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

When an erratic result is caused by a defective specimen or there is uncertainty in test procedure, a retest will be allowed. When the option of (2)(-a) above is used for the initial test and the acceptance value of 75 ft-lbf (100 J) minimum is not attained, retest using full size (10 mm × 10 mm) specimens will be allowed.

(d) Impact Tests of Material

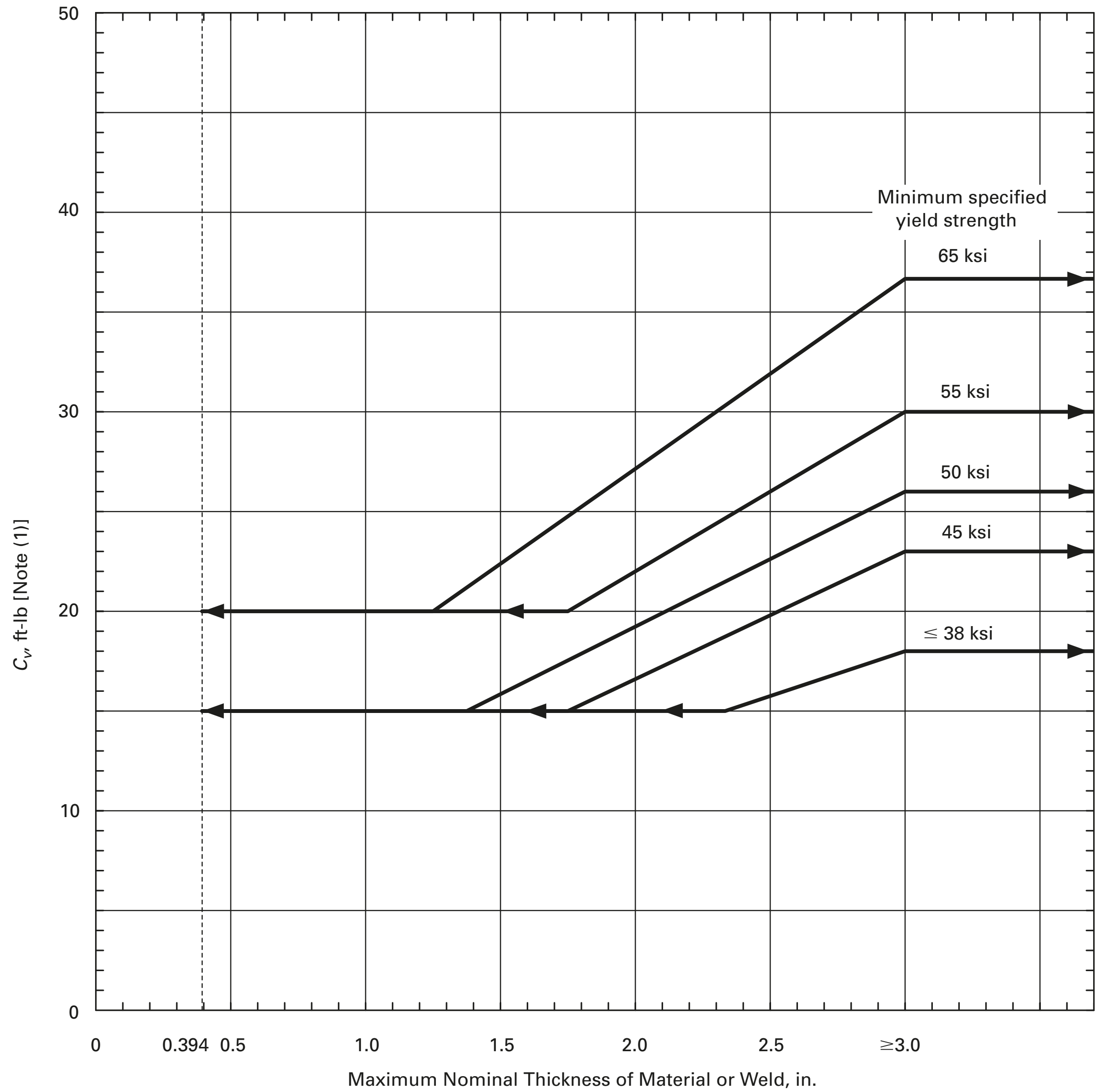
(1) Reports or certificates of impact tests by the material manufacturer will be acceptable evidence that the material meets the requirements of this paragraph, provided the specimens comply with UCS-85, UHT-5, or UHT-81, as applicable.

(2) The Manufacturer of the vessel may have impact tests made to prove the suitability of a material which the material manufacturer has not impact tested provided the number of tests and the method of taking the test specimens shall be as specified for the material manufacturer (see UG-85).

(e) Procedural Requirements

(1) Product Form Procedural Requirements. When no procedural requirements are listed in the material specifications, impact testing of each form of material shall comply with the applicable product form procedural requirements of the specifications listed in Table UG-84.3.

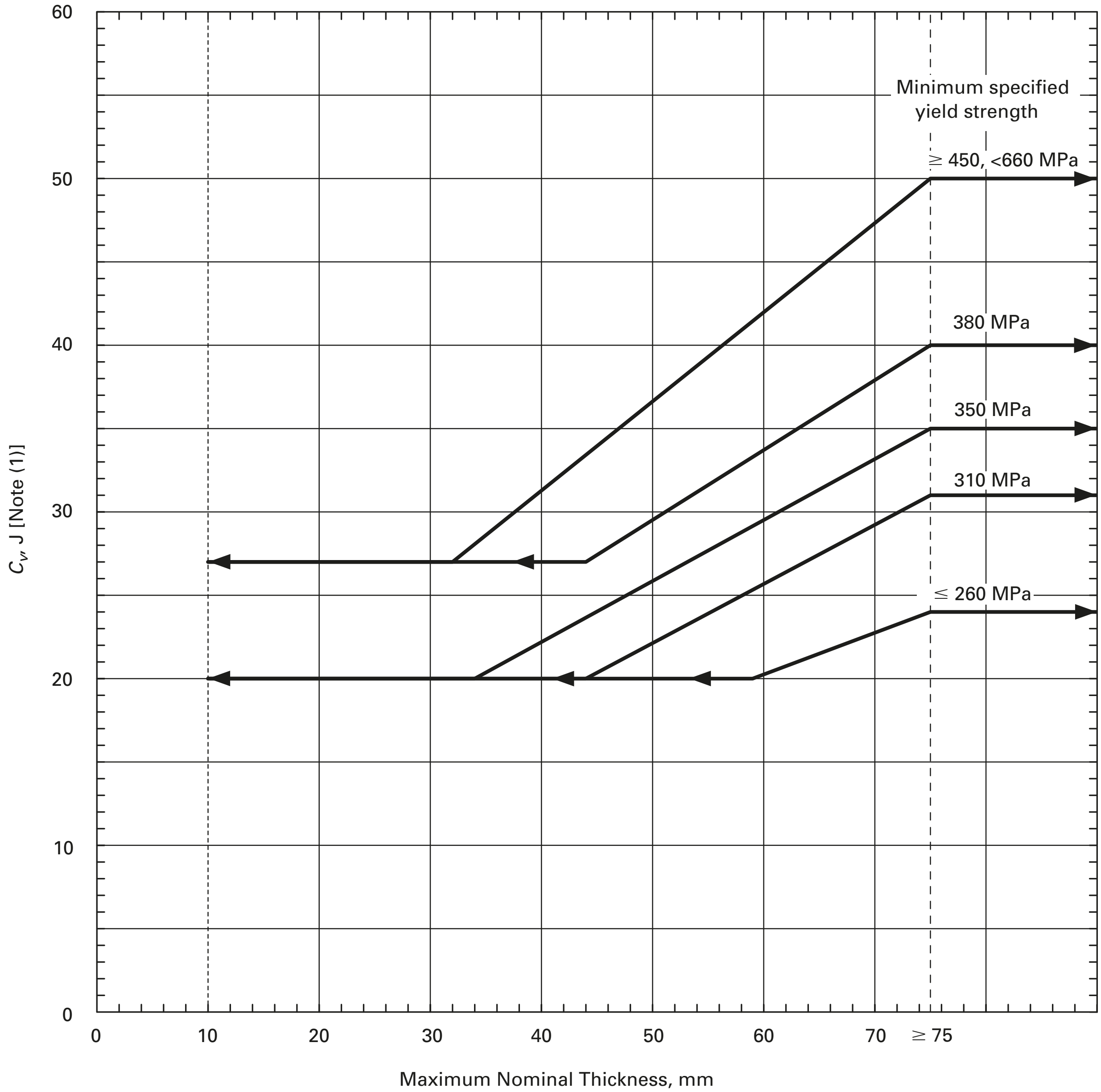
Figure UG-84.1
Charpy V-Notch Impact Test Requirements for Full-Size Specimens for Carbon and Low Alloy Steels, Having a Specified Minimum Tensile Strength of Less Than 95 ksi, Listed in Table UCS-23



GENERAL NOTES:
(a) Interpolation between yield strengths shown is permitted.
(b) The minimum impact energy for one specimen shall not be less than $^2/_3$ of the average energy required for three specimens. The average impact energy value of the three specimens may be rounded to the nearest ft-lb.
(c) Material produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, impact tested SA/AS 1548 (*L* impact designations), SA-437, SA-540 (except for materials produced under Table 2, Note 4 in SA-540), and SA-765 do not have to satisfy these energy values. See UCS-66(g).
(d) For materials having a specified minimum tensile strength of 95 ksi or more, see UG-84(c)(4)(-b).

NOTE:
(1) Average of three specimens.

Figure UG-84.1M
Charpy V-Notch Impact Test Requirements for Full-Size Specimens for Carbon and Low Alloy Steels, Having a Specified Minimum Tensile Strength of Less Than 655 MPa, Listed in Table UCS-23



GENERAL NOTES:

(a) Interpolation between yield strengths shown is permitted.

(b) The minimum impact energy for one specimen shall not be less than $^2/_3$ of the average energy required for three specimens. The average impact energy value of the three specimens may be rounded to the nearest J.

(c) Material produced and impact tested in accordance with SA-320, SA-333, SA-334, SA-350, SA-352, SA-420, impact tested SA/AS 1548 (*L* impact designations), SA-437, SA-540 (except for materials produced under Table 2, Note 4 in SA-540), and SA-765 do not have to satisfy these energy values. See UCS-66(g).

(d) For materials having a specified minimum tensile strength of 655 MPa or more, see UG-84(c)(4)(-b).

NOTE:

(1) Average of three specimens.

Table UG-84.2 Charpy Impact Test Temperature Reduction Below Minimum Design Metal Temperature

Actual Material Thickness [See UG-84(c)(5)(-b)] or Charpy Impact Specimen Width Along the Notch [Note (1)]	
Thickness, in. (mm)	Temperature Reduction, °F (°C)
0.394 (full-size standard bar) (10)	0 (0)
0.354 (9)	0 (0)
0.315 (8.00)	0 (0)
0.295 (3/4 size bar) (7.5)	5 (3)
0.276 (7)	8 (4)
0.262 (2/3 size bar) (6.7)	10 (6)
0.236 (6)	15 (8)
0.197 (1/2 size bar) (5.00)	20 (11)
0.158 (4)	30 (17)
0.131 (1/3 size bar) (3.3)	35 (19)
0.118 (3.00)	40 (22)
0.099 (1/4 size bar) (2.5)	50 (28)

GENERAL NOTE: For Table UCS-23 materials having a specified minimum tensile strength of less than 95,000 psi (655 MPa) when the subsize charpy impact width is less than 80% of the material thickness.

NOTE:
(1) Straight line interpolation for intermediate values is permitted.

(2) Small Parts. The Manufacturer of small parts, either cast or forged, may certify a lot of not more than 20 duplicate parts by reporting the results of one set of impact specimens taken from one such part selected at random, provided the same specification and heat of material and the same process of production, including heat treatment, were used for all of the lot. When the part is too small to provide the three specimens of at least minimum size shown in Figure UG-84, no impact test need be made.

Table UG-84.3 Specifications for Impact Tested Materials in Various Product Forms

Product Form	Spec. No.
Plates	
Parts UCS and UHT	SA-20, S5
Part UHA	SA-480
Pipe	SA-333
Tubes	SA-334
Forgings	SA-350
Castings	SA-352
Bolting materials (and bars)	SA-320
Piping fittings	SA-420

Table UG-84.4 Impact Test Temperature Differential

Minimum Specified Yield Strength, ksi (MPa)	Temperature Difference, °F (°C) [Note (1)]
≤40 (280)	10 (6)
≤55 (380)	5 (3)
>55 (380)	0 (0)

NOTE:
(1) Impact test temperature may be warmer than the minimum design temperature by the amount shown.

(3) Small Vessels. For small vessels in conformance with U-1(j), one set of impact specimens of the material may represent all vessels from the same heat of material not in excess of 100 vessels or one heat-treatment furnace batch, whichever is smaller.

(f) Impact Testing of Welds

(1) For steel vessels of welded construction the impact toughness of welds and heat-affected zones of procedure qualification test plates and vessel impact test plates (production impact test plates) shall be determined as required herein.

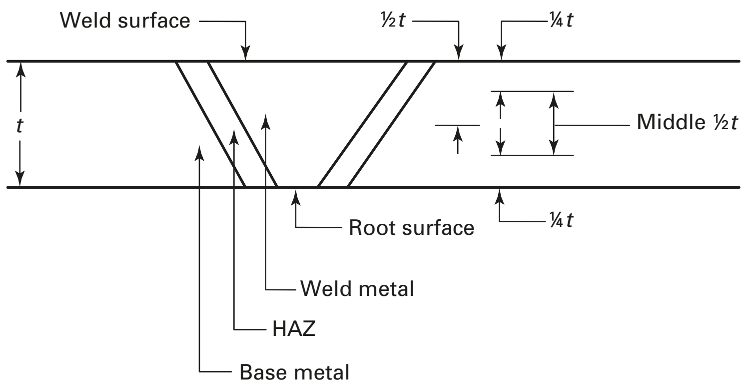
(2) All test plates shall be subjected to heat treatment, including cooling rates and aggregate time at temperature or temperatures as established by the Manufacturer for use in actual manufacture. Heat treatment requirements of UG-85, UCS-85, UHT-81, and UHT-82 shall apply to the test plates except that the provisions of UCS-85(f) and UCS-85(g) are not applicable.

(g) Location, Orientation, Temperature, and Values of Weld Impact Tests. All weld impact tests shall comply with the following: (**19**)

(1) Each set of weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch is normal to the surface of the material and one face of the specimen shall be within 1/16 in. (1.5 mm) of the surface of the material.

(2) Each set of heat-affected zone impact specimens shall be taken across the weld and of sufficient length to locate, after etching, the notch in the heat-affected zone. The number of heat-affected zone impact specimen sets to be removed, and the location of the centerline in the prepared test specimens, shall be as shown in Figure UG-84.5 and Table UG-84.6. Test specimens that are full sized or the largest obtainable subsized test specimens that have been removed and prepared with the width along the notch located fully within the specified range of removal depth are acceptable. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone material as possible in the resulting fracture. Where the material

Figure UG-84.5
HAZ Impact Specimen Removal



thickness permits, the axis of the notch may be inclined to allow the root of the notch to align parallel to the fusion line.

(3) For welds made by a solid-state welding process, such as for electric resistance-welded (ERW) pipe, the weld impact tests shall consist only of one set of three specimens taken across the weld with the notch at the weld centerline. Each specimen shall be oriented so that the notch is normal to the surface of the material and one face of the specimen shall be within $^{1}/_{16}$ in. (1.5 mm) of the surface of the material. The weld impact tests are not required if the weld and the base metal have been: annealed, normalized, normalized and tempered, double normalized and tempered, or quenched and tempered.

(4) The test temperature for welds and heat-affected zones shall not be higher than required for the base materials.

(5) Impact values shall be at least as high as those required for the base materials.

(6) When qualifying a Welding Procedure Specification (WPS) for welding base metals having different impact testing requirements and acceptance criteria, the following shall apply:

(-a) The weld metal impact test specimens shall meet the acceptance criteria for either base metal.

(-b) When HAZ tests are required, separate impact test specimens shall be removed from the HAZ of each base metal that requires impact testing, and those specimens shall meet the acceptance criteria applicable to the base metal from which they were removed.

Table UG-84.6 (**19**)
Required HAZ Impact Test Specimen Set Removal

Base Metal Thickness, *t*	Number of Specimen Sets and the Locations of Their Approximate Centerline: Single-Sided Weld	Two-Sided Weld
$t \leq {}^{3}/_{4}$ in. (19 mm)	One set, $^{1}/_{4}t$ to $^{1}/_{2}t$	One set, middle $^{1}/_{2}t$ [Note (1)]
$t > {}^{3}/_{4}$ in. (19 mm)	One set, $^{1}/_{4}t$ to $^{1}/_{2}t$	Two sets, $^{1}/_{4}t$ to $^{1}/_{2}t$ [Note (2)]

GENERAL NOTE: Testing shall be performed on sets of three impact test specimens as required by UG-84(c)(1). Each specimen shall be full size, or the largest subsize specimen that may be removed from the available material thickness. The specimen sets shall be removed at the indicated depth from the weld surface, as described in Notes (1) and (2).

NOTES:
(1) For two-sided welds in base metal thicknesses of $^{3}/_{4}$ in. (19 mm) or less, a single specimen set prepared with the centerline of the width of the notch falling within the middle $^{1}/_{2}t$ shall represent the HAZ of the welds applied to both surfaces.
(2) For two-sided welds in base metal thicknesses greater than $^{3}/_{4}$ in. (19 mm), the specimen sets shall be prepared with the centerline of the width along the notch falling between $^{1}/_{4}t$ and $^{1}/_{2}t$ from each weld surface.

(h) Impact Tests of Welding Procedure Qualifications

(1) General. For steel vessels of welded construction, the impact toughness of the welds and heat-affected zones of the procedure qualification test plates shall be determined in accordance with (g) above and the following subparagraphs:

(2) When Required. Welding procedure impact tests shall be made when required by UCS-67, UHT-82, or UHA-51. For vessels constructed to the rules of Part UCS, the test plate material shall satisfy all of the following requirements relative to the material to be used in production:

(-a) be of the same P-Number and Group Number;

(**19**) *(-b)* be in the same heat-treated condition, and this heat-treated condition shall be noted on the PQR and WPS used for construction; and

(-c) meet the minimum notch toughness requirements of (c)(4) for the thickest material of the range of base material qualified by the procedure (see Figure UG-84.1).

If impact tests are required for the deposited weld metal, but the base material is exempted from impact tests (as in UHA-51), welding procedure test plates shall be made. The test plate material shall be material of the same P-Number and Group Number used in the vessel. One set of impact specimens shall be taken with the notch approximately centered in the weld metal and perpendicular to the surface; the heat-affected zone need not be impact tested.

When the welding procedure employed for production welding is used for fillet welds only, it shall be qualified by a groove weld qualification test. The qualification test plate or pipe material shall meet the requirements of (-a), (-b), and (-c) above when impact testing is a requirement. This welding procedure test qualification is in addition to the requirements of Section IX, QW-202.2 for P-No. 11 materials.

(3) Material Over $1\frac{1}{2}$ in. (38 mm) Thick. When procedure tests are made on material over $1\frac{1}{2}$ in. (38 mm) in thickness, the following heat-affected zone and weld metal impact specimens are required:

(-a) Heat-affected zone specimens shall be as described in (g)(2) above.

(-b) Two sets of impact specimens shall be removed from the weld with one set located near [within $\frac{1}{16}$ in. (1.5 mm)] the surface of one side of the material and one set taken as near as practical midway between the surface and the center of thickness of the opposite side and oriented as described in (g)(1) above.

(4) Essential Variables. The supplementary essential variables specified in Section IX, QW-250, for impact testing are required.

(5) Multiple Process Welding Procedures. When qualifying a welding procedure with impact testing that employs multiple welding processes, or multiple sets of essential and supplementary essential variables for a welding process, the welding procedure shall be qualified by testing separate sets of impact test specimens removed from the weld metal and heat-affected zone, as follows:

(-a) The requirements of (f) shall be met.

(-b) The requirements of (g) and (3) specifying the location, number, and orientation of test specimen sets to be removed for each welding process or set of variables shall be modified as follows:

(-1) The weld thickness shall be considered the base metal thickness.

(-2) The surface of the last deposited layer of weld metal shall be considered the weld surface.

(-3) The root side of the first deposited layer of weld metal shall be considered the root surface.

(-c) If the weld thickness for a welding process or set of variables is small enough that the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm), toughness testing of the weld metal and heat-affected zone is not required for that welding process or set of variables.

(i) Vessel (Production) Impact Test Plates

(1) General. In addition to the requirements of (h) above, impact tests of welds and heat-affected zones shall be made in accordance with (g) above for each qualified welding procedure used on each vessel or group of vessels as defined in (3) below. The vessel impact test plate shall be from one of the heats of steel used for the vessel or group of vessels. For Category A joints, the test plate shall, where practicable, be welded as an extension to the end of a production joint so that the test plate weldment will represent as nearly as practicable the quality and type of welding in the vessel joint. For Category B joints that are welded using a different welding procedure than used on Category A joints, a test plate shall be welded under the production welding conditions used for the vessel, using the same type of equipment and at the same location and using the same procedures as used for the joint, and it shall be welded concurrently with the production welds or as close to the start of production welding as practicable.

(2) When Required. Vessel (production) impact test plates shall be made for all joints for which impact tests are required for the welding procedure by UCS-67, UHT-82, or UHA-51 (except where production test plates are specifically exempt by these paragraphs). Test shall be made of the weld metal and/or heat-affected zone to the extent required by the procedure test (see UCS-67 and UHA-51).

(3) Number of Vessel Impact Test Plates Required

(-a) For each vessel, one test plate shall be made for each welding procedure used for Category A and B joints, unless the vessel is one of several as defined in (-b) or (-c) below.

In addition, for Category A and B joints the following requirements shall apply:

(-1) If automatic, machine, or semiautomatic welding is performed, a test plate shall be made in each position employed in the vessel welding.

(-2) If manual welding is also employed, a test plate shall be made in the flat position only, except if welding is to be performed in other positions a test plate need be made in the vertical position only (where the major portions of the layers of welds are deposited in the vertical upward direction). The vertically welded test plate will qualify the manual welding in all positions.

(**19**) *(-b)* For several vessels or parts of vessels, a minimum of one test plate shall be made for each welding procedure used for Category A and B joints, provided that all of the following requirements are met:

(-1) Welding is completed within any 3-month period at one location.

(-2) The cumulative length of all joints welded by each welding procedure does not exceed 400 ft (120 m).

(-3) Materials are of the same specification and grade.

(-4) The plate thicknesses of the vessels or parts of vessels do not vary by more than $^1/_4$ in. (6 mm) or 25%, whichever is greater.

(-5) The number of heat-affected-zone impact specimen sets to be removed and the locations of their removal shall be as shown in Figure UG-84.5 and Table UG-84.6 for the largest plate thickness in the range specified in (-4).

(-6) The additional requirements specified in (-a) shall be met.

(-c) For small vessels not exceeding the volume limitations defined in U-1(j) made from one heat of material requiring impact tests, one welded test joint made from the same heat of material and welded with the same electrode and the same welding procedure may represent one lot of 100 vessels or less, or each heat treatment furnace batch, whichever is smaller.

(j) *Rejection*. If the vessel test plate fails to meet the impact requirements, the welds represented by the plate shall be unacceptable. Reheat treatment and retesting or retesting only are permitted.

UG-85 HEAT TREATMENT

When plate specification heat treatments are not performed by the material manufacturer, they shall be performed by, or be under the control of, the Manufacturer who shall then place the letter "T" following the letter "G" in the Mill plate marking (see SA-20) to indicate that the heat treatments required by the material specification have been performed. The Manufacturer shall also document in accordance with UG-93(b) that the specified heat treatment has been performed.

UCS-85, UHT-5(e), and UHT-81 provide requirements for heat treatment of test specimens.

INSPECTION AND TESTS

UG-90 GENERAL

(a) The inspection and testing of pressure vessels to be marked with the Certification Mark with the U Designator and the testing of vessels to be marked with the Certification Mark with the UM Designator shall conform to the general requirements for inspection and testing in the following paragraphs and, in addition, to the specific requirements for *Inspection and Tests* given in the applicable Parts of Subsections B and C.

(b) The Manufacturer has the responsibility of assuring that the quality control, the detailed examinations, and the tests required by this Division are performed. The Manufacturer shall perform his specified duties. See UG-92 and 10-15. Some, but not all, of these responsibilities, which are defined in the applicable rules, are summarized as follows:

(1) the Certificate of Authorization from the ASME Boiler and Pressure Vessel Committee authorizing the Manufacturer to fabricate the class of vessel being constructed [UG-117(a)];

(2) the drawings and design calculations for the vessel or part [10-5 and 10-15(d)];

(3) identification for all material used in the fabrication of the vessel or part (UG-93);

(4) securing Partial Data Reports [UG-120(c)];

(5) access for the Inspector in accordance with UG-92 and 10-15;

(6) examination of all materials before fabrication to make certain the materials meet the design thickness requirements, to detect defects [UG-93(d)], and to make certain the materials are permitted by this Division (UG-4) and that traceability (UG-77) to the material identification (UG-93) has been maintained;

(7) documentation of impact tests when such tests are required (UF-5, UCS-66, UHA-51, UHT-6, and ULT-5);

(8) concurrence of the Inspector prior to any base metal repairs (UG-78 and UF-37);

(9) examination of the shell and head sections to confirm they have been properly formed to the specified shapes within the permissible tolerances (UG-79, UG-80, UG-81, UF-27, and UF-29);

(10) qualification of the welding and/or brazing procedures before they are used in fabrication [UG-84(h), UW-28(b), and UB-31];

(11) qualification of welders and welding operators and brazers before using the welders or brazers in production work (UW-29, UW-48, UB-32, and UB-43);

(12) examination of all parts prior to joining to make certain they have been properly fitted for welding or brazing and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained (UW-31, UW-32, UW-33, and UB-17);

(13) examination of parts as fabrication progresses, for material marking (UG-94), that defects are not evident (UG-95), and that dimensional geometries are maintained (UG-96 and UF-30);

(14) provision of controls to assure that all required heat treatments are performed (UW-2, UW-10, UG-85, UF-31, and 10-11);

(15) provision of records of nondestructive testing examinations performed on the vessel or vessel parts. This shall include retaining the radiographic film if radiographic examinations are performed (UW-51, UW-52, and 10-10);

(16) making the required hydrostatic or pneumatic test and having the required inspection performed during such test (UG-99, UG-100, UG-101, and UW-50);

(17) applying the required stamping and/or nameplate to the vessel and making certain it is applied to proper vessel (UG-116, UG-118, and UG-119);

(18) preparing required Manufacturer's Data Report and having it certified by the Inspector (UG-120);

(19) providing for retention of radiographs (UW-51), ultrasonic test reports (12-4), Manufacturer's Data Reports (UG-120), and other documents as required by this Division (10-13).

(c) See below.

(1) The Inspector shall make all inspections specifically required of him plus such other inspections as he believes are necessary to enable him to certify that all vessels which he authorizes to be stamped with the Certification Mark have been designed and constructed in accordance with the requirements of this Division. Some, but not all, of the required inspections and verifications, which are defined in the applicable rules, are summarized as follows:

(-a) verifying that the Manufacturer has a valid Certificate of Authorization [UG-117(a)] and is working to a Quality Control System [UG-117(e)];

(-b) verifying that the applicable design calculations are available [U-2(b), U-2(c), 10-5, and 10-15(d)];

(-c) verifying that materials used in the construction of the vessel comply with the requirements of UG-4 through UG-14 (UG-93);

(-d) verifying that all welding and brazing procedures have been qualified (UW-28, UW-47, and UB-42);

(-e) verifying that all welders, welding operators, brazers, and brazing operators have been qualified (UW-29, UW-48, and UB-43);

(-f) verifying that the heat treatments, including PWHT, have been performed (UG-85, UW-10, UW-40, UW-49, and UF-52);

(-g) verifying that material imperfections repaired by welding were acceptably repaired [UG-78, UW-52(d)(2)(-c), UF-37, and UF-47(c)];

(-h) verifying that weld defects were acceptably repaired [UW-51(a) and UW-52(c)];

(-i) verifying that required nondestructive examinations, impact tests, and other tests have been performed and that the results are acceptable (UG-84, UG-93, UW-50, UW-51, UW-52, and UB-44);

(-j) making a visual inspection of vessel to confirm that the material identification numbers have been properly transferred (UG-77 and UG-94);

(-k) making a visual inspection of the vessel to confirm that there are no material or dimensional defects (UG-95, UG-96, and UG-97);

(-l) performing internal and external inspections and witnessing the hydrostatic or pneumatic tests (UG-96, UG-97, UG-99, UG-100, and UG-101);

(-m) verifying that the required marking is provided (UG-115) and that any nameplate has been attached to the proper vessel;

(-n) signing the Certificate of Inspection on the Manufacturer's Data Report when the vessel, to the best of his knowledge and belief, is in compliance with all the provisions of this Division. When the Inspector has certified by signing the Manufacturer's Data Report, this indicates acceptance by the Inspector. This acceptance does not imply assumption by the Inspector of any of the responsibilities of the Manufacturer.

(2) When mass production of pressure vessels makes it impracticable for the Inspector to personally perform each of his required duties,[4] the Manufacturer, in collaboration with the Inspector, shall prepare an inspection and quality control procedure setting forth, in complete detail, the method by which the requirements[4] of this Division will be maintained. This procedure shall be developed, accepted, and implemented in accordance with Mandatory Appendix 35.

UG-91 THE INSPECTOR (19)

(a) All references to *Inspectors* throughout this Division mean the Authorized Inspector as defined in this paragraph. All inspections required by this Division of Section VIII shall be:

(1) by an Inspector regularly employed by an ASME accredited Authorized Inspection Agency, as defined in ASME QAI-1, except that

(2) inspections may be by the regularly employed user's Inspector in the case of a User-Manufacturer that manufactures pressure vessels exclusively for its own use and not for resale [see UG-116(a)(1)].

Except as permitted in (2) above, the Inspector shall not be in the employ of the Manufacturer. All Inspectors shall have been qualified in accordance with ASME QAI-1.

(b) In addition to the duties specified, the Inspector has the duty to monitor the Manufacturer's Quality Control System as required in Mandatory Appendix 10.

UG-92 ACCESS FOR INSPECTOR

The Manufacturer of the vessel shall arrange for the Inspector to have free access to such parts of all plants as are concerned with the supply or manufacture of materials for the vessel, when so requested. The Inspector shall be permitted free access, at all times while work on the vessel is being performed, to all parts of the Manufacturer's shop that concern the construction of the vessel and to the site of field erected vessels during the period of assembly and testing of the vessel. The Manufacturer shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when vessels will be ready for any required tests or inspections.

UG-93 INSPECTION OF MATERIALS

(a) Except as otherwise provided in UG-4(b), UG-10, UG-11, or UG-15, requirements for acceptance of materials furnished by the material manufacturer or material supplier in complete compliance with a material specification of Section II shall be as follows.

(1) For plates,[7] the vessel Manufacturer shall ensure all requirements of the material specification, and all special requirements of this Division, that are to be fulfilled by the materials manufacturer have been complied with. The Manufacturer shall accomplish this by obtaining certificates of compliance or Material Test Reports. The Inspector shall determine if these documents represent the material and meet the requirements of the material specification.

(-a) These documents shall include results of all required tests and examinations, evidence of compliance with the material specifications, and additional requirements, as applicable. When the specification permits certain specific requirements to be completed later, those incomplete items shall be noted on the material documentation. When these specific requirements have been completed by someone other than the material manufacturer, this completion shall be documented and attached to the material documentation.

(-b) The vessel Manufacturer shall receive a copy of the test report or reports as prepared by the material manufacturer, or by the material manufacturer and any subsequent processors responsible for the data, and shall maintain the reports as part of the construction records.

(2) For all other product forms

(-a) the material shall be accepted by the Manufacturer as complying with the material specification if the material specification provides for the marking of each piece with the specification designation, including the grade, type, and class, if applicable, and each piece is so marked, or

(-b) if a Material Test Report is supplied by a materials manufacturer, the materials manufacturer may transcribe data produced by other organizations, provided he accepts responsibility for the accuracy and authenticity of the data

(3) If the material specification does not provide for the marking of each piece as indicated in (2) above, the material shall be accepted as complying with the material specification, provided the following requirements are met:

(-a) Each bundle, lift, or shipping container is marked with the specification designation, including the grade, type, and class if applicable by the material manufacturer or supplier.

(-b) The handling and storage of the material by the vessel Manufacturer shall be documented in his Quality Control System such that the Inspector can determine that it is the material identified in (-a) above. Traceability to specific lot, order, or heat is not required. Traceability is required only to material specification and grade and type and class, if applicable.

(4) For pipe or tube where the length is not adequate for the complete marking in accordance with the material specification or not provided in accordance with (3) above, the material shall be acceptable as complying with the material specification, provided the following are met:

(-a) a coded marking is applied to each piece of pipe or tube by the material manufacturer or material supplier; and

(-b) the coded marking applied by the material manufacturer or material supplier is traceable to the specification designation, including the grade, type, and class if applicable.

(b) Except as otherwise provided in UG-4(b), UG-10, UG-11, or UG-15, when some requirements of a material specification of Section II have been completed by other than the material manufacturer [see UG-84(d) and UG-85], then the vessel Manufacturer shall obtain supplementary material test reports or certificates of compliance and the Inspector shall examine these documents and shall determine that they represent the material and meet the requirements of the material specification.

(c) When requirements or provisions of this Division applicable to materials exceed or supplement the requirements of the material specification of Section II (see UG-24, UG-84, and UG-85), then the vessel Manufacturer shall obtain supplementary material test reports or certificates of compliance and the Inspector shall examine these documents and shall determine that they represent the material and meet the requirements or provisions of this Division.

(d) All materials to be used in constructing a pressure vessel shall be examined before fabrication for the purpose of detecting, as far as possible, imperfections which would affect the safety of the vessel.

(1) Particular attention should be given to cut edges and other parts of rolled plate which would disclose the existence of serious laminations, shearing cracks, and other imperfections.

(2) All materials that are to be tested in accordance with the requirements of UG-84 shall be inspected for surface cracks.

(3) When a pressure part is to be welded to a flat plate thicker than $^1/_2$ in. (13 mm) to form a corner joint under the provision of UW-13(e), the weld joint preparation in the flat plate shall be examined before welding as specified in (4) below by either the magnetic particle or liquid penetrant methods. After welding, both the peripheral edge of the flat plate and any remaining exposed surface of the weld joint preparation shall be reexamined by the magnetic particle or liquid penetrant methods as specified in (4) below. When the plate is nonferromagnetic, only the liquid penetrant method shall be used.

(4) For Figure UW-13.2 the weld joint preparation and the peripheral edges of flat plate forming a corner joint shall be examined as follows:

(-a) the weld edge preparation of typical weld joint preparations in the flat plate as shown in sketches (b), (c), (d), (e-2), (f), and (n);

(-b) the outside peripheral edge of the flat plate after welding as shown in sketches (a), (b), (c), and (d);

(-c) the outside peripheral edge of the flat plate after welding, as shown in sketches (e-1), (e-2), (f), and (g) if the distance from the edge of the completed weld to the peripheral edge of the flat plate is less than the thickness of the flat plate such as defined in UG-34(b);

(-d) the inside peripheral surface of the flat plate after welding as shown in sketches (m) and (n);

(-e) no examination is required on the flat plate as shown in sketches (h), (i), (j), (k), and (l).

(e) The Inspector shall assure himself that the thickness and other dimensions of material comply with the requirements of this Division.

(f) The Inspector shall satisfy himself that the inspection and marking requirements of UG-24 have been complied with for those castings assigned a casting quality factor exceeding 80%.

UG-94 MARKING ON MATERIALS

The Inspector shall inspect materials used in the construction to see that they bear the identification required by the applicable material specification, except as otherwise provided in UG-4(b), UG-10, UG-11, UG-15, or UG-93. Should the identifying marks be obliterated or the material be divided into two or more parts, the marks shall be properly transferred by the Manufacturer as provided in UG-77(a). See UG-85.

UG-95 EXAMINATION OF SURFACES DURING FABRICATION

As fabrication progresses, all materials used in the construction shall be examined for imperfections that have been uncovered during fabrication as well as to determine that the work has been done properly.

UG-96 DIMENSIONAL CHECK OF COMPONENT PARTS

(a) The Manufacturer shall examine the pressure-retaining parts to make certain they conform to the prescribed shape and meet the design thickness after forming. The Manufacturer of the vessel shall furnish accurately formed templates as required by the Inspector for verification. See UG-80.

(b) Before attaching nozzles, manhole frames, nozzle reinforcement and other appurtenances to the inside or outside of the vessel they shall be examined to make certain they properly fit the vessel curvature. See UG-82.

(c) The Inspector shall satisfy himself that the above dimensional requirements have been met. This shall include making such dimensional measurements as he considers necessary.

UG-97 INSPECTION DURING FABRICATION

(a) When conditions permit entry into the vessel, as complete an examination as possible shall be made before final closure.

(b) The Inspector shall make an external inspection of the completed vessel at the time of the final hydrostatic test or pneumatic test.

(c) All welds, including the nozzle welds, of homogeneously lead-lined vessels shall be visually inspected on the inside prior to application of lining. A visual examination of the lining shall be made after completion to ensure that there are no imperfections which might impair the integrity of the lining and subject the vessel to corrosion effects.

UG-98 MAXIMUM ALLOWABLE WORKING PRESSURE

(a) The maximum allowable working pressure for a vessel is the maximum pressure permissible at the top of the vessel in its normal operating position at the designated coincident temperature specified for that pressure. It is the least of the values found for maximum allowable working pressure for any of the essential parts of the vessel by the principles given in (b) below, and adjusted for any difference in static head that may exist between the part considered and the top of the vessel. (See 3-2.)

(b) The maximum allowable working pressure for a vessel part is the maximum internal or external pressure, including the static head thereon, as determined by the rules and equations in this Division, together with the effect of any combination of loadings listed in UG-22 that is likely to occur, for the designated coincident temperature, excluding any metal thickness specified as corrosion allowance. See UG-25.

(c) Maximum allowable working pressure may be determined for more than one designated operating temperature, using for each temperature the applicable allowable stress value.

UG-99 STANDARD HYDROSTATIC TEST

(a) A hydrostatic test shall be conducted on all vessels after

(1) all fabrication has been completed, except for operations that could not be performed prior to the test, such as weld end preparation [see U-1(e)(1)(-a)], and cosmetic grinding on the base material that does not reduce the actual thickness below the design thickness; and

(2) all examinations have been performed, except those required after the test.

The completed vessels, except those tested in accordance with the requirements of UG-100 and UG-101, shall have satisfactorily passed the hydrostatic test prescribed in this paragraph.

(b) Except as otherwise permitted in (a) above and 27-4, vessels designed for internal pressure shall be subjected to a hydrostatic test pressure that at every point in the vessel is at least equal to 1.3 times the maximum allowable working pressure[35] multiplied by the lowest stress ratio (LSR) for the pressure-boundary materials of which the vessel is constructed. The stress ratio for each pressure-boundary material is the ratio of the stress value S at its test temperature to the stress value S at its design temperature (see UG-21). Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. All loadings that may exist during this test shall be given consideration. The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge.

(c) A hydrostatic test based on a calculated pressure may be used by agreement between the user and the Manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressures calculated by multiplying the basis for calculated test pressure as defined in 3-2 for each pressure element by 1.3 and reducing this value by the hydrostatic head on that element. When this pressure is used, the Inspector shall reserve the right to require the Manufacturer or the designer to furnish the calculations used for determining the hydrostatic test pressure for any part of the vessel.

(d) The requirements of (b) above represent the minimum standard hydrostatic test pressure required by this Division. The requirements of (c) above represent a special test based on calculations. Any intermediate value of pressure may be used. This Division does not specify an upper limit for hydrostatic test pressure. However, if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined as prescribed in (c) above to the degree that the vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.

(e) Combination units [see UG-19(a) and UG-21] shall be tested by one of the following methods.

(1) Independent Pressure Chambers. Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels, that is, each chamber shall be tested without pressure in the adjacent chamber. If the common elements of a combination unit are designed for a larger differential pressure than the higher maximum allowable working pressure to be marked on the adjacent chambers, the hydrostatic test shall subject the common elements to at least their design differential pressure, corrected for temperature as in (b) above, as well as meet the requirements of (b) or (c) above for each independent chamber.

(2) Dependent Pressure Chambers. When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least 1.3 times the differential pressure to be marked on the unit, corrected for temperature as in (b).

Following the test of the common elements and their inspection as required by (g) below, the adjacent chambers shall be hydrostatically tested simultaneously [see (b) or (c) above]. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

The vessel stamping and the vessel Data Report must describe the common elements and their limiting differential pressure. See UG-116(j) and UG-120(b).

(f) Single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP less than or equal to zero) shall be subjected to either

(1) an internal hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100. The applied test pressure shall be not less than 1.3 times the specified external design pressure; or

(2) a vacuum test conducted at the lowest value of specified absolute internal design pressure. In conjunction with the vacuum test, a leak test shall be performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Leak testing personnel shall be qualified and certified as required by Section V, Article 1, T-120(e).

(g) Following the application of the hydrostatic test pressure, an inspection shall be made of all joints and connections. This inspection shall be made at a pressure not less than the test pressure divided by 1.3. Except for

leakage that might occur at temporary test closures for those openings intended for welded connections, leakage is not allowed at the time of the required visual inspection. Leakage from temporary seals shall be directed away so as to avoid masking leaks from other joints.

The visual inspection of joints and connections for leaks at the test pressure divided by 1.3 may be waived, provided:

(1) a suitable gas leak test is applied;

(2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector;

(3) all welded seams that will be hidden by assembly are given a visual examination for workmanship prior to assembly;

(4) the vessel will not contain a "lethal" substance.

(h) Any nonhazardous liquid at any temperature may be used for the hydrostatic test if below its boiling point. Combustible liquids having a flash point less than 110°F (43°C), such as petroleum distillates, may be used only for near atmospheric temperature tests. It is recommended that the metal temperature during hydrostatic test be maintained at least 30°F (17°C) above the minimum design metal temperature, but need not exceed 120°F (48°C), to minimize the risk of brittle fracture. [See UG-20 and Figure UCS-66.2, Note (6).] The test pressure shall not be applied until the vessel and its contents are at about the same temperature. If the test temperature exceeds 120°F (48°C), it is recommended that inspection of the vessel required by (g) above be delayed until the temperature is reduced to 120°F (48°C) or less.

CAUTION: A small liquid relief valve set to $1^1/_3$ times the test pressure is recommended for the pressure test system, in case a vessel, while under test, is likely to be warmed up materially with personnel absent.

(i) Vents shall be provided at all high points of the vessel in the position in which it is to be tested to purge possible air pockets while the vessel is filling.

(j) Before applying pressure, the test equipment shall be examined to see that it is tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected.

(**19**) *(k) Painting and Coating*

(1) Unless permitted by the user or his designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pressure test. [See UCI-99(b) and UCD-99(b).]

(2) When painting or coating prior to the hydrostatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent.

(3) Vessels for lethal service [see UW-2(a)]

(-a) shall not be painted or coated either internally or externally prior to the hydrostatic pressure test

(-b) shall not be internally lined by mechanical or welded attachments prior to the hydrostatic pressure test unless the requirements of UCL-51 are followed

(4) The requirements given in (1) and (2) do not apply to glass-lined vessels; see 27-4.

UG-100 PNEUMATIC TEST[36] (SEE UW-50) (19)

(a) Subject to the provisions of UG-99(a)(1) and UG-99(a)(2), a pneumatic test prescribed in this paragraph may be used in lieu of the standard hydrostatic test prescribed in UG-99 for vessels:

(1) that are so designed and/or supported that they cannot safely be filled with water;

(2) not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in UG-99.

(b) Except for enameled vessels, for which the pneumatic test shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel, the pneumatic test pressure at every point in the vessel shall be at least equal to 1.1 times the maximum allowable working pressure[35] multiplied by the lowest stress ratio (LSR) for the pressure-boundary materials of which the vessel is constructed. The stress ratio for each pressure-boundary material is the ratio of the stress value S at its test temperature to the stress value S at its design temperature (see UG-21). Bolting shall not be included in the determination of the LSR, except when 1.1 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. All loadings that may exist during this test shall be given consideration. In no case shall the pneumatic test pressure exceed 1.1 times the basis for the calculated test pressure as defined in 3-2.

(c) The metal temperature during pneumatic test shall be maintained at least 30°F (17°C) above the minimum design metal temperature to minimize the risk of brittle fracture. [See UG-20 and Figure UCS-66.2, Note (6).]

(d) The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to the test pressure divided by 1.1 and held for a sufficient time to permit inspection of the vessel. Any leaks that are present, except for leakage that might occur at temporary test closures for those openings intended for welded connections, shall be corrected, and the vessel shall be retested.

The visual inspection of the vessel at the required test pressure divided by 1.1 may be waived, provided:

(1) a suitable gas leak test is applied;

(2) substitution of the gas leak test is by agreement reached between Manufacturer and Inspector;

(3) all welded seams that will be hidden by assembly are given a visual examination for workmanship prior to assembly;

(4) the vessel will not contain a "lethal" substance.

(e) Painting and Coating

(1) Unless permitted by the user or his designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pneumatic pressure test.

(2) When painting or coating prior to the pneumatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent.

(3) Vessels for lethal service [see UW-2(a)]

(-a) shall not be painted or coated either internally or externally prior to the pneumatic pressure test

(-b) shall not be internally lined by mechanical or welded attachments prior to the pneumatic pressure test unless the requirements of UCL-51 are followed

UG-101 PROOF TESTS TO ESTABLISH MAXIMUM ALLOWABLE WORKING PRESSURE

(a) General

(1) The maximum allowable working pressure for vessels or vessel parts for which the strength cannot be computed with a satisfactory assurance of accuracy (see U-2) shall be established in accordance with the requirements of this paragraph, using one of the test procedures applicable to the type of loading and to the material used in construction. Production vessels or vessel parts that utilize the results of a proof test shall comply with all applicable construction rules of the current edition and applicable addenda of this Division.

(-a) Consideration of the use of proof-tested construction specifications based on past editions of this Division and documented in the original Proof Test Report requires that the Manufacturer determine whether or not there have been subsequent revisions to this Division that apply and must be evaluated. This evaluation may void the Division acceptability of establishing the vessel MAWP by proof testing (e.g., UCS-66, Part UHX, Mandatory Appendix 13, etc.). However, if applicable revisions are found, and it is judged that a new proof test is not required, the Manufacturer, using Duplicate and Similar Parts rules in (d) as guidelines, shall prepare a Supplement to the original Proof Test Report documenting any changes to the construction requirements and to the Manufacturer's Data Report. The following should be noted:

(-1) The production vessel material need not be identical with that used for the original proof tested vessel, but material equivalence must be confirmed and documented.

(-2) The MDMT established by current Division rules may be different from that originally assigned but must be suitable for the nameplate MDMT marking coincident with the established MAWP.

(-3) The Supplement to the original Proof Test Report shall be made available to the Inspector prior to the start of construction.

(2) Provision is made in these rules for two types of tests to determine the internal maximum allowable working pressure:

(-a) tests based on yielding of the part to be tested. These tests are limited to materials with a ratio of minimum specified yield to minimum specified ultimate strength of 0.625 or less.

(-b) tests based on bursting of the part.

(3) Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in (m) below.

(4) The Code recognizes that Manufacturers may maintain control of proof test reports under different ownerships than existed during the original application of the proof test. When a Manufacturer is acquired by a new owner(s), the proof test reports may be used by the new owner(s) without retesting, provided all of the following are met:

(-a) the new owner(s) takes responsibility for the proof tests;

(-b) the Proof Test Reports reflect the name of the new owner(s);

(-c) the Proof Test Reports indicate the actual test was performed by the former Manufacturer;

(-d) the Proof Test Report(s) is acceptable to the Inspector of the new owner(s) as indicated by his/her signature on the Manufacturer's report of the test.

(b) The tests in these paragraphs may be used only for the purpose of establishing the maximum allowable working pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Division. The maximum allowable working pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

Tests to establish the maximum allowable working pressure of vessels, or vessel parts, shall be witnessed by and be acceptable to the Inspector, as indicated by his signature on the Manufacturer's Proof Test Report. The report shall include sufficient detail to describe the test, the instrumentation and the methods of calibration used, and the results obtained. The report shall be made available to the Inspector for each application [see U-2(b) and UG-90(b)(2)].

(c) The vessel or vessel part for which the maximum allowable working pressure is to be established shall not previously have been subjected to a pressure greater than

1.3 times the desired or anticipated maximum allowable working pressure, adjusted for operating temperature as provided in (k) below.

(d) Duplicate and Similar Parts. When the maximum allowable working pressure of a vessel or vessel part has been established by a proof test, duplicate parts, or geometrically similar parts, that meet all of the requirements in (1) or (2) below, need not be proof tested but shall be given a hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100, except as otherwise provided in UCI-101, and UCD-101.

(1) Duplicate Parts. All of the following requirements shall be met in order to qualify a part as a duplicate of the part that had been proof tested:

(-a) same basic design configuration and type of construction;

(-b) the material of the duplicate part is either:

(-1) the same material specifications:

(+a) alloy;

(+b) grade, class;

(+c) type, form;

(+d) heat treatment; or

(-2) the same or closely similar material when only the material specification, the alloy, grade, or form is different, provided the material meets the following additional requirements:

(+a) has allowable stress in tension equal to or greater than the material used in the proof tested part at the test temperature [see (k) below];

(+b) has the same P-Number (Section IX);

(+c) for carbon or low alloy steels (Part UCS), has the same or tougher material grouping in UCS-66, Figure UCS-66, and Notes;

(-c) the nominal dimensions, diameter, or width and height, of the duplicate parts shall be the same, and the corresponding nominal thicknesses shall be the same as those used in the proof test. The length shall not be longer than that proof tested.

(-d) heat treatment shall be the same as performed on the original part that was tested;

(-e) the MAWP shall be calculated according to (e) below;

(-f) when there are permissible deviations from the original part that was proof tested, a supplement to the original Proof Test Report shall be prepared that states and evaluates each deviation.

(2) Geometrically Similar Parts. The maximum allowable working pressure for geometrically similar parts may be established by a series of proof tests that uniformly cover the complete range of sizes, pressure, or other variables by interpolation from smooth curves plotted from the results of the tests.[37]

(-a) Sufficient tests shall be performed to provide at least five data points that are at increments that are within 20% to 30% of the range covered.

(-b) The curves shall be based on the lower bound of the test data.

(-c) Extrapolation is not permitted.

(e) Proof test methods (l), (m), (n), and (o) below establish a pressure at which the test is terminated. The results of the test are recorded in a Proof Test Report according to (b).

(1) The MAWP for the first duplicate part, as defined in (d), to be put into service, shall be calculated according to the equations given in the proof test method applied.

The requirements for NDE are given in UG-24 and UW-12. Other requirements are based on thickness or material. These apply to parts which are to be put into service. It is not necessary to examine the part actually tested.

(2) For subsequent duplicate parts, the MAWP may be recalculated for a different extent of NDE in a supplement to the original Proof Test Report.

(3) The effect of the location of a weld joint may be evaluated and included in the Proof Test Report.

(f) A retest shall be allowed on a duplicate vessel or vessel part if errors or irregularities are obvious in the test results.

(g) In tests for determination of governing stresses, sufficient locations on the vessel shall be investigated to ensure that measurements are taken at the most critical areas. As a check that the measurements are being taken on the most critical areas, the Inspector may require a brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in (n) and (o) below. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

NOTE: Strains should be measured as they apply to membrane stresses and to bending stresses within the range covered by UG-23(c).

(h) Application of Pressure. In the procedures given in (l), (n), and (o) below, the Displacement Measurement Test, the hydrostatic pressure in the vessel or vessel part shall be increased gradually until approximately one-half the anticipated working pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated maximum allowable working pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made, and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

(i) Corrosion Allowance. The test procedures in this paragraph give the maximum allowable working pressure for the thickness of material tested. The thickness of the pressure vessel that is to be proof tested should be the

corroded thickness. When this is not practical and when the thickness as tested includes extra thickness as provided in UG-25, the maximum allowable working pressure at which the vessel shall be permitted to operate shall be determined by multiplying the maximum allowable working pressure obtained from the test by the ratio

$$(t-c)^n/t^n$$

where

c = allowance added for corrosion, erosion, and abrasion

n = 1 for curved surfaces such as parts of cylinders, spheres, cones with angle $\alpha \leq 60$ deg; for stayed surfaces similar to those described in UW-19(b) and UW-19(c); and parts whose stress due to bending is ≤ 67% of the total stress

= 2 for flat or nearly flat surfaces, such as flat sides, flanges, or cones with angle $\alpha > 60$ deg (except for stayed surfaces noted above) unless it can be shown that the stress due to bending at the limiting location is <67% of the total stress

t = nominal thickness of the material at the weakest point

(j) Determination of Yield Strength and Tensile Strength

(1) For proof tests based on yielding, (l), (n), or (o) below, the yield strength (or yield point for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress–strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification. For proof tests based on bursting [see (m) below], the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(2) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in (l), (m), (n), and (o) below for evaluation of proof test results to establish the maximum allowable working pressure.

(3) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimen shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen. When the sheet material is used, test specimens obtained from another piece cut from the same coil of sheet used in the proof tested component meet the requirements of this paragraph.

(k) Maximum Allowable Working Pressure at Higher Temperatures. The maximum allowable working pressure for vessels and vessel parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following formula:

$$P_0 = P_t \frac{S}{S_2}$$

where

P_0 = maximum allowable working pressure at the design temperature

P_t = maximum allowable working pressure at test temperature

S = maximum allowable stress value at the design temperature, as given in the tables referenced in UG-23 but not to exceed S_2

S_2 = maximum allowable stress value for the material used in the test at test temperature as given in the tables referenced in UG-23

(l) Brittle-Coating Test Procedure

(1) Subject to the limitations of (a)(2)(-a) above, this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point (see SA-370, 13.1). The component parts that require proof testing shall be coated with a brittle coating in accordance with (g) above. Pressure shall be applied in accordance with (h) above. The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating, or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding, or if desired, at some lower pressure.

(2) The maximum allowable working pressure P in pounds per square inch (MPa) at test temperature for parts tested under this paragraph shall be computed by one of the following equations.

(-a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H \frac{S_y}{S_{y\,\text{avg}}}$$

(-b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the maximum allowable working pressure:

(-1) For carbon steel meeting an acceptable Code specification, with a specified minimum tensile strength of not over 70,000 psi (480 MPa),

(U.S. Customary Units)

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 5000}\right)$$

(SI Units)

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 35}\right)$$

(-2) For any acceptable material listed in this Division,

$$P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped, psi (kPa)
S_y = specified minimum yield strength at room temperature, psi (kPa)
$S_{y\ avg}$ = actual average yield strength from test specimens at room temperature, psi (kPa)
S_μ = specified minimum tensile strength at room temperature, psi (kPa)

When the formula in (-1) or (-2) above is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal.

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(m) Bursting Test Procedure

(1) This procedure may be used for vessels or vessel parts under internal pressure when constructed of any material permitted to be used under the rules of this Division. The maximum allowable working pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined. Alternatively, the test may be stopped at any pressure before rupture that will satisfy the requirements for the desired maximum allowable working pressure.

(2) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following equations:

(-a) parts constructed of materials other than cast materials:

$$P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu\ avg}} \quad or \quad P = \frac{B}{4} \times \frac{S_\mu E}{S_{\mu r}}$$

(-b) parts constructed of cast iron — see UCI-101; parts constructed of cast ductile iron — see UCD-101;

(-c) parts constructed of cast materials, except cast iron and ductile iron:

$$P = \frac{Bf}{4} \times \frac{S_\mu E}{S_{\mu\ avg}} \quad \text{or} \quad P = \frac{Bf}{4} \times \frac{S_\mu E}{S_{\mu r}}$$

where

B = bursting test pressure, or hydrostatic test pressure at which the test was stopped
E = efficiency of welded joint, if used (see Table UW-12)
f = casting quality factor as specified in UG-24
S_μ = specified minimum tensile strength at room temperature
$S_{\mu\ avg}$ = average actual tensile strength of test specimens at room temperature
$S_{\mu r}$ = maximum tensile strength of range of specification at room temperature

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(n) Strain Measurement Test Procedure

(1) Subject to limitations of (a)(2)(-a) above, this procedure may be used for vessels or vessel parts under internal pressure, constructed of any material permitted to be used under the rules of this Division. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts [see (g) above] by means of strain gages of any type capable of indicating incremental strains to 0.00005 in./in. (0.005%). It is recommended that the gage length be such that the expected maximum strain within the gage length does not exceed the expected average strain within the gage length by more than 10%. The strain gages and the method of attachment shall be shown by test to be reliable and the results documented for a range of strain values that is at least 50% higher than expected, when used with the material surface finish and configuration being considered. [See (e) above.]

(2) Pressure shall be applied as provided in (h) above. After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(3) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the formula, justify the desired working pressure, but shall not exceed the pressure at which the plotted points for the most highly strained gage line reaches the value given below for the material used:

(-a) 0.2% permanent strain for aluminum-base and nickel-base alloys;

(-b) 0.2% permanent strain for carbon low alloy and high alloy steels;

(-c) 0.5% strain under pressure for copper-base alloys.

(4) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following equations:

(-a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H\left(\frac{S_y}{S_{y\ \mathrm{avg}}}\right)$$

(-b) If the actual average yield strength is not determined by test specimens,

$$P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped in accordance with (3) above

S_y = specified minimum yield strength at room temperature

$S_{y\ \mathrm{avg}}$ = actual average yield strength from test specimens at room temperature

The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(o) Displacement Measurement Test Procedure

(1) Subject to the limitations of (a)(2)(-a) above, this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point (see SA-370, 13.1). Displacement shall be measured at the most highly stressed parts [see (g) above] by means of measuring devices of any type capable of measuring to 0.001 in. (0.02 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure, or between a reference point and a fixed base point. Pressure shall be applied as provided in (h) above.

(2) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to assure that the readings represent only displacements of the parts on which measurements are being made and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(3) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(4) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(5) The maximum allowable working pressure P in pounds per square inch (kilopascals) at test temperature for parts tested under this paragraph shall be computed by one of the following equations.

(-a) If the average yield strength is determined in accordance with (j) above,

$$P = 0.5H\left(\frac{S_y}{S_{y\ \mathrm{avg}}}\right)$$

(-b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the maximum allowable working pressure.

(-1) For carbon steel, meeting an acceptable Code specification, with a specified minimum tensile strength of not over 70,000 psi (480 MPa),

(U.S. Customary Units)

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 5000}\right)$$

(SI Units)

$$P = 0.5H\left(\frac{S_\mu}{S_\mu + 35}\right)$$

(-2) For any acceptable material listed in this Division,

$$P = 0.4H$$

where

H = hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part tested
S_y = specified minimum yield strength at room temperature
$S_{y\ \mathrm{avg}}$ = actual average yield strength from test specimens at room temperature
S_μ = specified minimum tensile strength at room temperature

When the formula in (-1) or (-2) above is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal. The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

(p) Procedure for Vessels Having Chambers of Special Shape Subject to Collapse

(1) Pressure chambers of vessels, portions of which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by UG-28(i), shall withstand without excessive deformation a hydrostatic test of not less than three times the desired maximum allowable working pressure.

(2) The maximum allowable working pressure at other temperatures shall be determined as provided in (k) above.

UG-102 TEST GAGES

(a) An indicating gage shall be connected directly to the vessel or with a pressure line that does not include intermediate valves. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For large vessels, it is recommended that a recording gage be used in addition to indicating gages.

(b) Dial indicating pressure gages used in testing shall be graduated over a range of about double the intended maximum test pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more than 4 times that pressure. Digital reading pressure gages having a wider range of pressure may be used, provided the readings give the same or greater degree of accuracy as obtained with dial pressure gages.

(c) All gages shall be calibrated against a standard dead-weight tester or a calibrated master gage. Gages shall be recalibrated at any time that there is reason to believe that they are in error.

UG-103 NONDESTRUCTIVE TESTING

Where magnetic particle examination is prescribed in this Division it shall be done in accordance with Mandatory Appendix 6. Where liquid penetrant examination is prescribed it shall be done in accordance with Mandatory Appendix 8.

MARKING AND REPORTS

UG-115 GENERAL

(a) The marking and certification of all pressure vessels built under this Division shall comply with the requirements of the following paragraphs and in addition with the requirements for *Marking and Reports* given in the applicable Parts of Subsections B and C.

(b) The units of measurement used in Manufacturer's Data Reports, Manufacturer's Certificates of Compliance (UG-120), and capacity certification of pressure relief devices, and in marking or stamping pressure vessels, pressure vessel parts, and pressure relief devices, required by this Division, shall be either U.S. Customary units, SI, or any local customary units. See U-4.

UG-116 REQUIRED MARKING (19)

(a) Each pressure vessel shall be marked with the following:

(1) See below.

(-a) the official Certification Mark with the U Designator shown in Figure UG-116, sketch (a) on vessels inspected in accordance with the requirements in UG-90 through UG-97 (when inspected by a user's Inspector as provided in UG-91, the word USER shall be marked above the Certification Mark); or

(-b) the official Certification Mark with the UM Designator shown in Figure UG-116, sketch (b) on vessels constructed in accordance with the provisions in U-1(j); or

(-c) the official Certification Mark with the PRT Designator shown in Figure UG-116, sketch (c) on parts [see (h)]

(2) name of the Manufacturer of the pressure vessel preceded by the words "certified by"

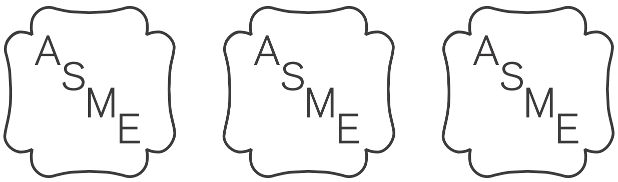
(3) maximum allowable working pressure[10,35] (internal or external[38]) ________at temperature ________

(4) minimum design metal temperature ________at maximum allowable working pressure[10] ________

(5) Manufacturer's serial number

(6) year built

Figure UG-116
Official Certification Mark to Denote the American Society of Mechanical Engineers' Standard



U (a) | UM (b) | PRT (c)

(7) the maximum designed steaming capacity for vessels in accordance with U-1(g)(1)

(b) See below.

(1) The type of construction used for the vessel shall be indicated directly under the Certification Mark by applying the appropriate designators and letter(s) as follows:

Type of Construction	Letter(s)
Tensile enhanced by heat treat (see UHT-115)	UHT
Layered (see ULW-115)	WL
Low temperature (see ULT-115)	ULT
Graphite (see UIG-116)	G
Cold stretched (see Mandatory Appendix 44, 44-7)	CS

(2) Vessels embodying a combination of types of construction shall be marked to indicate all of the types of construction used.

(c) When a vessel is intended for special service and the special requirements have been complied with [see UG-120(d)], the appropriate lettering shall be applied as listed below:

Special Service	Letter(s)
Lethal service	L
Unfired steam boiler	UB
Direct firing	DF

This lettering shall be separated by a hyphen and applied after the lettering of (b) above.

(d) The maximum allowable working pressure and temperature to be indicated on vessels embodying a combination of types of construction and material shall be based on the most restrictive detail of construction and material used.

(e) When radiographic or ultrasonic examination has been performed on a vessel in accordance with UW-11, marking shall be applied under the Certification Mark as follows:

(1) "RT 1" when all pressure-retaining butt welds, other than Category B and C butt welds associated with nozzles and communicating chambers that neither exceed NPS 10 (DN 250) nor $1\frac{1}{8}$ in. (29 mm) wall thickness [except as required by UHT-57(a)], satisfy the full radiography requirements of UW-11(a) for their full length; full radiography of the above exempted Category B and C butt welds, if performed, may be recorded on the Manufacturer's Data Report; or

(2) "RT 2" when the complete vessel satisfies the requirements of UW-11(a)(5) and when the spot radiography requirements of UW-11(a)(5)(-b) have been applied; or

(3) "RT 3" when the complete vessel satisfies the spot radiography requirements of UW-11(b); or

(4) "RT 4" when only part of the complete vessel has satisfied the radiographic requirements of UW-11(a) or where none of the markings "RT 1," "RT 2," or "RT 3" are applicable.

The extent of radiography and the applicable joint efficiencies shall be noted on the Manufacturer's Data Report.

(f) See below.

(1) The letters HT shall be applied under the Designators when the complete vessel has been postweld heat treated as provided in UW-10.

(2) The letters PHT shall be applied under the Designators when only part of the complete vessel has been postweld heat treated as provided in UW-10.

The extent of the postweld heat treatment shall be noted on the Manufacturer's Data Report.

(g) The Manufacturer shall have a valid Certificate of Authorization, and, with the acceptance of the Inspector, shall apply the Certification Mark to the vessel, which, together with the final certification [see U-1(j) and UG-120], shall indicate that all requirements of this Division have been met.

(1) Except as provided in (2) below, the Certification Mark shall be applied after the hydrostatic test or pneumatic test.

(2) The Certification Mark may be preapplied to a nameplate. The nameplate may be attached to the vessel after the final fabrication and examination sequence but before the hydrostatic tests or pneumatic test, provided the procedure for sequence of stamping is described in the Manufacturer's accepted Quality Control System.

(h) See below.

(1) Parts of vessels for which Partial Data Reports are required in UG-120(c) shall be marked by the parts Manufacturer, with a nameplate or stamping, with the following:

(-a) the official Certification Mark with, as applicable, either

(-1) the U Designator shown in Figure UG-116, sketch (a) above the word "PART"

(-2) the PRT Designator shown in Figure UG-116, sketch (c)

(-b) name of the Manufacturer of the part of the pressure vessel preceded by the words "certified by";

(-c) the Manufacturer's serial number.

Parts may be stamped with the Certification Mark without being pressure tested prior to shipment. If testing was not performed, this shall be indicated in the Remarks section of the U-2 and U-2A Manufacturer's Partial Data Reports (see Nonmandatory Appendix W, Forms U-2 and U-2A).

This requirement does not apply to such items as handhole covers, manhole covers and their accessories. [See (k) below.]

(2) As an alternative to nameplates or stamping, parts 5 in O.D. and under may be marked with an identification acceptable to the Inspector and traceable to the Form U-2 or Form U-2A Manufacturer's Partial Data Report. Such marking shall be of a type that will remain visible until the parts are installed. The Certification Mark is not required.

(3) No accessory or part of a pressure vessel may be marked "ASME" or "ASME Std." unless so specified in this Division.

(4) A nameplate furnished with the Certification Mark on prefabricated or preformed parts may be removed from the completed pressure vessel if all of the following conditions are satisfied:

(-a) The nameplate interferes with further fabrication or service.

(-b) The Manufacturer of the completed vessel has agreement from the Authorized Inspector to remove the nameplate.

(-c) The removal of the nameplate shall be noted in the "Remarks" section of the vessel Manufacturer's Data Report.

(-d) The removed nameplate shall be destroyed.

(i) All required markings shall be located in a conspicuous place on the vessel, preferably near a manhole or handhole (see M-3).

(j) Combination Units

(1) Those chambers included within the scope of this Division shall be marked. The marking shall include the name of each chamber (e.g., process chamber, jacket, tubes, channel) and its corresponding data. The markings shall be grouped in one location on the combination unit or applied to each individual chamber. Each detachable chamber shall be marked to identify it with the combination unit. When required, the marking shall include the following:

(-a) for differential pressure design, the maximum differential design pressure for each common element and the name of the higher pressure chamber [see UG-19(a)(2)]

(-b) for mean metal temperature design, the maximum mean metal design temperature for each common element [see UG-19(a)(3)].

(-c) for a common element adjacent to a chamber not included within the scope of this Division, the common element design conditions from that chamber

(2) It is recommended that the design conditions for those chambers not included within the scope of this Division be marked on the combination unit. The markings may be on the applicable chamber or grouped as described in (1), provided they are not included in the markings covered by the Certification Mark.

(k) Removable pressure parts shall be permanently marked in a manner to identify them with the vessel or chamber of which they form a part. This does not apply to manhole covers, handhole covers, and their accessory parts, provided the marking requirements of UG-11 are met.

UG-117 CERTIFICATES OF AUTHORIZATION AND CERTIFICATION MARKS (19)

(a) A Certificate of Authorization to use the Certification Mark with the U, UM, PRT, UV, or UD Designator shown in Figures UG-116, UG-129.1, and UG-129.2 will be granted by the Society pursuant to the provisions of the following paragraphs. Stamps for applying the Certification Mark shall be obtained from the Society. For those items to be marked with the UM, UV, or UD Designator, a Certified Individual meeting the current requirements of ASME QAI-1 shall provide oversight to ensure that each use of the UM, UV, or UD Designator is in accordance with the requirements of this Division. In addition, each use of the UM, UV, or UD Designators is to be documented on the Certificate of Compliance (Form U-3, U-3A, or U-3P) for vessels bearing the UM Designator, or a Certificate of Conformance (Form UV-1 or Form UD-1) as appropriate.

(1) Requirements for the Certified Individual (CI). The CI shall

(-a) be qualified in accordance with ASME CA-1 and the requirements of this Division

(-b) have the following qualifications as a minimum:

(-1) knowledge of the requirements of this Division for the application of the Certification Mark with the appropriate designator;

(-2) knowledge of the Manufacturer's or Assembler's quality program;

(-3) training commensurate with the scope, complexity, or special nature of the activities to which oversight is to be provided.

(-c) have a record, maintained and certified by the Manufacturer or Assembler, containing objective evidence of the qualifications of the CI and the training program provided.

(2) Duties of the Certified Individual (CI). The CI shall

(-a) verify that each item to which the Certification Mark is applied meets all applicable requirements of this Division and has a current capacity certification for the UV or UD Designator;

(-b) for the UV or UD Designator, review documentation for each lot of items to be stamped to verify, for the lot, that requirements of this Division have been completed;

(-c) sign the appropriate Certificate of Compliance/Conformance (Form U-3, U-3A, U-3P, UV-1, or UD-1) as appropriate prior to release of control of the item.

(3) Certificate of Compliance/Conformance (Form U-3, U-3A, U-3P, UV-1, or UD-1)

(-a) The appropriate Certificate of Conformance shall be filled out by the Manufacturer or Assembler and signed by the Certified Individual. Mass-produced pressure relief devices may be recorded on a single entry, provided the devices are identical and produced in the same lot.

(-b) The Manufacturer's or Assembler's written quality control program shall include requirements for completion of Certificates of Conformance forms and retention by the Manufacturer or Assembler for a minimum of 5 yr.

(b) Application for Certificate of Authorization. Any organization desiring a Certificate of Authorization shall apply to ASME in accordance with the certification process of ASME CA-1. Authorization to use Certification Marks maybe granted, renewed, suspended, or withdrawn as specified in ASME CA-1. Applicants for a UM Certificate of Authorization must already hold an S or U Certificate.

(c) Issuance of Authorization. Certificate of Authorization shall be issued in accordance with ASME CA-1 (see www.asme.org/shop/certification-accreditation).

(d) Designated Oversight.. The Manufacturer shall comply with the requirements of ASME CA-1 for designated oversight by use of an Authorized Inspection Agency or Certified Individual, as applicable.

(e) Quality Control System. Any Manufacturer holding or applying for a Certificate of Authorization shall demonstrate a quality control program that meets the requirements of ASME CA-1 and establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection of vessel and vessel parts (by the Authorized Inspector or Certified Individual, as applicable), pressure testing, and certification, will be met. The Quality Control System shall be in accordance with the requirements of Mandatory Appendix 10.

(f) Evaluation of the Quality Control System. The issuance or renewal of a Certificate of Authorization is based upon ASME's evaluation and approval of the Quality Control System, and shall be in accordance with ASME CA-1. Before issuance or renewal of a Certificate of Authorization for use of the U, UM, or PRT Designator, the Manufacturer's facilities and organization are subject to a joint review by a representative of the Authorized Inspection Agency and an individual certified as an ASME designee who is selected by the concerned legal jurisdiction.

Before issuance or renewal of a Certificate of Authorization for use of the UV or UD Designator, the valve or rupture disk device Manufacturer's or Assembler's facilities and organization are subject to a review by a representative from an ASME Designated Organization.

Certificates of Authorization are valid for the period given in ASME CA-1. UM Certificates are valid for 1 yr, but reviews after the first and second years of each 3-yr period are performed by the Authorized Inspection Agency only and shall include at a minimum an Authorized Inspector Supervisor.

Any changes made to the Quality Control System shall be made and accepted in accordance with the requirements specified in ASME CA-1. For Manufacturers of mass-produced pressure vessels,[39] acceptance of these changes by the ASME designee is also required.

For those areas where there is no jurisdiction or where a jurisdiction does not choose to select an ASME designee to review a vessel or vessel parts Manufacturer's facility, that function shall be performed by an ASME designee selected by ASME. Where the jurisdiction is the Manufacturer's Inspection Agency, the joint review and joint report shall be made by the jurisdiction and an ASME designee selected by ASME.

(g) Code Construction Before Receipt of Certificate of Authorization. When used to demonstrate his Quality Control System, a Manufacturer may start fabricating Code items before receipt of a Certificate of Authorization to use a Certification Mark under the conditions specified in ASME CA-1.

UG-118 METHODS OF MARKING

(a) The required marking shall be applied to the vessel by one of the following methods:

(1) nameplate as provided in UG-119

(2) stamped directly on the vessel under the following conditions:

(-a) Unless the requirements of (-b) or (-c) are met, such stamping shall not be used on vessels constructed of steel plates less than $^1/_4$ in. (6 mm) thick or of nonferrous plates less than $^1/_2$ in. (13 mm) thick but may be used on vessels constructed of thicker plates.

(-b) For Ferrous Materials

(-1) The materials shall be limited to P-No. 1, Group Nos. 1 and 2.

(-2) The minimum nominal plate thickness shall be 0.1875 in. (5 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (4 mm).

(-3) The minimum design metal temperature shall be no colder than −20°F (−29°C).

(-c) For Nonferrous Materials

(-1) The materials shall be limited to aluminum as follows: SB-209 alloys 3003, 5083, 5454, and 6061; SB-241 alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 alloys 3003, 5083, and 6061.

(-2) The minimum nominal plate thickness shall be 0.249 in. (6.30 mm), or the minimum nominal pipe thickness shall be 0.133 in. (3.38 mm).

(3) electrochemically etched, including the Certification Mark, directly on the vessel under the following conditions:

(-a) The electrochemically etched marking is acceptable to the user as indicated in the User's Design Requirements per Nonmandatory Appendix KK, or equivalent.

(-b) The material of construction shall be limited to high alloy steels and nonferrous materials.

(-c) The process controls for electrochemical etching shall be described in the Quality Control System and shall be acceptable to the Authorized Inspector. The process controls shall be established so that it can be demonstrated that the characters will be at least 0.004 in. (0.102 mm) deep.

(-d) The external vessel-surface condition where electrochemical etching is acceptable shall be clean, uncoated, and unpainted.

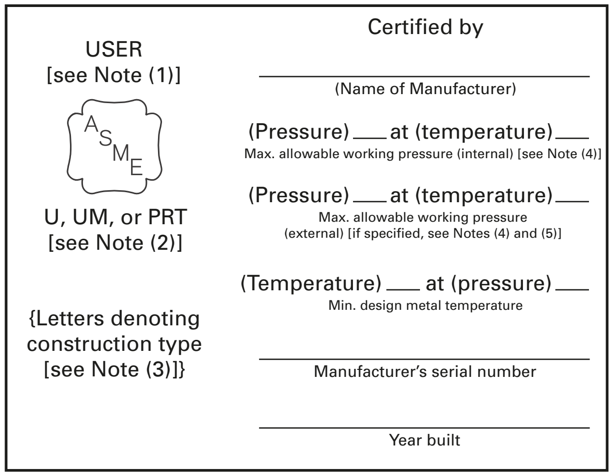
(-e) The electrochemical etching shall not result in any detrimental effect to the materials of the vessel.

(b) Stamped or electrochemically etched letters and figures shall be in characters not less than $^5/_{16}$ in. (8 mm) high. The character size may be reduced as shown in the following table for small diameter vessels with space limitations:

Nominal Outside Vessel Diameter, Min., in. (mm)	Nominal Outside Vessel Diameter, Max., in. (mm)	Character Size, Min., in. (mm)
...	$3^1/_2$ (89)	$^1/_8$ (3)
>$3^1/_2$ (89)	$4^1/_2$ (114)	$^3/_{16}$ (5)
>$4^1/_2$ (114)	$6^5/_8$ (168)	$^1/_4$ (6)

(c) Stamping or electrochemical etching shall be arranged substantially as shown in Figure UG-118 when space permits and shall be located in a conspicuous place on the vessel [see UG-116(i)].

Figure UG-118
Form of Stamping



GENERAL NOTE: Information within parentheses, brackets, or braces is not part of the required marking. Phrases identifying data may be abbreviated; minimum abbreviations shall be MAWP, MDMT, S/N, FV, and year, respectively. See ASME PTB-4 for sample Nameplate markings.

NOTES:
(1) "USER" shall be included when the vessel is inspected by a user's Inspector as provided in UG-91.
(2) See UG-116(a)(1)(-a), UG-116(a)(1)(-b), and UG-116(a)(1)(-c).
(3) See UG-116(b)(1), UG-116(c), UG-116(e), UG-116(f), and UG-116(h)(1)(-a).
(4) For cases where the MAWP (internal) and MAWP (external) values have the same designated coincident temperature, the values may be combined on a single line as follows:

$$P_{int}/FV\ (psi)\ at\ Temp\ (°F)$$

(5) The maximum allowable working pressure (external) is required only when specified as a design condition.

(19) UG-119 NAMEPLATES

(a) Nameplates shall be used on vessels except when markings are directly applied in accordance with UG-118. Nameplates shall be metal suitable for the intended service and shall bear the markings called for in UG-116. The marking arrangement shall be substantially as shown in Figure UG-118. Required nameplates shall be located in a conspicuous place on the vessel.

(b) The nameplate thickness shall be sufficient to resist distortion due to the application of the marking and to be compatible with the method of attachment. The nameplate nominal thickness shall not be less than 0.020 in.

(c) Nameplates may have markings produced by either casting, etching, embossing, debossing, stamping, or engraving, except that the Certification Mark shall be stamped on the nameplate.

(1) The required markings on a nameplate shall be in characters not less than $^5/_{32}$ in. (4 mm) high, except that characters for pressure relief device markings may be smaller.

(2) Characters shall be either indented or raised at least 0.004 in. (0.10 mm) and shall be legible and readable.

(d) The nameplate may be marked before it is affixed to the vessel, in which case the Manufacturer shall ensure that the nameplate with the correct marking has been applied to the proper vessel, and the Inspector shall satisfy himself that this has been done.

(e) The nameplate shall be attached to the vessel or to a pad, bracket, or structure that is welded, brazed, soldered, or attached with mechanical fasteners directly to the vessel. Mechanical fasteners shall be of a material and design that is compatible with the vessel, bracket materials, and the vessel service. After installation of the pad, bracket, or structure, the heads of the fasteners shall be welded,

brazed, or soldered to the pad, bracket, or structure that supports the nameplate. The nameplate shall be located within 30 in. (760 mm) of the vessel. Removal shall require the willful destruction of the nameplate, or its attachment system. (See M-3.)

(1) Nameplates may be attached either by welding, brazing, or soldering.

(2) Nameplates may be attached by tamper-resistant mechanical fasteners of suitable metal construction.

(3) Nameplates may be attached with pressure-sensitive acrylic adhesive systems provided that, in addition to the requirements of this paragraph, those of Mandatory Appendix 18 are met.

(f) An additional nameplate in accordance with (a) through (d) may be installed on the skirt, supports, jacket, or other permanent attachment to a vessel. All data on the additional plate, including the Certification Mark with the Designator, shall be as required for the mandatory nameplate. The marking need not be witnessed by the Inspector. The additional nameplate shall be marked: “DUPLICATE.”

(g) When a nameplate is employed, the Manufacturer’s name or identifying trademark, and vessel serial number (or National Board Number, if applicable,) may also be marked directly on the vessel in close proximity to the nameplate attachment. The marking shall be of a visible permanent type that is not detrimental to the vessel, and its location shall be indicated on the Data Report.

(1) If the thickness limitations of UG-118 preclude marking directly on the vessel shell or heads, it may be applied to the skirt, supports, jacket, or other permanent attachment to the vessel.

(19) UG-120 DATA REPORTS

(a) A Data Report shall be filled out on Form U-1, U-1A, or U-1P by the Manufacturer and shall be signed by the Manufacturer and the Inspector for each pressure vessel marked with the Certification Mark with the U Designator.

(1) Same day production of vessels may be reported on a single Form, provided all of the following requirements are met:

(-a) vessels must be identical;

(-b) vessels must be manufactured for stock or for the same user or his designated agent;

(-c) serial numbers must be in uninterrupted sequence; and

(-d) the Manufacturer’s written Quality Control System includes procedures to control the development, distribution, and retention of the Data Reports.

(2) For guidance in preparing the Manufacturer's Data Report Forms, see Nonmandatory Appendix W. Horizontal spacing for information on each line may be altered as necessary. All information must be addressed; however, footnotes described in the “Remarks” block are acceptable, e.g., for multiple cases of “none” or “not applicable.”

(3) The Manufacturer shall

(-a) furnish a copy of the Manufacturer’s Data Report to the user and, upon request, to the Inspector:

(-b) submit a copy of the Manufacturer’s Data Report to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed, where required by law;

(-c) keep a copy of the Manufacturer’s Data Report on file in a safe repository for at least 3 years.

In lieu of (-c) above, the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229. Where acceptable to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed, the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors in lieu of (-b) above.

(4) A Manufacturer’s Certificate of Compliance on Form U-3, U-3A, or U-3P shall be completed and signed by the Manufacturer for each pressure vessel marked with the Certification Mark with the UM Designator. This Certificate shall be maintained by the Manufacturer for 5 years and a copy made available upon request, or the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229. Where acceptable to the appropriate enforcement authority in the jurisdiction in which the vessel is to be installed, the vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors. Identical vessels up to 1 day’s production may be recorded on a single Certificate of Compliance.

(b) Combination Units

(1) Those chambers included within the scope of this Division shall be described on the same Data Report. This includes the following, as applicable:

(-a) for differential pressure design, the maximum differential design pressure for each common element and the name of the higher pressure chamber [see UG-19(a)(2)]

(-b) for mean metal temperature design, the maximum mean metal design temperature for each common element [see UG-19(a)(3)]

(-c) for a common element adjacent to a chamber not included within the scope of this Division, the common element design conditions from that chamber

(2) It is recommended that those chambers not included within the scope of this Division be described in the “Remarks” section of the Data Report.

(3) For a fixed tubesheet heat exchanger, as defined in UHX-3.2, Form U-5 shall be filled out with the information required by UHX-19.3.2, signed by the Manufacturer and Inspector, and included with the Manufacturer’s Data Report.

(c) Partial Data Reports

(1) Data Reports to document the construction activities of pressure vessel parts requiring inspection under this Division that are furnished by a parts Manufacturer other than the Manufacturer responsible for the completed vessel shall be executed on the applicable Partial Data Report, Form U-2 or Form U-2A, by the parts Manufacturer and his Inspector in accordance with the requirements of this Division. The Manufacturer's Partial Data Report shall be forwarded, in duplicate, to the Manufacturer of the completed vessel [see U-2(b)]. Form U-2A may be used for this purpose, provided all the applicable information is recorded on this Form; otherwise Form U-2 shall be used. These Partial Data Reports, together with his own inspection, shall be the final Inspector's authority to witness the application of a Certification Mark to the vessel [see UG-90(c)]. When Form U-2 or Form U-2A is used, it shall be attached to the associated Form U-1, U-1A, or U-1P by the Manufacturer of the vessel to be marked with the Certification Mark. Manufacturers and Assemblers of parts who do not perform or assume any design responsibility for the parts they manufacture shall identify on the Partial Data Report the organization responsible for the design of the part.

(-a) Data Reports for those parts of a pressure vessel which are furnished by a parts Manufacturer to the user of an existing Code vessel as replacement or repair parts shall be executed on Form U-2 or Form U-2A by the parts Manufacturer and his Inspector in accordance with the requirements of this Division. A copy of the parts Manufacturer's Partial Data Report shall be furnished to the user or his designated agent and maintained in accordance with (a) above.

(-b) The parts Manufacturer shall indicate under "Remarks" the extent he has performed any or all of the design functions. When the parts Manufacturer performs only a portion of the design, he shall state which portions of the design he performed.

(-c) Same day production of vessel parts may be reported on a single Form U-2 or Form U-2A, provided all of the following are met:

(-1) vessel parts shall be identical;

(-2) Manufacturer's serial numbers must be in uninterrupted sequence; and

(-3) The Manufacturer's written Quality Control System includes procedures to control the development, distribution, and retention of the Partial Data Reports.

(-d) For guidance in preparing Partial Data Reports, see Nonmandatory Appendix W.

(-e) Manufacturers with multiple locations under the operational control of a single organization[40], each location with its own Certificate of Authorization, may transfer welded or brazed pressure vessel parts, or completely welded pressure vessels that have not been pressure tested or received final inspection, from one location to another without Partial Data Reports, provided the Quality Control System describes the method of identification, transfer, and receipt of the parts. These methods shall include the following requirements:

(-1) Identification requirements shall include details of the specific marking to be applied. Identification shall be on each part and shall be legible, permanent, and not detrimental to the part.

(-2) The Certificate Holder shall have a transmittal form that is included with each transfer. It shall list all items with corresponding identification number, with indication that the items do not contain the Certification Mark. This form shall be signed by the Certificate Holder.

(-3) The receiving location shall inspect each item upon receipt.

(-4) The Manufacturer of the completed vessel shall retain all transfer forms as part of the vessel records; see Mandatory Appendix 10, 10-13.

(-f) For cases in which a Manufacturer has multiple locations that include both shop and field locations, and the field assembly of a vessel is completed by one Manufacturer's location that is different from the part Manufacturer's location(s), the name of the Manufacturer responsible for field assembly shall be shown on Line 1 of the Manufacturer's Data Report. The Manufacturer responsible for field assembly shall complete and sign both the Shop and Field portions of the Manufacturer's Data Report.

(2) A Manufacturer with multiple locations, each holding its own Certificate of Authorization, may transfer pressure vessel parts from one of its locations to another without Partial Data Reports, provided the Quality Control System describes the method of identification, transfer, and receipt of the parts. For cases in which a Manufacturer has multiple locations that include both shop and field locations, and the field assembly of the vessel is completed by one Manufacturer's location that is different from the part Manufacturer's location(s), the name of the Manufacturer responsible for field assembly shall be shown on Line 1 of the Manufacturer's Data Report. The Manufacturer responsible for field assembly shall complete and sign both the Shop and Field portions of the Manufacturer's Data Report.

(d) This Division, in paragraphs such as UW-2, UF-1, UF-32(b), UB-1, UB-22, UCS-66, UNF-56, UHA-51, UCL-27, and UHT-6, establishes special requirements to qualify a vessel for certain "special services." (Paragraphs, such as UW-2, prohibit certain types of construction or materials in some special services.) The special services to which special requirements are applicable are classified as follows:

(1) lethal service [for example, see UW-2(a)];

(2) services below certain temperatures (for example, see UW-2(b), UCS-65, UHA-51, and UHT-6);

(3) unfired steam boiler [for example, see UW-2(c)];

(4) direct firing [for example, see UW-2(d)].

When a vessel is intended for such special services, the special service and the paragraphs of special requirements complied with shall be indicated on the Data Reports.

(e) Pressure-retaining covers and their attaching bolting and nuts shall be listed in the Remarks section of the Manufacturer's Data Report or on an attached Form U-4 when required. The minimum information shall include the material specification, material grade, size, and thread designation.

(f) An unfired steam boiler, referenced in U-1(g)(1), shall have its maximum designed steaming capacity recorded in the "Remarks" section of the Data Report.

(g) For sample forms and guidance in their preparation, see Nonmandatory Appendix W.

OVERPRESSURE PROTECTION

UG-125 GENERAL

(a) Other than unfired steam boilers, all pressure vessels within the scope of this Division, irrespective of size or pressure, shall be provided with overpressure protection in accordance with the requirements of UG-125 through UG-138, or with overpressure protection by system design in accordance with the requirements of UG-140, or a combination of the two. Unfired steam boilers shall be provided with overpressure protection in accordance with the requirements of UG-125 through UG-138. In addition, the following shall apply:

(1) It is the user's or his/her designated agent's responsibility to identify all potential overpressure scenarios and the method of overpressure protection used to mitigate each scenario.

(2) It is the responsibility of the user to ensure that the required overpressure protection system is properly installed prior to initial operation.

(3) If a pressure relief device(s) is to be installed, it is the responsibility of the user or his/her designated agent to size and select the pressure relief device(s) based on its intended service. Intended service considerations shall include, but not necessarily be limited to, the following:

(-a) normal operating and upset conditions

(-b) fluids

(-c) fluid phases

(4) The overpressure protection system need not be supplied by the vessel Manufacturer.

(5) Unless otherwise defined in this Division, the definitions relating to pressure relief devices in Section 2 of ASME PTC 25 shall apply.

(b) An unfired steam boiler shall be equipped with pressure relief devices required by Section I insofar as they are applicable to the service of the particular installation.

(c) Other than unfired steam boilers, when a pressure relief device is provided, it shall prevent the pressure from rising more than 10% or 3 psi (20 kPa), whichever is greater, above the maximum allowable working pressure except as permitted in (1) and (2) below and UG-127(d)(3). (See UG-134 for pressure settings.)

(1) When multiple pressure relief devices are provided and set in accordance with UG-134(a), they shall prevent the pressure from rising more than 16% or 4 psi (30 kPa), whichever is greater, above the maximum allowable working pressure.

(2) When a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) shall be capable of preventing the pressure from rising more than 21% above the maximum allowable working pressure. Supplemental pressure relief devices shall be installed to protect against this source of excessive pressure if the pressure relief devices used to satisfy the capacity requirements of (c) and (1) have insufficient capacity to provide the required protection. See Nonmandatory Appendix M, M-13 for cases where the metal temperature due to fire or other sources of external heat can cause vessel failure prior to reaching the MAWP.

(3) Pressure relief devices, intended primarily for protection against exposure of a pressure vessel to fire or other unexpected sources of external heat installed on vessels having no permanent supply connection and used for storage at ambient temperatures of nonrefrigerated liquefied compressed gases,[41] are excluded from the requirements of (1) and (2) above, provided:

(-a) the pressure relief devices are capable of preventing the pressure from rising more than 20% above the maximum allowable working pressure of the vessels;

(-b) the set pressure marked on these devices shall not exceed the maximum allowable working pressure of the vessels;

(-c) the vessels have sufficient ullage to avoid a liquid full condition;

(-d) the maximum allowable working pressure of the vessels on which these pressure relief devices are installed is greater than the vapor pressure of the stored liquefied compressed gas at the maximum anticipated temperature[42] that the gas will reach under atmospheric conditions; and

(-e) pressure relief valves used to satisfy these provisions also comply with the requirements of UG-129(a)(5), UG-131(c)(2), and UG-134(d)(2).

(d) Pressure relief devices shall be constructed, located, and installed so that they are readily accessible for testing, inspection, replacement, and repair and so that they cannot be readily rendered inoperative (see Nonmandatory Appendix M).

(e) Pressure relief valves or nonreclosing pressure relief devices[43] may be used to protect against overpressure. Nonreclosing pressure relief devices may be used either alone or, if applicable, in combination with pressure relief valves on vessels.

NOTE: Use of nonreclosing pressure relief devices of some types may be advisable on vessels containing substances that may render a pressure relief valve inoperative, where a loss of valuable material by leakage should be avoided, or where contamination of the atmosphere by leakage of noxious fluids must be avoided. The use of rupture disk devices may also be advisable when very rapid rates of pressure rise may be encountered.

(f) Vessels that are to operate completely filled with liquid shall be equipped with pressure relief devices designed for liquid service, unless otherwise protected against overpressure.

(g) The pressure relief devices required in (a) above need not be installed directly on a pressure vessel when either of the following conditions apply:

(1) the source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the maximum allowable working pressure at the operating temperature except as permitted in (c) above (see UG-98), or under the conditions set forth in Nonmandatory Appendix M.

(2) there are no intervening stop valves between the vessel and the pressure relief device or devices except as permitted under UG-135(d).

NOTE: Pressure reducing valves and similar mechanical or electrical control instruments, except for pilot-operated pressure relief valves as permitted in UG-126(b), are not considered as sufficiently positive in action to prevent excess pressures from being developed.

(h) Pressure relief valves for steam service shall meet the requirements of UG-131(b).

UG-126 PRESSURE RELIEF VALVES[44]

(a) Safety, safety relief, and relief valves shall be of the direct spring-loaded type.

(b) Pilot-operated pressure relief valves may be used, provided that the pilot is self-actuated and the main valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot should fail.

(c) The set pressure tolerances, plus or minus, of pressure relief valves shall not exceed 2 psi (15 kPa) for pressures up to and including 70 psi (500 kPa) and 3% for pressures above 70 psi (500 kPa).

UG-127 NONRECLOSING PRESSURE RELIEF DEVICES

(a) Rupture Disk Devices[45]

(1) General. Every rupture disk shall have a marked burst pressure established by rules of UG-137(d)(3) within a manufacturing design range[46] at a specified disk temperature[47] and shall be marked with a lot[48] number. The burst pressure tolerance at the specified disk temperature shall not exceed ±2 psi (±15 kPa) for marked burst pressure up to and including 40 psi (300 kPa) and ±5% for marked burst pressure above 40 psi (300 kPa).

(2) Relieving Capacity. Rupture disk devices certified using the flow resistance method shall use (-a), and rupture disk devices certified using the coefficient of discharge method shall use (-b) below

(-a) The rated flow capacity of a pressure relief system that uses a rupture disk device as the sole relieving device shall be determined by a value calculated under the requirements of (-1) or (-2) below.

(-1) When the rupture disk device discharges directly to the atmosphere and

(+a) is installed within eight pipe diameters from the vessel nozzle entry; and

(+b) with a length of discharge pipe not greater than five pipe diameters from the rupture disk device; and

(+c) the nominal diameters of the inlet and discharge piping are equal to or greater than the stamped NPS (DN) designator of the device, the calculated relieving capacity of a pressure relief system shall not exceed a value based on the applicable theoretical flow equation [see UG-131(e)(2) and Mandatory Appendix 11] for the various media multiplied by a coefficient of discharge K equal to 0.62. The area A in the theoretical flow equation shall be the minimum net flow area[49] as specified by the rupture disk device Manufacturer.

(-2) The calculated capacity of any pressure relief system may be determined by analyzing the total system resistance to flow. This analysis shall take into consideration the flow resistance of the rupture disk device, piping and piping components including the exit nozzle on the vessels, elbows, tees, reducers, and valves. The calculation shall be made using accepted engineering practices for determining fluid flow through piping systems. This calculated relieving capacity shall be multiplied by a factor of 0.90 or less to allow for uncertainties inherent with this method. The certified flow resistance[50] K_R for the rupture disk device, expressed as the velocity head loss, shall be determined in accordance with UG-131(n) through UG-131(u).

(-b) The relieving capacity of the pressure relief system that uses a rupture disk device as the sole relieving device shall be determined by taking into consideration the certified capacity marked on the device and the characteristics of the system fluid and system components upstream and downstream of the rupture disk device. The certified coefficient of discharge K_D for the rupture disk device shall be determined in accordance with UG-131(b) through UG-131(j).

(3) Application of Rupture Disks

(-a) A rupture disk device may be used as the sole pressure-relieving device on a vessel.

NOTE: When rupture disk devices are used, it is recommended that the design pressure of the vessel be sufficiently above the intended operating pressure to provide sufficient margin between operating pressure and rupture disk bursting pressure to prevent premature failure of the rupture disk due to fatigue or creep.

Application of rupture disk devices to liquid service should be carefully evaluated to assure that the design of the rupture disk device and the dynamic energy of the system on which it is installed will result in sufficient opening of the rupture disk.

(-b) A rupture disk device may be installed between a pressure relief valve[51] and the vessel, provided:

(-1) the combination of the pressure relief valve and the rupture disk device is ample in capacity to meet the requirements of UG-125(c);

(-2) the marked capacity of a pressure relief valve (nozzle type) when installed with a rupture disk device between the inlet of the valve and the vessel shall be multiplied by a factor of 0.90 of the rated relieving capacity of the valve alone, or alternatively, the capacity of such a combination shall be established in accordance with (-3) below;

(-3) the capacity of the combination of the rupture disk device and the pressure relief valve may be established in accordance with the appropriate paragraphs of UG-132;

(-4) the space between a rupture disk device and a pressure relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator. This arrangement permits detection of disk rupture or leakage.[52]

(-5) the opening[49] provided through the rupture disk, after burst, is sufficient to permit a flow equal to the capacity of the valve [(-2) and (-3) above], and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the capacity and functioning of the specific combination of rupture disk device and pressure relief valve have been established by test in accordance with UG-132.

(-c) A rupture disk device may be installed on the outlet side[53] of a pressure relief valve which is opened by direct action of the pressure in the vessel, provided:

(-1) the pressure relief valve will not fail to open at its proper pressure setting regardless of any back pressure that can accumulate between the pressure relief valve disk and the rupture disk. The space between the pressure relief valve disk and the rupture disk shall be vented or drained to prevent accumulation of pressure, or suitable means shall be provided to ensure that an accumulation of pressure does not affect the proper operation of the pressure relief valve.[54]

(-2) the pressure relief valve is ample in capacity to meet the requirements of UG-125(c);

(-3) the marked burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping shall not exceed the design pressure of the outlet portion of the pressure relief valve and any pipe or fitting between the valve and the rupture disk device. However, in no case shall the marked burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping exceed the maximum allowable working pressure of the vessel or the set pressure of the pressure relief valve.

(-4) the opening provided through the rupture disk device after breakage is sufficient to permit a flow equal to the rated capacity of the attached pressure relief valve without exceeding the allowable overpressure;

(-5) any piping beyond the rupture disk cannot be obstructed by the rupture disk or fragment;

(-6) the system is designed to consider the adverse effects of any leakage through the pressure relief valve or through the outlet side rupture disk device, to ensure system performance and reliability.[55]

(-7) the bonnet of a balancing bellows or diaphragm type pressure relief valve shall be vented to prevent accumulation of pressure in the bonnet.

(b) Pin Device[56]

(1) General. Every pin device shall have a marked set pressure established by the rules of UG-138(d)(4) and UG-138(d)(5) at a specified pin temperature.[57] The set pressure tolerance shall not exceed ±2 psi (±15 kPa) for marked set pressures up to and including 40 psi (300 kPa) and ±5% for marked set pressures above 40 psi (300 kPa).

(2) Relieving Capacity. Pin devices certified using the flow resistance method shall use (-a) and pin devices certified using the coefficient of discharge method shall use (-b) below.

(-a) The rated flow capacity of a pressure relief system that uses a pin device as the sole relieving device shall be determined by a value calculated under the requirements of (-1) or (-2) below.

(-1) When the pin device discharges directly to atmosphere and

(+a) is installed within eight pipe diameters from the vessel nozzle entry.

(+b) with a length of discharge pipe not greater than five pipe diameters from the pin device.

(+c) the nominal diameters of the inlet and discharge piping are equal to or greater than the stamped NPS (DN) designator of the device, the calculated relieving capacity of a pressure relief system shall not exceed a value based on the applicable theoretical flow equation [see UG-131(e)(2) and Mandatory Appendix 11] for the various media multiplied by a coefficient of discharge K equal to 0.62. The area A in the theoretical flow equation shall be the minimum net flow area[49] as specified by the pin device Manufacturer.

(-2) The calculated capacity of any pressure relief system may be determined by analyzing the total system resistance to flow. This analysis shall take into consideration the flow resistance of the pin device, piping and piping components including the exit nozzle on the vessels,elbows, tees, reducers, and valves. The calculation shall be made using accepted engineering practices for

determining fluid flow through piping systems. This calculated relieving capacity shall be multiplied by a factor of 0.90 or less to allow for uncertainties inherent with this method. The certified flow resistance[50] K_R for the pin device, expressed as the velocity head loss, shall be determined in accordance with UG-131(n) through UG-131(u).

(-b) The relieving capacity of the pressure relief system that uses a pin device as the sole relieving device shall be determined by taking into consideration the certified capacity marked on the device and the characteristics of the system fluid and system components upstream and downstream of the pin device. The certified coefficient of discharge K_D for the pin device shall be determined in accordance with UG-131(b) through UG-131(j).

(3) Application of Pin Devices

(-a) A pin device may be used as the sole pressure-relieving device on a vessel.

(-b) A pin device may be installed between a pressure relief valve and the vessel, provided

(-1) the combination of the pressure relief valve and the pin device is ample in capacity to meet the requirements of UG-125(c)

(-2) the combined capacity of the pressure relief valve and pin device shall be the rated capacity of the valve multiplied by a factor of 0.90 provided the appropriate resistance factor K_{RG}, K_{RGL}, or K_{RL} of the device is less than 6.0 or by a combination capacity factor established in accordance with the appropriate paragraphs of UG-132.

(-3) the space between a pin device and a pressure relief valve shall be provided with a pressure gage, a try cock, free vent, or suitable telltale indicator.

(-4) the opening[49] provided through the pin device, after activation, is sufficient to permit flow equal to the capacity of the valve [(-2) above], and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless the capacity and functioning of the specific combination of pin device and pressure relief valve have been established by test in accordance with UG-132.

(-5) The set pressure of the pin device is equal to or greater than 90% of the set pressure of the pressure relief valve.

(-c) A pin device shall not be installed on the outlet side of a pressure relief valve that is opened by direct action of the pressure in the vessel.

(-d) A pin-actuated pilot-operated pressure relief device may be used to satisfy the requirements of UG-125, provided the requirements of UG-125 through UG-136 for pilot-operated pressure relief valves are met.

(c) Spring-Loaded Nonreclosing Pressure Relief Device

(1) A spring-loaded nonreclosing pressure relief device, pressure actuated by means which permit the spring-loaded portion of the device to open at the specified set pressure and remain open until manually reset, may be used provided the design of the spring-loaded nonreclosing device is such that if the actuating means fail, the device will achieve full opening at or below its set pressure. Such a device may not be used in combination with any other pressure relief device. The tolerance on opening point shall not exceed ±5%.

(2) The calculated capacity rating of a spring-loaded nonreclosing pressure relief device shall not exceed a value based on the applicable theoretical formula (see UG-131) for the various media, multiplied by: K = coefficient = 0.62.

The area A (square inches) in the theoretical formula shall be the flow area through the minimum opening of the spring-loaded nonreclosing pressure relief device.

(3) In lieu of the method of capacity rating in (2) above, a Manufacturer may have the capacity of a spring-loaded nonreclosing pressure relief device design certified in general accordance with the procedures of UG-131, as applicable.

(d) Open Flow Paths or Vents

(1) Flow paths or vents, open directly or indirectly to the atmosphere, may be used as the sole pressure-relieving device on a vessel.

(2) The calculated capacity of any pressure relief system may be determined by analyzing the total system resistance to flow. This analysis shall take into consideration the flow resistance of the piping and piping components including the exit nozzle on the vessels, elbows, tees, reducers, and valves. The calculation shall be made using accepted engineering practices for determining fluid flow through piping systems. This calculated relieving capacity shall be multiplied by a factor of 0.90 or less to allow for uncertainties inherent in this method.

(3) The aggregate capacity of the open flow paths, or vents, shall be sufficient to prevent overpressure in excess of those specified in UG-125(c). When the MAWP is 15 psi (105 kPa) or less, in no case shall the pressure be allowed to rise more than 21% above the MAWP.

UG-128 LIQUID PRESSURE RELIEF VALVES

Any liquid pressure relief valve used shall be at least NPS $^1\!/_2$ (DN 15).

UG-129 MARKING (19)

(a) Safety, Safety Relief, Relief, Liquid Pressure Relief, and Pilot-Operated Pressure Relief Valves. Each safety, safety relief, relief, liquid pressure relief, and pilot-operated pressure relief valve NPS $^1\!/_2$ (DN 15) and larger shall be plainly marked by the Manufacturer or Assembler with the required data in such a way that the marking will not be obliterated in service. The marking may be placed on the valve or on a metal plate or plates securely fastened to the valve.

(1) the name, or an acceptable abbreviation, of the Manufacturer and the Assembler;

(2) Manufacturer's design or type number;

(3) NPS size (DN) ________ (the nominal pipe size of the valve inlet);

(4) set pressure ________ psi (kPa), and, if applicable per UG-136(d)(4)(-d)

(-a) cold differential test pressure _______ psi (kPa)

(-b) superimposed back pressure _______ psi (kPa)

(5) certified capacity (as applicable):

(-a) lb/hr (kg/hr) of saturated steam at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for valves certified on steam complying with UG-131(b); or

(-b) gal/min (l/min) of water at 70°F (20°C) at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for valves certified on water; or

(-c) SCFM (standard cubic feet per minute at 60°F and 14.7 psia) [m^3/min (cubic meters per minute at 20°C and 101 kPa)], or lb/min (kg/min), of air at an overpressure of 10% or 3 psi (kPa), whichever is greater. Valves that are capacity certified in accordance with UG-131(c)(2) shall be marked "at 20% overpressure."

(-d) In addition to one of the fluids specified above, the Manufacturer may indicate the capacity in other fluids (see Mandatory Appendix 11).

(6) year built, or alternatively, a coding may be marked on the valve such that the valve Manufacturer or Assembler can identify the year the valve was assembled or tested;

(7) the Certification Mark with the UV Designator placed under the Mark, as shown in Figure UG-129.1. A marking method other than the stamp issued by the Society may be used, provided it is acceptable to the ASME Designated Organization. The pilot of a pilot-operated pressure relief valve shall be plainly marked by the Manufacturer or Assembler showing the name of the Manufacturer, the Manufacturer's design or type number, the set pressure in pounds per square inch (kPa), and the year built, or alternatively, a coding that the Manufacturer can use to identify the year built.

On valves smaller than NPS ½ (DN 15), the markings may be made on a metal plate attached by wire or adhesive meeting the requirements of Mandatory Appendix 18 or other means suitable for the service conditions.

(8) restricted lift ________ in. (mm) (For restricted lift valves only)

(b) Safety and safety relief valves certified for a steam discharging capacity under the provisions of Section I and bearing the Certification Mark with the V Designator for safety valves may be used on pressure vessels. The rated capacity in terms of other fluids shall be determined by the method of conversion given in Mandatory Appendix 11. [See UG-131(h).]

(c) *Pressure Relief Valves in Combination With Rupture Disk Devices*. Pressure relief valves in combination with rupture disk devices shall be marked with the capacity as established in accordance with UG-127(a)(3)(-b)(-2) (using 0.90 factor) or the combination capacity factor established by test in accordance with UG-132(a) or UG-132(b), in addition to the marking of (a) and (e) below. The marking may be placed on the pressure relief valve or rupture disk device or on a plate or plates that satisfy the requirements of UG-119. The marking shall include the following:

Figure UG-129.1
Official Certification Mark to Denote the American Society of Mechanical Engineers' Standard for Pressure Relief Valves

(1) name of Manufacturer of valve;

(2) design or type number of valve;

(3) name of Manufacturer of rupture disk device;

(4) design or type number of rupture disk device;

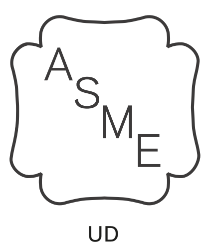
(5) capacity or combination capacity factor;

(6) name of organization responsible for this marking. This shall be either the vessel user, vessel Manufacturer, rupture disk Manufacturer, or pressure relief valve Manufacturer.

(d) *Pressure Relief Valves in Combination With Pin Devices*. Pressure relief valves in combination with pin devices shall be marked with the capacity as established in accordance with UG-127(b)(3)(-b)(-2) (using 0.90 factor) or the combination capacity factor established by test in accordance with UG-132(a) or UG-132(b), in addition to the marking of (a) and (f) below. The marking may be placed on the pressure relief valve or pin device or on a metal plate or plates securely fastened to the device. The marking shall include the following:

(1) name of Manufacturer of valve;

Figure UG-129.2
Official Certification Mark to Denote the American Society of Mechanical Engineers' Standard for Nonreclosing Pressure Relief Devices



(2) design or type number of valve;
(3) name of Manufacturer of pin device;
(4) design or type number of pin device;
(5) capacity or combination capacity factor;
(6) name of organization responsible for this marking. This shall be either the vessel user, vessel Manufacturer, pin device Manufacturer, or pressure relief valve Manufacturer.

(e) Rupture Disk Devices. Every rupture disk and holder shall be plainly marked by the Manufacturer in such a way that the marking will not be obliterated in service.

(1) Each rupture disk shall be marked with the following information. The markings may be placed on the flange of the disk or a metal tag. The metal tag either shall be securely fastened to the disk or, when attaching the tag is impracticable, shall accompany the disk, provided the lot number is also marked on the disk. See UG-135(g).

(-a) the name or an acceptable abbreviation of the Manufacturer;
(-b) Manufacturer's design or type number;
(-c) lot number;
(-d) disk material;
(-e) size ________ [NPS (DN) of rupture disk holder];
(-f) marked burst pressure ________ psi (kPa);
(-g) specified disk temperature ________ °F (°C);
(-h) for capacity certified devices

(-1) lb/hr (kg/hr) of saturated steam at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for devices certified on steam complying with UG-131(b), or

(-2) gal/min (l/min) of water at 70°F (20°C) at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for devices certified on water, or

(-3) SCFM (standard cubic feet per minute at 60°F and 14.7 psia) (m^3/min at 20°C and 101 kPa), or lb/min (kg/min) of air, at an overpressure of 10% or 3 psi, whichever is greater. Devices that are capacity certified in accordance with the UG-131(c)(2) shall be marked "at 20% overpressure."

(-4) In addition to one of the fluids specified above, the Manufacturer may indicate the capacity in other fluids (see Mandatory Appendix 11).

(-i) for flow resistance certified devices
(-1) minimum net flow area ____ in.^{2} (mm^2)
(-2) certified flow resistance (one or more as applicable)
(+a) K_{RG} ________ for rupture disks certified on air or gases
(+b) K_{RL} ________ for rupture disks certified on liquid
(+c) K_{RGL} ________ for rupture disks certified on air or gases, and liquid

(-j) Certification Mark with the UD Designator placed under the Mark, as shown in Figure UG-129.2. A marking method other than the stamp issued by the Society may be used, provided it is acceptable to the ASME Designated Organization.

(-k) year built, or alternatively, a coding may be marked on the rupture disk such that the rupture disk device Manufacturer can identify the year the rupture disk device was assembled and tested.

(2) Each holder shall be marked with items (1)(-a), (1)(-b), (1)(-e), (1)(-j), and (1)(-k) above and flow direction.

(f) Pin Devices and Pin-Actuated Pilot-Operated Pressure Relief Devices. Pin devices shall be plainly marked by the Manufacturer with the required data in such a way that the marking will not be obliterated in service. The marking may be placed on the device housing or on a metal plate or plates securely fastened to the device. The marking shall include the following:

(1) the name, or an acceptable abbreviation of the Manufacturer
(2) Manufacturer's design or type number
(3) NPS (DN) size ________ (the nominal pipe size of the device inlet)
(4) set pressure psi ________ (kPa)
(5) flow direction
(6) pin to pin device identifier
(7) for capacity certified devices

(-a) lb/hr of saturated steam at an overpressure 10% or 3 psi (20 kPa), whichever is greater for devices certified on steam complying with UG-131(b), or

(-b) gal/min of water at 70°F (20°C) at an overpressure of 10% or 3 psi (20 kPa), whichever is greater for devices certified on water, or

(-c) SCFM (standard cubic feet per minute at 60°F and 14.7 psia) (m^3/min at 20°C and 101 kPa), or lb/min, of air at an overpressure of 10% or 3 psi, whichever is greater. Devices that are capacity certified in accordance with UG-131(c)(2) shall be marked "at 20% overpressure."

(-d) In addition to one of the fluids specified above, the Manufacturer may indicate the capacity in other fluids (see Mandatory Appendix 11).

(8) for flow resistance certified devices:
(-a) minimum net flow area ________ in.^{2} (mm^2)
(-b) certified flow resistance (one or more as applicable)
(-1) K_{RG} ________ for pin devices certified on air or gases
(-2) K_{RL} ________ for pin devices certified on liquid
(-3) K_{RGL} ________ for pin devices certified on air or gases, and liquid

(9) Certification Mark with the UD Designator placed under the Mark, as shown in Figure UG-129.2. A marking method other than the stamp issued by the Society may be used, provided it is acceptable to the ASME Designated Organization.

(10) year built, or alternatively, a coding may be marked on the device such that the device Manufacturer can identify the year the device was tested

(11) The pin shall be marked according to one of the following methods:

(-a) for pin devices using a replaceable pin to control set pressure, the pin shall be marked with its lot number, pin temperature[57] °F (°C) and the information required by (1), (4), (6), (10), or

NOTE: When the pin size or configuration does not permit the use of an attached metal tag, a metal tag may be attached using a nonmetallic connector with an adhesive that complies with Mandatory Appendix 18 of this Division.

(-b) for pin devices that are single use and permanently assembled, the marking requirements of (8)(-a), (8)(-b), and (-a) shall be applied to the device, or

(-c) for pin devices that have a replaceable pin within the sealed body per UG-138, the pin shall be marked with its lot number.

(g) Spring-Loaded Nonreclosing Pressure Relief Devices. Spring-loaded nonreclosing pressure relief devices shall be marked in accordance with (a) above except that the Certification Mark is to be applied only when the capacity has been established and certified in accordance with UG-127(c)(3) and all other requirements of UG-130 have been met.

(h) For units other than those included above, see U-4.

UG-130 CERTIFICATION MARK

Each pressure relief device[58] to which the Certification Mark with the appropriate Designator (see Figures UG-129.1 and UG-129.2) will be applied shall have been fabricated or assembled by a Manufacturer or Assembler holding a valid Certificate of Authorization (UG-117) and capacity certified in accordance with the requirements of this Division. A Certified Individual (CI) shall provide oversight as required by UG-117(a). Each use of the Certification Mark with the appropriate Designator shall also be documented on a Certificate of Conformance Form UV-1 or UD-1, as appropriate.

(19) UG-131 CERTIFICATION OF CAPACITY OF PRESSURE RELIEF DEVICES

(a) Before the Certification Mark is applied to any pressure relief device, the device Manufacturers shall have the capacity of their devices certified in accordance with the provisions of these paragraphs except where noted.

(1) For pressure relief valves and pin devices to be certified for capacity, (b) through (m) apply.

(2) For rupture disks or pin devices to be certified for capacity, (b) through (j) apply.

(3) For rupture disks to be certified for flow resistance, (n) through (u) apply.

(4) For pin devices to be certified for flow resistance, (k) through (p) and (r) through (u) shall apply.

(b) See below.

(1) Capacity certification tests for pressure relief devices for compressible fluids shall be conducted on dry saturated steam, or air, or gas. When dry saturated steam is used, the limits for test purposes shall be 98% minimum quality and 20°F (10°C) maximum superheat. Correction from within these limits may be made to the dry saturated condition. Pressure relief devices for steam service may be rated as above, but at least one device of each series shall be tested on steam to demonstrate the steam capacity and performance.

(2) Capacity certification tests for pressure relief devices for incompressible fluids shall be conducted on water at a temperature between 40°F (5°C) and 125°F (50°C).

(c) See below.

(1) Capacity certification tests shall be conducted at a pressure which does not exceed the pressure for which the pressure relief device is set to operate by more than 10% or 3 psi (20 kPa), whichever is greater, except as provided in (2) below. For pressure relief valves minimum pressure for capacity certification tests shall be at least 3 psi (20 kPa) above set pressure. The reseating pressure shall be noted and recorded.

(2) Capacity certification tests of pressure relief devices for use in accordance with UG-125(c)(3) may be conducted at a pressure not to exceed 120% of the stamped set pressure of the device.

(3) See below.

(-a) Pressure relief valves for compressible fluids having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5% of the set pressure or 3 psi (20 kPa), whichever is greater.

(-b) The blowdown of pressure relief valves for incompressible fluids and pressure relief valves for compressible fluids having nonadjustable blowdown shall be noted and recorded.

(4) Capacity certification of pilot-operated pressure relief devices may be based on tests without the pilot devices installed, provided prior to capacity tests it has been demonstrated by test to the satisfaction of the Authorized Observer that the pilot device will cause the main device to open fully at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater, and that the pilot device in combination with the main device will meet all the requirements of this Division.

(d) See below.

(1) A capacity certification test is required on a set of three devices for each combination of size, design, and pressure setting. The stamped capacity rating for each combination of design, size, and test pressure shall not

exceed 90% of the average capacity of the three devices tested. The capacity for each set of three devices shall fall within a range of ±5% of the average capacity. Failure to meet this requirement shall be cause to refuse certification of that particular pressure relief device design.

(2) If a Manufacturer wishes to apply the Certification Mark to a design of pressure relief devices, four devices of each combination of pipe size and orifice size shall be tested. These four devices shall be set at pressures which cover the approximate range of pressures for which the device will be used or covering the range available at the certified test facility that shall conduct the tests. The capacities based on these four tests shall be as follows:

(-a) For compressible fluids, the slope, S_m, of the measured capacity versus the absolute flow-rating pressure shall be determined for each test point as follows:

$$S_m = W/P_f$$

where

P_f = absolute flow-rating pressure, psia (kPa)
S_m = slope, lb/hr/psia (kg/h/kPa) or SCFM/psia (m^3/min/kPa)
W = measured capacity, lb/hr (kg/h) of saturated steam or SCFM air at 60°F and 14.7 psia (m^3/min at 20°C and 101 kPa)

The average slope, S_{avg}, shall be the arithmetic mean of all calculated slope values, S_m. All experimentally determined slope values, S_m, shall fall within a range of ±5% of the average slope, S_{avg}. If all slope values, S_m, are not within ±5% of the average slope, S_{avg}, two additional devices shall be tested for each device beyond the ±5% range, up to a limit of four additional devices.

The average slope, S_{avg}, shall be multiplied by 0.90, and this product shall be taken as the rated slope, S, for that design and orifice size combination. The relieving capacity to be stamped on the device shall not exceed the rated slope, S, multiplied by the absolute relieving pressure.

For direct spring-loaded valves, the results may be extrapolated to valves with set pressures higher than the highest set pressure used in the capacity certification tests, if the spring in the valve with the higher set pressure meets the requirements of UG-136(a)(2).

(-b) For incompressible fluids, the flow factor, F_m, shall be determined from the ratio of the measured volumetric capacity versus the square root of the differential flow-rating pressure for each test point as follows:

$$F_m = Q/\left(P_f - P_d\right)^{1/2}$$

where

F_m = flow factor, gal/min$\sqrt{\text{psid}}$ $\left(\text{L/min}/\sqrt{\text{kPa}}\right)$
P_d = absolute discharge pressure, psia (kPa)
P_f = absolute flow-rating pressure, psia (kPa)
Q = measured volumetric capacity, gal/min (L/min), corrected to 70°F (20°C)

The average flow factor, F_{avg}, shall be the arithmetic mean of all calculated flow factors, F_m. All experimentally determined flow factors, F_m, shall fall within a range of ±5% of the average flow factor, F_{avg}. If all the flow factors, F_m, are not within ±5% of F_{avg}, two additional devices shall be tested for each device beyond the ±5% range, up to a limit of four additional devices.

The average flow factor, F_{avg}, shall be multiplied by 0.90, and this product shall be taken as the flow factor, F, for that design and orifice size combination. The relieving capacity to be stamped on the device shall not exceed the flow factor, F, multiplied by the square root of the differential relieving pressure.

For direct spring-loaded valves, the results may be extrapolated to valves with set pressures higher than the highest set pressure used in the capacity certification tests, if the spring in the valve with the higher set pressure meets the requirements of UG-136(a)(2).

(e) Instead of individual capacity certification as provided in (d) above, a coefficient of discharge K may be established for a specific pressure relief device design according to the following procedure.

(1) For each design, the pressure relief device Manufacturer shall submit for test at least three devices for each of three different sizes (a total of nine devices) together with detailed drawings showing the device construction. Each device of a given size shall be set at a different pressure.

For each valve design intended to be restricted in lift, the Manufacturer shall have capacity tests conducted on three valves of different sizes. Each size valve shall be tested for capacity at the minimum lift for which certification is required, and at two intermediate lift points between the full rated lift and minimum lift certification points. Each of the three test valves shall be set at a different pressure.

For each restricted lift valve tested, it shall be verified that actual measured capacity at restricted lift will equal or exceed the ASME rated capacity at full rated lift multiplied by the ratio of measured restricted lift to full rated lift.

(2) Tests shall be made on each pressure relief device to determine its capacity-lift (if applicable), set pressure and blow-down pressures (for pressure relief valves), and actual capacity in terms of the fluid used in the test. A coefficient K_D shall be established for each test run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where actual flow is determined quantitatively by test, and theoretical flow is calculated by the appropriate formula which follows:

For tests with dry saturated steam,

$$W_T = 51.5AP$$

NOTE: For dry saturated steam pressures over 1,500 psig (10.3 MPa gage) and up to 3,200 psig (22.1 MPa gage), the value of W_T, calculated by the above equation, shall be corrected by being multiplied by the following factors, which shall be used only if it is 1.0 or greater.

(U.S. Customary Units)

$$\left(\frac{0.1906P - 1,000}{0.2292P - 1,061}\right)$$

(SI Units)

$$\left(\frac{27.6P - 1\,000}{33.2P - 1\,061}\right)$$

For tests with air,

$$W_T = 356AP\sqrt{\frac{M}{T}}$$

For tests with natural gas,

$$W_T = CAP\sqrt{\frac{M}{ZT}}$$

For tests with water,

$$W_T = 2407A\sqrt{(P - P_d)w}$$

where

A = actual discharge area through the device at developed lift, in.^{2}
C = constant for gas or vapor based on the ratio of specific heats
k = c_p/c_v (see Figure 11-1)
M = molecular weight
P = (set pressure × 1.10) plus atmospheric pressure, psia, or set pressure plus 3 psi (20 kPa) plus atmospheric pressure, whichever is greater
P_d = pressure at discharge from device
T = absolute temperature at inlet, °F + 460°F (273°C)
w = specific weight of water at device inlet conditions
W_T = theoretical flow
Z = compressibility factor corresponding to P and T

All experimentally determined coefficients, K_D, shall fall within a range of ±5% of the average K_D found. The average of the coefficients, K_D, of the nine tests required shall be multiplied by 0.90, and this product shall be taken as the coefficient, K, of that design. The coefficient of the design shall not be greater than 0.878 (the product of 0.9 × 0.975).

To convert lb/hr of water to gal/min of water, multiply the capacity in lb/hr by 1/500.

(3) The official relieving capacity of all sizes and pressures of a given design, for which K has been established under the provisions of (2) above, that are manufactured subsequently shall not exceed the value calculated by the appropriate formula in (2) above multiplied by the coefficient K (see Mandatory Appendix 11).

(4) The coefficient shall not be applied to devices whose beta ratio (ratio of valve throat to inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that the individual coefficient of discharge K_D for devices at the extreme ends of a larger range is within ±5% of the average coefficient K. For designs where the lift is used to determine the flow area, all devices shall have the same nominal lift-to-seat diameter ratio (L/D).

(5) The coefficient shall not be applied to direct spring-loaded valves with springs that do not meet the requirements of UG-136(a)(2).

(6) For direct spring-loaded valves, the results may be extrapolated to valves with set pressures higher than the highest set pressure used in the capacity certification tests if the spring in the valve with the higher set pressure meets the requirements of UG-136(a)(2).

(7) For pressure relief valves, the results may be extrapolated to valves larger or smaller than the valves used in the capacity certification tests, provided all dimensions of the flow path and all dimensions of the parts that can affect the overall thrust exercised by the medium on the moving parts are scaled with the corresponding dimensions of the valves used in the capacity certification testing.

(f) Capacity and flow-resistance certification shall be conducted in accordance with ASME PTC 25. Testing shall be conducted by an accredited testing laboratory with Authorized Observers. Testing laboratories shall be accredited, and test supervisors shall have been accepted as Authorized Observers, in accordance with the rules of ASME CA-1.

(g) Capacity test data reports for each device model, type, and size, signed by the Manufacturer and the Authorized Observer witnessing the tests shall be submitted to the ASME Designated Organization for review and acceptance.[59] Where changes are made in the design, capacity certification tests shall be repeated.

(h) For absolute pressures up to 1,500 psia (10 MPa) absolute), it is permissible to rate safety valves under Section I, PG-69.1.2 with capacity ratings at a flow pressure of 103% of the set pressure, for use on pressure vessels, without further test. In such instances, the capacity rating of the valve may be increased to allow for the flow pressure permitted in (c)(1) and (c)(3) above, namely, 110% of the set pressure, by the multiplier,

(U.S. Customary Units)

$$\frac{1.10p + 14.7}{1.03p + 14.7}$$

(SI Units)

$$\frac{1.10p + 100}{1.03p + 100}$$

where

p = set pressure, psig (kPa gage)

Such valves shall be marked in accordance with UG-129. This multiplier shall not be used as a divisor to transform test ratings from a higher to a lower flow.

For steam pressures above 1,500 psig (10.3 MPa gage), the above multiplier is not applicable. For pressure relief valves with relieving pressures between 1,500 psig (10.9 MPa gage) and 3,200 psig (22.1 MPa gage), the capacity shall be determined by using the equation for steam and the correction factor for high pressure steam in (e)(2) above with the permitted absolute relieving pressure (for Customary units, $1.10p$ + 14.7; for SI units, $1.10p$ + 101) and the coefficient K for that valve design.

(i) Rating of nozzle type pressure relief valves, i.e., coefficient K_D, greater than 0.90 and nozzle construction, for saturated water shall be according to 11-2.

(j) When changes are made in the design of a pressure relief device in such a manner as to affect the flow path, lift, or performance characteristics of the device, new tests in accordance with this Division shall be performed.

(k) If the design exceeds the laboratory pressure capability, (d)(2), (e), or (r) shall be followed with the exception that the valves shall be tested with their disks fixed at the minimum design lift to establish the rated capacity.

(l) If the design exceeds the laboratory size or capacity capability, (e) or (r) shall be followed with the exception that flow models of three different sizes, each tested at three different pressures, shall be used in place of valves required in (e)(1) or (r). Such flow models shall be sized consistent with the capabilities of the accepted test laboratory where the test will be conducted, and shall accurately model those features that affect flow capacity, such as orifice size, valve lift, and internal flow configuration. The test models need not be functional pressure relief valves but shall be geometrically similar to the final product.

(m) In the case of either (k) or (l), the valve design (i.e., parameters such as spring properties, seat geometry, and mechanical valve lift) shall be evaluated to ensure that production valves will achieve design lift as modeled above.

(n) The certified flow resistance K_R of the nonreclosing pressure relief device used in UG-127(a)(2) or UG-127(b)(2) shall be either K_R = 2.4, or as determined in accordance with (o) through (u) below.

(o) Flow resistance certification tests for nonreclosing pressure relief device for air or gas service K_{RG} shall be activated and flow tested with air or gas. Flow resistance certification tests for liquid service K_{RL} shall be activated with water and flow tested with air or gas. Nonreclosing pressure relief device for air or gas and liquid service K_{RGL} may be certified with air or gas as above, but at least one device of the number required under (r) below for each size of each series shall be activated with water and flow tested with air or gas to demonstrate the liquid service flow resistance.

(p) Flow resistance certification tests shall be conducted at an inlet pressure which does not exceed 110% of the device set pressure.

(q) See below.

(1) The flow resistance for devices tested with non-pressure-containing items, such as seals, support rings, and vacuum supports, is applicable for the same device design without seals, support rings, or vacuum supports.

(2) A change in material for rupture disks and their non-pressure-containing disk items, such as seals, support rings, and vacuum supports, is not considered a design change and does not require retesting.

(3) Additional linings, coatings, or platings may be used for the same design of devices, provided:

(-a) the certificate holder has performed a verification test with the additional linings, coatings, or platings and has documented that the addition of these materials does not affect the device opening configuration; and

(-b) such verification tests shall be conducted with devices of the smallest size and minimum set pressure for which the certified flow resistance with additional materials is to be used.

(r) Flow resistance certification shall be determined by one of the following methods:

(1) One Size Method

(-a) For each nonreclosing pressure relief device design, three activation components from the same lot shall be individually activated and the device tested in accordance with (s) below. The set pressure shall be the minimum of the nonreclosing pressure relief device design of the size tested.

(-b) The certified flow resistance K_R determined in (s) below shall apply only to the nonreclosing pressure relief device design of the size tested.

(-c) When additional activation components of the same design are constructed at a later date, the test results on the original components may be included as applicable in the three size method described in (2) below.

(2) Three Size Method

(-a) This method of flow resistance certification may be used for a nonreclosing pressure relief device design of three or more sizes. The set pressure shall be the minimum of the activation component for each of the sizes submitted for test.

(-b) For each nonreclosing pressure relief device design, three activation components from the same lot shall be activated and the device flow tested in accordance with (s) below for each of three different sizes of the same design.

(-c) The certified flow resistance K_R shall apply to all sizes and pressures of the design of the nonreclosing pressure relief device tested.

(s) A certified flow resistance K_R may be established for a specific nonreclosing pressure relief device design according to the following procedure.

(1) For each design, the nonreclosing pressure relief device Manufacturer shall submit for test the required devices in accordance with (r) above together with the cross section drawings showing the device design.

(2) Tests shall be made on each device to determine its set pressure and flow resistance at a facility which meets the requirements of (f) above.

(3) Calculate an average flow resistance using the individual flow resistances determined in (2) above. All individual flow resistances shall fall within the average flow resistance by an acceptance band of plus or minus three times the average of the absolute values of the deviations of the individual flow resistances from the average flow resistance. Any individual flow resistance that falls outside of this band shall be replaced on a two for one basis. A new average flow resistance shall be computed and the individual flow resistances evaluated as stated above.

(4) The certified flow resistance K_R for a nonreclosing pressure relief device design shall not be less than zero and shall not be less than the sum of the average flow resistance plus three times the average of the absolute values of the deviations of individual flow resistances from the average flow resistance.

(t) Flow resistance test data reports for each nonreclosing pressure relief device design, signed by the Manufacturer and the Authorized Observer witnessing the tests, shall be submitted to the ASME Designated Organization for review and acceptance.[59]

(u) When changes are made in the design of a nonreclosing pressure relief device which affect the flow path or activation performance characteristics of the device, new tests in accordance with this Division shall be performed.

UG-132 CERTIFICATION OF CAPACITY OF PRESSURE RELIEF VALVES IN COMBINATION WITH NONRECLOSING PRESSURE RELIEF DEVICES

(a) Capacity of Pressure Relief Valves in Combination With a Nonreclosing Pressure Relief Device at the Inlet

(1) For each combination of pressure relief valve design and nonreclosing pressure relief device design, the pressure relief valve Manufacturer or the nonreclosing pressure relief device Manufacturer may have the capacity of the combination certified as prescribed in (3) and (4) below.

(2) Capacity certification tests shall be conducted on saturated steam, air, or natural gas. When saturated steam is used, corrections for moisture content of the steam shall be made.

(3) The pressure relief valve Manufacturer or the nonreclosing pressure relief device Manufacturer may submit for tests the smallest nonreclosing pressure relief device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in the particular inlet size.

(4) Tests may be performed in accordance with the following subparagraphs. The nonreclosing pressure relief device and pressure relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(-a) The test shall embody the minimum set pressure of the nonreclosing pressure relief device design which is to be used in combination with the pressure relief valve design. The marked set pressure of the nonreclosing pressure relief device shall be between 90% and 100% of the marked set pressure of the valve.

(-b) The test procedure to be used shall be as follows:

The pressure relief valve (one valve) shall be tested for capacity as an individual valve, without the nonreclosing pressure relief device at a pressure 10% or 3 psi (20 kPa), whichever is greater, above the valve set pressure.

The nonreclosing pressure relief device shall then be installed at the inlet of the pressure relief valve and the nonreclosing pressure relief device activated to operate the valve. The capacity test shall be performed on the combination at 10% or 3 psi (20 kPa), whichever is greater, above the valve set pressure duplicating the individual pressure relief valve capacity test.

(-c) Tests shall be repeated with two additional activation components of the same nominal rating for a total of three activation components to be tested with the single pressure relief valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(-d) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity determined by the combination tests to the capacity determined on the individual valve.

The Combination Capacity Factor shall be used as a multiplier to make appropriate changes in the ASME rated relieving capacity of the pressure relief valve in all sizes of the design. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design of pressure relief valve and the same design of nonreclosing pressure relief device as those tested.

(-e) The test laboratory shall submit the test results to the ASME Designated Organization for acceptance of the Combination Capacity Factor.[60]

(b) Optional Testing of Nonreclosing Pressure Relief Devices and Pressure Relief Valves

(1) If desired, a valve Manufacturer or a nonreclosing pressure relief device Manufacturer may conduct tests in the same manner as outlined in (a)(4)(-c) and (a)(4)(-d) above using the next two larger sizes of the design of nonreclosing pressure relief device and pressure relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be certified, it may be used for all larger sizes of the combination, but shall not be greater than one.

(2) If desired, additional tests may be conducted at higher pressures in accordance with (a)(4)(-c) and (a)(4)(-d) above to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but shall not be greater than one.

UG-133 DETERMINATION OF PRESSURE-RELIEVING REQUIREMENTS

(a) Except as permitted in (b) below, the aggregate capacity of the pressure relief devices connected to any vessel or system of vessels for the release of a liquid, air, steam, or other vapor shall be sufficient to carry off the maximum quantity that can be generated or supplied to the attached equipment without permitting a rise in pressure within the vessel of more than 16% above the maximum allowable working pressure when the pressure relief devices are blowing.

(b) Pressure relief devices as permitted in UG-125(c)(2), as protection against excessive pressure caused by exposure to fire or other sources of external heat, shall have a relieving capacity sufficient to prevent the pressure from rising more than 21% above the maximum allowable working pressure of the vessel when all pressure relief devices are blowing.

(c) Vessels connected together by a system of adequate piping not containing valves which can isolate any vessel, and those containing valves in compliance with Nonmandatory Appendix M, M-5, may be considered as one unit in figuring the required relieving capacity of pressure relief devices to be furnished.

(d) Heat exchangers and similar vessels shall be protected with a pressure relief device of sufficient capacity to avoid overpressure in case of an internal failure.

(e) The official rated capacity, or the certified flow resistance and minimum net flow area, of a pressure relief device shall be that which is stamped on the device and guaranteed by the Manufacturer.

(f) The rated pressure-relieving capacity of a pressure relief valve for other than steam or air shall be determined by the method of conversion given in Mandatory Appendix 11.

(g) The relieving capacity of a pressure relief device for compressible fluids may be prorated at any relieving pressure greater than $1.10p$, as permitted under UG-125, by applying a multiplier to the official relieving capacity as follows:

(U.S. Customary Units)

$$\frac{P + 14.7}{1.10p + 14.7}$$

(SI Units)

$$\frac{P + 101}{1.10p + 101}$$

where

P = relieving pressure, psig (kPa gage)
p = set pressure, psig (kPa gage)

For steam pressures above 1,500 psig (10 MPa gage), the above multiplier is not applicable. For steam valves with relieving pressures greater than 1,500 psig (10 MPa gage) and less than or equal to 3,200 psig (22.1 MPa gage), the capacity at relieving pressures greater than $1.10p$ shall be determined using the equation for steam and the correction factor for high pressure steam in UG-131(e)(2) with the permitted absolute relieving pressure and the coefficient K for that valve design.

(h) When sizing and selecting valves, the restricted lift nameplate capacity shall be determined by multiplying the capacity at full rated lift as defined in UG-131(e)(3) by the ratio of the restricted lift to the full rated lift.

UG-134 PRESSURE SETTINGS AND PERFORMANCE REQUIREMENTS

(a) When a single pressure relief device is used, the set pressure[60] marked on the device shall not exceed the maximum allowable working pressure of the vessel. When the required capacity is provided in more than one pressure relief device, only one pressure relief device need be set at or below the maximum allowable working pressure, and the additional pressure relief devices may be set to open at higher pressures but in no case at a pressure higher than 105% of the maximum allowable working pressure, except as provided in (b) below.

(b) For pressure relief devices permitted in UG-125(c)(2) as protection against excessive pressure caused by exposure to fire or other sources of external heat, the device marked set pressure shall not exceed 110% of the maximum allowable working pressure of the vessel. If such a pressure relief device is used to meet the requirements of both UG-125(c) and UG-125(c)(2), the device marked set pressure shall not be over the maximum allowable working pressure.

(c) The pressure relief device set pressure shall include the effects of static head and constant back pressure.

(d) See below.

(1) The set pressure tolerance for pressure relief valves shall not exceed ±2 psi (15 kPa) for pressures up to and including 70 psi (500 kPa) and ±3% for pressures above 70 psi (500 kPa), except as covered in (2) below.

(2) The set pressure tolerance of pressure relief valves which comply with UG-125(c)(3) shall be within −0%, +10%.

(e) The burst pressure tolerance for rupture disk devices at the specified disk temperature shall not exceed ±2 psi (15 kPa) of marked burst pressure up to and including 40 psi (300 kPa) and ±5% of marked burst pressure above 40 psi (300 kPa).

(f) The set pressure tolerance for pin devices shall not exceed ±2 psi (15 kPa) of marked set pressure up to and including 40 psi (300 kPa) and ±5% of marked set pressures above 40 psi (300 kPa) at specified pin temperature.

(g) Pressure relief valves shall be designed and constructed such that when installed per UG-135, the valves will operate without chattering and shall not flutter at the flow-rated pressure in a way that either would interfere with the measurement of capacity or would result in damage.

UG-135 INSTALLATION

(a) Pressure relief devices intended for relief of compressible fluids shall be connected to the vessel in the vapor space above any contained liquid or to piping connected to the vapor space in the vessel which is to be protected. Pressure relief devices intended for relief of liquids shall be connected below the liquid level. Alternative connection locations are permitted, depending on the potential vessel overpressure scenarios and the type of relief device selected, provided the requirements of UG-125(a)(3) and UG-125(c) are met.

(b) See below.

(1) The opening through all pipe, fittings, and nonreclosing pressure relief devices (if installed) between a pressure vessel and its pressure relief valve shall have at least the area of the pressure relief valve inlet. The characteristics of this upstream system shall be such that the pressure drop will not reduce the relieving capacity below that required or adversely affect the proper operation of the pressure relief valve.

(2) The opening in the vessel wall shall be designed to provide unobstructed flow between the vessel and its pressure relief device (see Nonmandatory Appendix M).[61]

(c) When two or more required pressure relief devices are placed on one connection, the inlet internal cross-sectional area of this connection shall be either sized to avoid restricting flow to the pressure relief devices or made at least equal to the combined inlet areas of the safety devices connected to it. The flow characteristics of the upstream system shall satisfy the requirements of (b) above. (See Nonmandatory Appendix M.)

(d) There shall be no intervening stop valves between the vessel and its pressure relief device or devices, or between the pressure relief device or devices and the point of discharge, except:

(1) when these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure-relieving capacity provided by the unaffected pressure relief devices below the required relieving capacity; or

(2) under conditions set forth in Nonmandatory Appendix M.

(e) The pressure relief devices on all vessels shall be so installed that their proper functioning will not be hindered by the nature of the vessel's contents.

(f) Discharge lines from pressure relief devices shall be designed to facilitate drainage or shall be fitted with drains to prevent liquid from lodging in the discharge side of the pressure relief device, and such lines shall lead to a safe place of discharge. The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the pressure relief devices below that required to properly protect the vessel, or adversely affect the proper operation of the pressure relief devices. [See UG-136(a)(8) and Nonmandatory Appendix M.]

(g) For rupture disks that are marked with only a lot number in accordance with UG-129(e)(1), following the installation of the disk, the metal tag shall be sealed to the installation in a manner that will prevent removal of the disk without breaking the seal. The seal shall identify the organization responsible for performing the installation.

UG-136 MINIMUM REQUIREMENTS FOR PRESSURE RELIEF VALVES

(a) Mechanical Requirements

(1) The design shall incorporate guiding arrangements necessary to ensure consistent operation and tightness.

(2) The spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and height measured 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 0.5% of the free height.

For direct spring-loaded valves that have set pressures above the maximum pressure used in the capacity certification tests, the spring force ratio shall not exceed 1.1 times the spring force ratio of the valve with the highest set pressure that was used in the capacity certification tests. For direct spring-loaded valves that have orifices larger than the largest size used in the capacity certification tests, the spring force ratio shall not exceed 1.1 times the spring force ratio of the valve with the largest size orifice in the capacity certification tests. The spring force ratio, R_{sf}, shall be calculated as follows:

$$R_{sf} = F_{so}/F_{sc}$$

where

F_{sc} = force exerted by the spring when the valve is closed or seated
F_{so} = force exerted by the spring when the valve is at rated lift

(3) Each pressure relief valve on air, water at the valve inlet that exceeds 140°F (60°C), excluding overpressure or relief events, or steam service shall have a substantial lifting device which when activated will release the seating force on the disk when the pressure relief valve is subjected to a pressure of at least 75% of the set pressure of the valve. Pilot-operated pressure relief valves used on these services shall be provided with either a lifting device as described above or means for connecting and applying pressure to the pilot adequate to verify that the moving parts critical to proper operation are free to move.

(4) The seat of a pressure relief valve shall be fastened to the body of the pressure relief valve in such a way that there is no possibility of the seat lifting.

(5) In the design of the body of the pressure relief valve, consideration shall be given to minimizing the effects of deposits.

(6) Pressure relief valves having threaded inlet or outlet connections shall be provided with wrenching surfaces to allow for normal installation without damaging operating parts.

(7) Means shall be provided in the design of all pressure relief valves for use under this Division for sealing all initial adjustments which can be made without disassembly of the valve. Seals shall be installed by the Manufacturer or Assembler at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment without breaking the seal. For pressure relief valves larger than NPS $^1/_2$ (DN 15), the seal shall serve as a means of identifying the Manufacturer or Assembler making the initial adjustment.

(8) If the design of a pressure relief valve is such that liquid can collect on the discharge side of the disk, except as permitted in (9) below, the valve shall be equipped with a drain at the lowest point where liquid can collect (for installation, see UG-135).

(9) Pressure relief valves that cannot be equipped with a drain as required in (8) above because of design or application may be used provided:

(-a) the pressure relief valves are used only on gas service where there is neither liquid discharged from the valve nor liquid formed by condensation on the discharge side of the valve; and

(-b) the pressure relief valves are provided with a cover or discharge piping per UG-135(f) to prevent liquid or other contaminant from entering the discharge side of the valve; and

(-c) the pressure relief valve is marked FOR GAS SERVICE ONLY in addition to the requirements of UG-129.

(10) For pressure relief valves of the diaphragm type, the space above the diaphragm shall be vented to prevent a buildup of pressure above the diaphragm. Pressure relief valves of the diaphragm type shall be designed so that failure or deterioration of the diaphragm material will not impair the ability of the valve to relieve at the rated capacity.

(11) Valve capacity, including valves certified per UG-131, may be restricted by restricting the lift of a valve provided the following requirements are met:

(-a) The valve size shall be NPS ¾ (DN 20) or larger.

(-b) No changes shall be made in the design of the valve except to change the valve lift by use of a lift restraining device described in (-c) below.

(-c) The restriction of valve capacity shall be permitted only by the use of a lift restraining device that shall limit valve lift and shall not otherwise interfere with flow through the valve. The design of the lift restraining device shall be subject to review by an ASME Designated Organization.

(-d) The lift restraining device shall be designed so that, if adjustable, the adjustable feature can be sealed. Seals shall be installed by the valve Manufacturer or Assembler at the time of initial adjustment.

(-e) Valves shall not have their lifts restricted to a value less than 30% of full rated lift, or less than 0.080 in. (2 mm).

(b) Material Selections

(1) Cast iron seats and disks are not permitted.

(2) Adjacent sliding surfaces such as guides and disks or disk holders shall both be of corrosion resistant material. Springs of corrosion resistant material or having a corrosion resistant coating are required. The seats and disks of pressure relief valves shall be of suitable material to resist corrosion by the fluid to be contained.

The Manufacturer shall consider the potential for galling and the effects on the performance of the pressure relief valve in the selection of materials for sliding surfaces. The Manufacturer shall consider the potential for brinelling and the effects on the performance of the pressure relief valve in the selection of materials for the seating surfaces.

NOTE: The degree of corrosion resistance, appropriate to the intended service, shall be a matter of agreement between the Manufacturer and the user or his designated agent.

(19) *(3)* Materials used in bodies, bonnets or yokes, and body-to-bonnet or body-to-yoke bolting shall be listed in Section II and this Division. Bodies, bonnets or yokes, and body-to-bonnet or body-to-yoke bolting shall meet all applicable requirements of Subsection C.

(4) Materials used in all other parts required for the pressure-relieving or pressure-retaining function shall be

(-a) listed in Section II; or

(-b) listed in ASTM specifications; or

(-c) controlled by the Manufacturer of the pressure relief valve by a specification ensuring control of chemical and physical properties and quality at least equivalent to ASTM standards.

(19) *(c) Inspection of Manufacturing and/or Assembly of Pressure Relief Valves*

(1) A Manufacturer or Assembler shall demonstrate to the satisfaction of a representative from an ASME Designated Organization that his manufacturing, production, and testing facilities and quality control procedures will insure close agreement between the performance of random production samples and the performance of those valves submitted for Capacity Certification.

(2) Manufacturing, assembly, inspection, and test operations including capacity are subject to inspections at any time by a representative from an ASME Designated Organization.

(3) A Manufacturer or Assembler may be granted permission to apply the Certification Mark with the UV Designator to production pressure relief valves capacity certified in accordance with UG-131 provided the following tests are successfully completed. This permission shall expire on the sixth anniversary of the date it is initially granted. The permission may be extended for 6 year periods if the following tests are successfully repeated within the 6-month period before expiration.

(-a) Two sample production pressure relief valves of a size and capacity within the capability of an ASME-accepted laboratory shall be selected by a representative from an ASME Designated Organization. Pressure relief valves having adjustable blowdown construction shall have the control elements positioned by the Manufacturer or Assembler for a blowdown typical of production methods.

(-b) Operational and capacity tests shall be conducted in the presence of a representative from an ASME Designated Organization at an ASME-accepted laboratory. The pressure relief valve Manufacturer or Assembler shall be notified of the time of the test and may have representatives present to witness the test. If a pressure relief valve with adjustable blowdown construction selected from a Manufacturer exhibits a blowdown that exceeds 7% of the set pressure or 3 psi (20 kPa), whichever is greater, during operational and capacity tests, then an adjustment shall be made to meet this performance condition, and the operational and capacity tests shall be repeated. This adjustment may be made on the flow test facility.

(-c) Should any pressure relief valve fail to relieve at or above its certified capacity or should it fail to meet performance requirements in UG-134, the test shall be repeated at the rate of two replacement pressure relief valves, selected in accordance with (-a) above, for each pressure relief valve that failed.

(-d) Should any of the replacement pressure relief valves fail to meet the capacity or performance requirements of this Division, the Manufacturer or Assembler shall determine the cause of failure and take corrective action to guard against future occurrence. This cause of failure and corrective action shall be documented and submitted to the ASME Designated Organization within 60 days of the failure or be cause for revocation of the authorization to use the Certification Mark on that particular type of valve. Upon acceptance of the submitted corrective action by the ASME Designated Organization, the requirements of (3) above shall apply.

(4) For valves that exceed the laboratory testing capabilities and for which lift at rated overpressure can be measured, the alternative method described below shall be used in lieu of the test requirements of (3)(-a) through (3)(-c).

(-a) Two production valves that are representative of the design shall be tested per ASME PTC 25, Part III to demonstrate to the satisfaction of the representative of the ASME Designated Organization that

(-1) the measured set pressure is consistent with the stamped set pressure within the tolerances required by UG-134(d)

(-2) the valve will achieve the minimum lift for its certified capacity

(-3) the valve will operate without chatter or flutter

If only one valve of the design will be produced within the 6-yr period within which the permission is granted, only that valve need be tested as stated above.

(-b) The testing shall be performed at a facility that is mutually agreeable to the manufacturer, the representative of an ASME Designated Organization, and the facility owner. The facility shall be capable of demonstrating the characteristics stated in (-a)(-1) through (-a)(-3).

(-c) In the event of failure of the tests, (3)(-d) shall apply.

(5) For valves that exceed the laboratory testing capabilities and for which lift at rated overpressure cannot be measured, the alternative method described below shall be used.

(-a) For initial certification, two functional models that are representative of the design shall be used provided the test requirements of (3)(-a) through (3)(-d) are followed and the following additional tests are completed satisfactorily:

(-1) Two production valves that are representative of the design shall be tested per ASME PTC 25, Part III to demonstrate to the satisfaction of the representative of the ASME Designated Organization that

(+a) the measured set pressure is consistent with the stamped set pressure within the tolerances required by UG-134(d)

(+b) seat tightness and a secondary pressure zone leakage test are demonstrated in accordance with (d)(3) and (d)(5)

If only one valve of the design will be produced within the 6-yr period within which the permission is granted, only that valve need be tested as stated above.

(-2) The testing shall be performed at a facility that is mutually agreeable to the manufacturer, the representative of an ASME Designated Organization, and the facility owner. The facility shall be capable of demonstrating the characteristics stated in (-1)(+a) and (-1)(+b).

(-3) In the event of failure of the tests, (3)(-d) shall apply.

(-b) For 6-yr renewal of capacity certification, (-a)(-1) through (-a)(-3) shall apply.

(6) Use of the Certification Mark by an Assembler indicates the use of original, unmodified parts in strict accordance with the instructions of the Manufacturer of the pressure relief valve.

(-a) An assembler may transfer original and unmodified pressure relief parts produced by the Manufacturer to other Assemblers provided the following conditions are met:

(-1) both Assemblers have been granted permission to apply the Certification Mark with the V or UV Designator to the specific valve type in which the parts are to be used;

(-2) the Quality Control System of the Assembler receiving the pressure relief valve parts shall define the controls for the procurement and acceptance of those parts; and

(-3) the pressure relief valve parts are appropriately packaged, marked, or sealed by the Manufacturer to ensure that the parts are:

(+a) produced by the Manufacturer; and

(+b) the parts are original and unmodified.

(-b) However, an Assembler may convert original finished parts by either machining to another finished part or applying a corrosion-resistant coating to valve springs for a specific application under the following conditions:

(-1) Conversions shall be specified by the Manufacturer. Drawings and/or written instructions used for part conversion shall be obtained from the Manufacturer and shall include a drawing or description of the converted part before and after the conversion.

(-2) The Assembler's quality control system, as accepted by a representative from an ASME Designated Organization, must describe in detail the conversion of original parts, provisions for inspection and acceptance, personnel training, and control of current Manufacturer's drawings and/or written instructions.

(-3) The Assembler must document each use of a converted part and that the part was used in strict accordance with the instructions of the Manufacturer.

(-4) The Assembler must demonstrate to the Manufacturer the ability to perform each type of conversion. The Manufacturer shall document all authorizations granted to perform part conversions. The Manufacturer and Assembler shall maintain a file of such authorizations.

(-5) For an Assembler to offer restricted lift valves, the Assembler must demonstrate to the satisfaction of the Manufacturer the ability to perform valve lift restrictions. The Manufacturer shall document all authorizations granted to restrict the lift of the valves, and shall maintain records of lift restrictions made by the Assembler. The Assembler shall maintain a file of such authorizations.

(-6) At least annually a review shall be performed by the Manufacturer of an Assembler's system and conversion capabilities. The Manufacturer shall document the results of these reviews. A copy of this documentation shall be kept on file by the Assembler. The review results shall be made available to a representative from an ASME Designated Organization.

(7) In addition to the requirements of UG-129, the marking shall include the name of the Manufacturer and the final Assembler. The Certification Mark shall be that of the final Assembler.

NOTE: Within the requirements of (c) and (d): A *Manufacturer* is defined as a person or organization who is completely responsible for design, material selection, capacity certification, manufacture of all component parts, assembly, testing, sealing, and shipping of pressure relief valves certified under this Division. An *Assembler* is defined as a person or organization who purchases or receives from a Manufacturer or another Assembler the necessary component parts or pressure relief valves and assembles, adjusts, tests, seals, and ships pressure relief valves certified under this Division, at a geographical location other than and using facilities other than those used by the Manufacturer. An Assembler may be organizationally independent of a Manufacturer or may be wholly or partly owned by a Manufacturer.

(d) Production Testing by Manufacturers and Assemblers

(1) Each pressure relief valve to which the Certification Mark is to be applied shall be subjected to the following tests by the Manufacturer or Assembler. A

Manufacturer or Assembler shall have a documented program for the application, calibration, and maintenance of gages and instruments used during these tests.

(2) Pressure Testing

(-a) The pressure-containing parts of the shell of each valve are subject to pressure testing. The valve shell is defined by parts, such as the body, bonnet, and cap, that isolate primary or secondary pressure from atmosphere.

(-b) A valve shell part is exempt from pressure testing if

(-1) the stress that would be applied under hydrostatic test conditions does not exceed 50% of the allowable stress, and

(-2) the part is not cast or welded

(-c) A valve shell part requiring pressure testing shall be tested either

(-1) hydrostatically at a minimum 1.5 times the design pressure of the part, or

(-2) pneumatically at a minimum 1.25 times the design pressure of the part. Pneumatic testing can be hazardous; it is therefore recommended that special precautions be taken when conducting a pneumatic test.

(-d) Pressure testing may be done in the part or assembled condition.

(-e) Pressure testing shall be conducted after all machining and welding operations have been completed.

(-f) Parts subjected to pressure testing shall not exhibit a sign of leakage.

(3) The secondary pressure zone of each closed bonnet pressure relief valve exceeding NPS 1 (DN 25) inlet size when such pressure relief valves are designed for discharge to a closed system shall be tested with air or other gas at a pressure of at least 30 psi (200 kPa). Parts subjected to pressure testing shall not exhibit a sign of leakage.[62]

(**19**) *(4)* Each pressure relief valve shall be tested to demonstrate its set pressure. Test fixtures and test drums, where applicable, shall be of adequate size and capacity to ensure that pressure relief valve action is consistent with the stamped set pressure within the tolerances required by UG-134(d). Testing shall be performed in accordance with the following:

(-a) Pressure relief valves marked for liquid service shall be tested with water or other suitable liquid.

(-b) Pressure relief valves marked for gas or vapor service shall be tested with air or other suitable gas, except as permitted in (-e) below.

(-c) Pressure relief valves marked for steam service or having special internal parts for steam service shall be tested with steam, except as permitted in (-e) below.

(-d) When pressure relief valve service conditions differ from test stand conditions due to superimposed back pressure and/or temperature, the actual test pressure (cold differential test pressure) shall be adjusted and marked on the valve per UG-129(a)(4)(-a). When superimposed back pressure contributes to the cold differential test pressure, it shall also be marked on the valve per UG-129(a)(4)(-b).

(-e) When pressure relief valves in (-b) or (-c) are beyond the capability of the production test facility, either because of size or set pressure, the valves may be tested using alternative test media. Steam service valves may be tested on air or other gas. Gas or vapor service valves may be tested on steam. The test pressure using an alternative medium shall be the product of the Manufacturer's correction factor for the differential between steam and air or gas multiplied by the set pressure. If a cold differential test pressure is applicable due to superimposed back pressure and/or service temperature, then the Manufacturer's correction factor shall be applied to the cold differential test pressure. The correction factor between steam and air or gas shall not be included in the cold differential test pressure marked on the valve per UG-129(a)(4)(-a).

(-f) When a direct spring-loaded pressure relief valve is beyond the production test equipment capabilities, an alternative test method presented in (-5) or (-6) may be used, provided all of the conditions of (-1) through (-4) are met:

(-1) testing the valve at full pressure may cause damage to the valve;

(-2) the valve lift has been mechanically verified to meet or exceed the required lift;

(-3) for valves with adjustable blowdown, the blowdown control elements are set to the valve manufacturer's specification, and

(-4) the valve design is compatible with the alternative test method selected.

(-5) The valve, with its lift temporarily restricted during the test, if required to prevent valve damage, shall be tested on the appropriate medium to demonstrate popping or set pressure.

(-6) The valve may be fitted with an auxiliary lift-assist device and tested on the appropriate medium at a pressure less than the valve set pressure. The lift-assist device and test procedure shall be calibrated to provide the set pressure setting with the tolerance of UG-134(d)(1).

(5) After completion of the tests required by (4) above, a seat tightness test shall be conducted. Unless otherwise designated by a Manufacturer's published pressure relief valve specification or another specification agreed to by the user, the seat tightness test and acceptance criteria shall be in accordance with API 527.

(6) Testing time on steam pressure relief valves shall be sufficient, depending on size and design, to insure that test results are repeatable and representative of field performance.

(e) Design Requirements. At the time of the submission of pressure relief valves for capacity certification, or testing in accordance with (c)(3) above, the ASME Designated Organization has the authority to review the design for

conformity with the requirements of (a) and (b) and to reject or require modification of designs which do not conform, prior to capacity testing.

(f) Welding and Other Requirements. All welding, brazing, heat treatment, and nondestructive examination used in the construction of bodies, bonnets, and yokes shall be performed in accordance with the applicable requirements of this Division.

(g) Set Pressure Change. The set pressure of a valve may be changed after completion of the Form UV-1 but prior to putting the valve in service for overpressure protection, provided all of the following requirements are met:

(1) All parts conversions, valve adjustments, testing, and updating of the existing Form UV-1 or creating a new Form UV-1 shall be performed by the Manufacturer or an Assembler that has been granted permission to apply the Certification Mark with the UV Designator to the specific valve type.

(2) The change to the set pressure shall be validated per (d)(4).

(3) The set pressure and capacity marked on the valve shall be obliterated. The new set pressure and capacity shall be marked in accordance with UG-129. When marking is accomplished by metal nameplate, the original nameplate shall be removed and destroyed, and a new nameplate affixed to the valve.

(4) All other requirements of this Section for the use of the Certification Mark with the UV Designator shall apply, in particular leak testing per (d)(3) and (d)(5), and resealing adjustments per (a)(7).

(19) UG-137 MINIMUM REQUIREMENTS FOR RUPTURE DISK DEVICES

(a) Mechanical Requirements

(1) The design shall incorporate arrangements necessary to ensure consistent operation and tightness.

(2) Rupture disk devices having threaded inlet or outlet connections shall be designed to allow for normal installation without damaging the rupture disk.

(b) Material Selections

(1) The rupture disk material is not required to conform to a material specification listed in Section II. The rupture disk material shall be controlled by the Manufacturer of the rupture disk device by a specification ensuring the control of material properties.

(2) Materials used in rupture disk holders and their pressure-retaining bolting shall be listed in Section II and this Division. Rupture disk holders and their pressure-retaining bolting shall meet all applicable requirements of Subsection C.

(3) Materials used in all other parts required for the pressure-relieving or pressure-retaining function shall be

(-a) listed in Section II; or

(-b) listed in ASTM specifications; or

(-c) controlled by the Manufacturer of the rupture disk device by a specification insuring control of chemical and physical properties and quality at least equivalent to ASTM standards.

(c) Inspection of Manufacturing of Rupture Disk Devices

(1) A Manufacturer shall demonstrate to the satisfaction of a representative of an ASME Designated Organization that its manufacturing, production, and testing facilities and quality control procedures will insure close agreement between the performance of random production samples and the performance of those devices submitted for Certification.

(2) Manufacturing, assembly, inspection, and test operations are subject to inspections at any time by an ASME designee.

(3) A Manufacturer may be granted permission to apply the Certification Mark with the UD Designator to production rupture disk devices certified in accordance with UG-131 provided the following tests are successfully completed. This permission shall expire on the sixth anniversary of the date it is initially granted. The permission may be extended for 6-year periods if the following tests are successfully repeated within the 6-month period before expiration:

(-a) Two production sample rupture disk devices of a size and capacity within the capability of an ASME-accepted laboratory shall be selected by a representative of an ASME Designated Organization.

(-b) Burst and flow testing shall be conducted in the presence of a representative of an ASME Designated Organization at a place which meets the requirements of UG-131(f). The device Manufacturer shall be notified of the time of the test and may have representatives present to witness the test.

(-c) Should any device fail to meet or exceed the performance requirements (burst pressure, minimum net flow area, and flow resistance) of UG-127, the test shall be repeated at the rate of two replacement devices, selected and tested in accordance with (-a) and (-b) above for each device that failed.

(-d) Should any of the replacement devices fail to meet the capacity or performance requirements of this Division, the Manufacturer shall determine the cause of failure and take corrective action to guard against future occurrence. This cause of failure and corrective action shall be documented and submitted to the ASME Designated Organization within 60 days of the failure or be cause for revocation of the authorization to use the Certification Mark on that particular type of device. Upon acceptance of the submitted corrective action by the ASME Designated Organization, the requirements of (3) above shall apply.

(d) Production Testing by Manufacturers

(1) Each rupture disk device to which the Certification Mark is to be applied shall be subjected to the following tests by the Manufacturer. The Manufacturer shall

have a documented program for the application, calibration, and maintenance of gages and instruments used during these tests.

(2) Pressure Testing

(-a) The pressure-containing parts of each rupture disk holder are subject to pressure testing.

(-b) A rupture disk holder part is exempt from pressure testing if

(-1) the stress that would be applied under hydrostatic test conditions does not exceed 50% of the allowable stress and the part is not cast or welded, or

(-2) the part is downstream of the rupture disk when the outlet of the rupture disk device is not designed to contain pressure, or

(-3) the part is fully contained within the holder

(-c) A rupture disk holder part requiring pressure testing shall be tested either

(-1) hydrostatically at a minimum 1.5 times the design pressure of the part, or

(-2) pneumatically at a minimum 1.25 times the design pressure of the part. Pneumatic testing can be hazardous; it is therefore recommended that special precautions be taken when conducting a pneumatic test.

(-d) Pressure testing may be done in the part or assembled condition.

(-e) Pressure testing shall be conducted after all machining and welding operations have been completed.

(-f) Parts subjected to pressure testing shall not exhibit a sign of leakage.

(3) Each lot of rupture disks shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service. Sample rupture disks, selected from each lot of rupture disks, shall be made from the same material and of the same size as those to be used in service. Test results shall be applicable only to rupture disks used in disk holders supplied by the rupture disk Manufacturer.

(-a) At least two sample rupture disks from each lot of rupture disks shall be burst at the specified disk temperature. The marked burst pressure shall be determined so that the sample rupture disk burst pressures are within the burst pressure tolerance specified by UG-127(a)(1).

(-b) At least four sample rupture disks, but not less than 5% from each lot of rupture disks, shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. This data shall be used to establish a smooth curve of burst pressure versus temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in UG-127(a)(1).

The value for the marked burst pressure shall be derived from the curve for a specified temperature.

(-c) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. These data shall be used to establish a smooth curve of percent change of burst pressure versus temperature for the lot of material. The acceptance criteria of smooth curve shall be as in (-b) above.

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room temperature rating of the lot of disks. The percent change shall be used to establish the marked burst pressure at the specified disk temperature for the lot of disks.

(e) Design Requirements. At the time of the inspection in accordance with (c)(3) above, a representative from an ASME Designated Organization has the authority to review the design for conformity with the requirements of (a) and (b) and to reject or require modification of designs that do not conform, prior to capacity testing.

(f) Welding and Other Requirements. All welding, brazing, heat treatment, and nondestructive examination used in the construction of rupture disk holders and pressure parts shall be performed in accordance with the applicable requirements of this Division.

UG-138 MINIMUM REQUIREMENTS FOR PIN DEVICES (19)

(a) Mechanical Requirements

(1) The design shall incorporate guiding arrangements necessary to ensure consistent operation and tightness.

(2) The seat of a pin device shall be fastened to the body of the pin device in such a way that there is no possibility of the seat moving from its required position.

(3) In the design of the pin device, consideration shall be given to minimize the effects of deposits.

(4) Pin devices having threaded inlet or outlet connections shall be provided with wrenching surfaces to allow for normal installation without damaging operating parts.

(5) Means shall be provided in the design for sealing all critical parts to ensure that these parts are original and unmodified. Seals shall be installed in a manner to prevent changing or modifying parts without breaking the seal. If the pin is replaceable, this component is not required to be sealed if it is marked in accordance with UG-129(f)(11)(-a). Seals shall be installed by the Manufacturer. For pin devices larger than NPS $^1/_2$ (DN15), the seal shall serve as a means of identifying the device Manufacturer.

(6) If the design of the pin device is such that liquid can collect on the discharge side, except as permitted in (7) below, the device shall be equipped with a drain at the lowest point where liquid can collect (for installation, see UG-135).

(7) Devices that cannot be equipped with a drain as required in (6) above because of design or application may be used provided

(-a) the devices are used only on gas service where there is neither liquid discharged from the device nor liquid formed by condensation on the discharge side of the device

(-b) the devices are provided with a cover or discharge piping per UG-135(f) to prevent liquid or other contaminant from entering the discharge side of the device

(-c) the device is marked FOR GAS SERVICE ONLY in addition to the other required marking

(8) Pins shall be manufactured by the device Manufacturer.

(b) Material Selections

(1) Cast iron seats and disks are not permitted.

(2) Adjacent sliding and sealing surfaces shall both be of a corrosion-resistant material suitable for use with the fluid to be contained.

(3) Materials used in bodies and pressure-containing members, excluding proprietary pin material, shall be listed in Section II and this Division. Bodies and pressure-containing members, excluding proprietary pin material, shall meet all applicable requirements of Subsection C.

(4) Materials used in all other parts required for the pressure-relieving or pressure-retaining function shall be

(-a) listed in Section II; or

(-b) listed in ASTM specifications; or

(-c) controlled by the Manufacturer of the pin device by a specification ensuring control of chemical and physical properties and quality at least equivalent to ASTM specifications.

(5) Materials used for pins shall be controlled by the Manufacturer of the device by a specification ensuring the control of material properties.

(c) Inspection of Manufacturing of Pin Devices

(1) A Manufacturer shall demonstrate to the satisfaction of a representative from an ASME Designated Organization that his manufacturing, production, and testing facilities and quality control procedures will ensure close agreement between the performance of random production samples and the performance of those devices submitted for Certification.

(2) Manufacturing, assembly, inspection, and test operations including capacity are subject to inspections at any time by a representative from an ASME Designated Organization.

(3) A Manufacturer may be granted permission to apply the Certification Mark with the UD Designator to production pin devices certified in accordance with UG-131 provided the following tests are successfully completed. This permission shall expire on the sixth anniversary of the date it is initially granted. The permission may be extended for 6-yr periods if the following tests are successfully repeated within the 6-month period before expiration.

(-a) Two production sample pin devices of a size and capacity within the capability of an ASME-accepted laboratory shall be selected by a representative of an ASME Designated Organization.

(-b) Operational and capacity tests shall be conducted in the presence of a representative from an ASME Designated Organization at an ASME-accepted laboratory. The pin device Manufacturer shall be notified of the time of the test and may have representatives present to witness the test.

(-c) Should any pin device fail to meet or exceed performance requirements (set pressure and certified capacity or flow resistance) of UG-127, the test shall be repeated at the rate of two replacement devices, selected and tested in accordance with (-a) and (-b) above for each device that failed.

(-d) Should any of the replacement devices fail to meet the capacity or performance requirements of this Division, the Manufacturer shall determine the cause of failure and take corrective action to guard against future occurrence. This cause of failure and corrective action shall be documented and submitted to the ASME Designated Organization within 60 days of the failure or be cause for revocation of the authorization to use the Certification Mark on that particular type of device. Upon acceptance of the submitted corrective action by the ASME Designated Organization, the requirements of (3) above shall apply.

(4) For valves that exceed the laboratory testing capabilities and for which lift at rated overpressure can be measured, the alternative method described below shall be used in lieu of the test requirements of (3)(-a) through (3)(-c).

(-a) Two production valves that are representative of the design shall be tested per ASME PTC 25, Part III to demonstrate to the satisfaction of the representative of the ASME Designated Organization that

(-1) the measured set pressure is consistent with the stamped set pressure within the tolerances required by UG-134(f)

(-2) the valve will achieve complete opening or the minimum lift required to meet its certified capacity

(-3) the valve will operate without chatter or flutter

If only one valve of the design will be produced within the 6-yr period within which the permission is granted, only that valve need be tested as stated above.

(-b) The testing shall be performed at a facility that is mutually agreeable to the manufacturer, the representative of an ASME Designated Organization, and the

facility owner. The facility shall be capable of demonstrating the characteristics stated in (-a)(-1) through (-a)(-3).

(-c) In the event of failure of the tests, (3)(-d) shall apply.

(5) For valves that exceed the laboratory testing capabilities and for which lift at rated overpressure cannot be measured, the alternative method described below shall be used.

(-a) For initial certification, two functional models that are representative of the design shall be used, provided the test requirements of (3)(-a) through (3)(-d) are followed and the following additional tests are completed satisfactorily:

(-1) Two production valves that are representative of the design shall be tested per ASME PTC 25, Part III to demonstrate to the satisfaction of the representative of the ASME Designated Organization that

(+a) the measured set pressure is consistent with the stamped set pressure within the tolerances required by UG-134(f)

(+b) seat tightness and a secondary pressure zone leakage test are demonstrated in accordance with (d)(3) and (d)(6)

If only one valve of the design will be produced within the 6-yr period within which the permission is granted, only that valve need be tested as stated above.

(-2) The testing shall be performed at a facility that is mutually agreeable to the manufacturer, the representative of an ASME Designated Organization, and the facility owner. The facility shall be capable of demonstrating the characteristics stated in (-1)(+a) and (-1)(+b).

(-3) In the event of failure of the tests, (3)(-d) shall apply.

(-b) For 6-yr renewal of capacity certification, (-a)(-1) through (-a)(-3) shall apply.

(d) Production Testing by Manufacturers

(1) Each device to which the Certification Mark is to be applied shall be subjected to the following tests by the Manufacturer. The Manufacturer shall have a documented program for the application, calibration, and maintenance of gages and instruments used during these tests.

(2) Pressure Testing

(-a) The pressure-containing parts of each pin device are subject to pressure testing.

(-b) A pin device part is exempt from pressure testing if

(-1) the stress that would be applied under hydrostatic test conditions does not exceed 50% of the allowable stress and the part is not cast or welded, or

(-2) the part is downstream of the pressure-containing element for a device designed for discharging directly to atmosphere, or

(-3) the part is downstream of the pressure-containing element and fully within the holder

(-c) A pin device part requiring pressure testing shall be tested either

(-1) hydrostatically at a minimum 1.5 times the design pressure of the part, or

(-2) pneumatically at a minimum 1.25 times the design pressure of the part. Pneumatic testing can be hazardous; it is therefore recommended that special precautions be taken when conducting a pneumatic test.

(-d) Pressure testing may be done in the part or assembled condition.

(-e) Pressure testing shall be conducted after all machining and welding operations have been completed.

(-f) Parts subjected to pressure testing shall not exhibit a sign of leakage.

(3) The secondary pressure zone exceeding NPS 1 (DN 25) inlet size, when such devices are designed for discharge to a closed system, shall be tested with air or other gas at a pressure of at least 30 psi (200 kPa). There shall be no visible signs of leakage.[62]

(4) Set pressure qualification of a pin device shall be accomplished by completing set pressure testing in the device. At least two pins from the same lot shall be tested in the device. For single use permanently assembled pin devices having the same specification and configuration, to be supplied as a single lot, at least two completed devices shall be tested. The tests shall be conducted at the pin temperature or according to (5)(-d) below. The tests shall be within the tolerance defined in UG-127(b)(1).

(5) For all pin lot qualification testing:

(-a) Sample pins selected from each lot shall be made from the same material, heat and of the same critical dimension as those to be used in service.

(-b) Test results shall be applicable only to pins used in pin devices supplied by the device Manufacturer.

(-c) At least two pins or two single-use permanently assembled pin devices from the same lot shall be tested.

(-d) Tests shall be conducted at ambient temperature or the pin temperature (as agreed between device Manufacturer and user).[63] The manufacturer shall establish a temperature range for which testing at ambient temperature is applicable. For qualification of a pin lot at a single pin temperature at least two pin tests shall be conducted at the specified pin temperature.

(-e) Pin testing shall be completed in the actual pin device(s) or using one or more of methods (-1) or (-2) below.

(-1) Lot qualification testing shall be done in a test pin device of the same form and pressure area dimensions as that in which the pins will be used. At least two set pressure tests shall be completed at the pin temperature in accordance with (-d). The tests shall be within the tolerance defined in UG-127(b)(1).

(-2) The set pressure of a lot of pins for a pin device may be verified by a characterization test that determines the activation loading (force) under device opening conditions. The following characterization test conditions shall apply:

(+a) The pin retaining arrangement shall be the same for all characterization tests applied to a pin device.

(+b) Using pins from the same lot as tested under (4) or (-1), at least two pins shall be tested to determine the activation force that correlates to the pin device tested set pressure. The average of these tests defines the base force that shall be used to permit further pin qualification using characterization rather than pin device set pressure testing. The following shall be used to define a corrected base force that corresponds to the nominal set pressure of the pin device:

$$\text{corrected base force} = \frac{(\text{nominal set pressure}) \times (\text{average base force})}{\text{average tested set pressure per UG-138(d)(4) or UG-138(d)(5)(-e)(-1)}}$$

(+c) The qualification of additional pin quantities or lots may use this corrected base force in place of pin device set pressure testing provided the pins function at activation forces that are within ±3% of the corrected base force for set pressures above 40 psi (275 kPa). For set pressures below 40 psi (275 kPa), the tested components shall function at activation forces within a plus/minus tolerance of the corrected base force determined as follows:

$$\pm\%\ \text{tolerance for actual test forces} = \frac{40\ \text{psi}\ (275\ \text{kPa})}{\text{corresponding nominal set pressure, psi (kPa)}} \times 3\%$$

(6) A seat tightness test shall be conducted on each pin device. The test conditions and acceptance criteria shall be in accordance with the Manufacturer's published pin device specification or another specification agreed to by the user and the Manufacturer.

(e) Design Requirements. At the time of the inspection in accordance with (c)(3) above, a representative from an ASME Designated Organization has the authority to review the design for conformity with the requirements of (a) and (b) and to reject or require modification of designs that do not conform, prior to capacity testing.

(f) Welding and Other Requirements. All welding, brazing, heat treatment, and nondestructive examination used in the construction of bodies, bonnets, and yokes shall be performed in accordance with the applicable requirements of this Division.

UG-140 OVERPRESSURE PROTECTION BY SYSTEM DESIGN

(a) A pressure vessel does not require a pressure relief device if the pressure is self-limiting (e.g., the maximum discharge pressure of a pump or compressor), and this pressure is less than or equal to the MAWP of the vessel at the coincident temperature and the following conditions are met:

(1) The decision to limit the pressure by system design is the responsibility of the user. The user shall request that the Manufacturer's data report state that overpressure protection is provided by system design per (a).

(2) The user shall conduct a detailed analysis to identify and examine all potential overpressure scenarios. The "Causes of Overpressure" described in ANSI/API Standard 521, Pressure-Relieving and Depressuring Systems, shall be considered. Other standards or recommended practices that are more appropriate to the specific application may also be considered. A multidisciplinary team experienced in methods such as hazards and operability analysis (HazOp); failure modes, effects, and criticality analysis (FMECA); "what-if" analysis; or other equivalent methodology shall establish that there are no sources of pressure that can exceed the MAWP at the coincident temperature.

(3) The results of the analysis shall be documented and signed by the individual in responsible charge of the management of the operation of the vessel. This documentation shall include as a minimum the following:

(-a) detailed process and instrument flow diagrams (P&IDs), showing all pertinent elements of the system associated with the vessel

(-b) a description of all operating and upset scenarios, including scenarios involving fire and those that result from operator error, and equipment and/or instrumentation malfunctions

(-c) an analysis showing the maximum coincident pressure and temperature that can result from each of the scenarios listed in item (-b) above does not exceed the MAWP at that temperature

(b) If the pressure is not self-limiting, a pressure vessel may be protected from overpressure by system design or by a combination of overpressure by system design and pressure relief devices, if the following conditions are met. The rules below are not intended to allow for normal operation above the MAWP at the coincident temperature.

(1) The vessel is not exclusively in air, water, or steam service except where any of the following apply:

(-a) These services are critical to preventing the release of fluids that may result in safety or environmental concerns.

(-b) Failure or premature opening of the pressure relief device would result in an unacceptably high probability of failure or damage to the vessel or other equipment in the system.

(-c) Failure or premature opening of the pressure relief device would result in significant operational upset(s).

(2) The decision to limit the overpressure by system design is the responsibility of the user. The user shall request that the Manufacturer's data report state that overpressure protection is provided by system design per (b) if no pressure relief device compliant with UG-125 through UG-138 is to be installed. If no pressure relief device is to be installed, acceptance of the jurisdiction may be required.

(3) The user shall conduct a detailed analysis to identify and examine all scenarios that could result in an overpressure condition and magnitude of the overpressure. The "Causes of Overpressure" as described in ANSI/API Standard 521, Pressure-Relieving and Depressuring Systems, shall be considered. Other standards or recommended practices that are more appropriate to the specific application may also be considered. A multidisciplinary team experienced in methods such as hazards and operability analysis (HazOp); failure modes, effects, and criticality analysis (FMECA); "what-if" analysis; or other equivalent methodology shall conduct the analysis.

(4) The overpressure scenario shall be readily apparent so that operators or protective instrumentation will take corrective action to prevent operation above the MAWP at the coincident temperature.

(5) There shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the design temperature. The overpressure limit shall not exceed the test pressure. Credible events or scenario analysis as described in WRC Bulletin 498 "Guidance on the Application of Code Case 2211 — Overpressure Protection by Systems Design" shall be considered.

(6) The results of the analysis shall be documented and signed by the individual in responsible charge of the management of the operation of the vessel. This documentation shall include as a minimum the following:

(-a) detailed process and instrument flow diagrams (P&IDs), showing all pertinent elements of the system associated with the vessel

(-b) a description of all operating and upset scenarios, including those involving fire and those that result from operator error, and equipment and/or instrumentation malfunctions

(-c) a detailed description of any safety critical instrumentation used to limit the system pressure, including the identification of all truly independent redundancies and a reliability evaluation (qualitative or quantitative) of the overall safety system

(-d) an analysis showing the maximum pressure that can result from each of the scenarios

SUBSECTION B REQUIREMENTS PERTAINING TO METHODS OF FABRICATION OF PRESSURE VESSELS

PART UW REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY WELDING

GENERAL

UW-1 SCOPE

The rules in Part UW are applicable to pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection C that pertain to the class of material used.

(19) ### UW-2 SERVICE RESTRICTIONS

(a) When vessels are to contain lethal[64] substances, either liquid or gaseous, all butt-welded joints shall be fully radiographed in accordance with UW-51, except for butt welds subject to the provisions of (2) and (3) below and UW-11(a)(4), and butt welds in stiffening rings designed under the rules of UG-29. ERW pipe or tube is not permitted to be used as a shell or nozzle in lethal service applications. When fabricated of carbon or low alloy steel, such vessels shall be postweld heat treated in accordance with Table UCS-56, unless otherwise exempted by General Note (b)(3) of Table UCS-56-1. When a vessel is to contain fluids of such a nature that a very small amount mixed or unmixed with air is dangerous to life when inhaled, it shall be the responsibility of the user and/or his designated agent to determine if it is lethal. If determined as lethal, the user and/or his designated agent [see U-2(a)] shall so advise the designer and/or Manufacturer. It shall be the responsibility of the Manufacturer to comply with the applicable Code provisions (see UCI-2 and UCD-2).

(1) The joints of various categories (see UW-3) shall be as follows:

(-a) Except for welded tubes and pipes internal to heat exchanger shells, all joints of Category A shall be Type No. (1) of Table UW-12.

(-b) All Category B and C joints shall be Type No. (1) or No. (2) of Table UW-12.

(-c) Category C joints for lap joint stub ends shall be as follows:

(-1) The finished stub end shall be attached to its adjacent shell with a Type No. (1) or Type No. (2) joint of Table UW-12. The finished stub end can be made from a forging or can be machined from plate material. [See UW-13(h).]

(-2) The lap joint stub end shall be fabricated as follows:

(+a) The weld is made in two steps as shown in Figure UW-13.5.

(+b) Before making weld No. 2, weld No. 1 is examined by full radiography in accordance with UW-51, regardless of size. The weld and fusion between the weld buildup and neck is examined by ultrasonics in accordance with Mandatory Appendix 12.

(+c) Weld No. 2 is examined by full radiography in accordance with UW-51.

(-3) The finished stub end may either conform to ASME B16.9 dimensional requirements or be made to a non-standard size, provided all requirements of this Division are met.

(-d) All joints of Category D shall be full penetration welds extending through the entire thickness of the vessel wall or nozzle wall.

(2) Radiographic examination of the welded seam in exchanger tubes and pipes, to a material specification permitted by this Division, which are butt welded without the addition of filler metal may be waived, provided the tube or pipe is totally enclosed within a shell of a vessel which meets the requirements of (a).

(3) If only one side of a heat exchanger contains a lethal substance, the other side need not be built to the rules for a vessel in lethal service if:

(-a) exchanger tubes are seamless; or

(-b) exchanger tubes conform to a tube specification permitted by this Division, are butt welded without addition of filler metal, and receive in lieu of full radiography all of the following nondestructive testing and examination:

(-1) hydrotest in accordance with the applicable specification;

(-2) pneumatic test under water in accordance with the applicable material specification, or if not specified, in accordance with SA-688;

(-3) ultrasonic or nondestructive electric examination of sufficient sensitivity to detect surface calibration notches in any direction in accordance with SA-557, S1 or S3.

No improvement in longitudinal joint efficiency is permitted because of the additional nondestructive tests.

(4) All elements of a combination vessel in contact with a lethal substance shall be constructed to the rules for lethal service.

(b) When vessels are to operate below certain temperatures designated by Part UCS (see UCS-68), or impact tests of the material or weld metal are required by Part UHA, the joints of various categories (see UW-3) shall be as follows:

(1) All joints of Category A shall be Type No. (1) of Table UW-12 except that for austenitic chromium–nickel stainless steel Types 304, 304L, 316, 316L, 321, and 347, which satisfy the requirements of UHA-51(f), Type No. (2) joints may be used.

(2) All joints of Category B shall be Type No. (1) or No. (2) of Table UW-12.

(3) All joints of Category C shall be full penetration welds extending through the entire section at the joint.

(4) All joints of Category D shall be full penetration welds extending through the entire thickness of the vessel wall or nozzle wall except that partial penetration welds may be used between materials listed in Table UHA-23 as follows:

(-a) for materials shown in UHA-51(d)(1)(-a) and UHA-51(d)(2)(-a) at minimum design metal temperatures (MDMTs) of −320°F (−196°C) and warmer;

(-b) for materials shown in UHA-51(d)(1)(-b) and UHA-51(d)(2)(-b) at MDMTs of −50°F (−45°C) and warmer.

(c) Unfired steam boilers with design pressures exceeding 50 psi (343 kPa)shall satisfy all of the following requirements:

(1) All joints of Category A (see UW-3) shall be in accordance with Type No. (1) of Table UW-12, and all joints in Category B shall be in accordance with Type No. (1) or No. (2) of Table UW-12.

(2) All butt-welded joints shall be fully radiographed except under the provisions of UW-11(a)(4) and except for ERW pipe weld seams. When using ERW pipe as the shell of an unfired steam boiler, its thickness shall not exceed ½ in. (13 mm), its diameter shall not exceed 24 in. (DN 600), and the ERW weld shall be completed using high frequency (HFI) welding.

(3) When fabricated of carbon or low-alloy steel, such vessels shall be postweld heat treated.

(4) See also U-1(g)(1), UG-16(b), and UG-125(b).

(d) Pressure vessels or parts subject to direct firing [see U-1(h)] may be constructed in accordance with all applicable rules of this Division and shall meet the following requirements:

(1) All welded joints in Category A (see UW-3) shall be in accordance with Type No. (1) of Table UW-12, and all welded joints in Category B, when the thickness exceeds $^5/_8$ in. (16 mm), shall be in accordance with Type No. (1) or No. (2) of Table UW-12. No welded joints of Type No. (3) of Table UW-12 are permitted for either Category A or B joints in any thickness.

(2) When the thickness at welded joints exceeds $^5/_8$ in. (16 mm) for carbon (P-No. 1) steels and for all thicknesses for low alloy steels (other than P-No. 1 steels), postweld heat treatment is required. For all other material and in any thickness, the requirements for postweld heat treatment shall be in conformance with the applicable Subsections of this Division. See also U-1(h), UG-16(b), and UCS-56.

(3) The user, his designated agent, or the Manufacturer of the vessel shall make available to the Inspector the calculations used to determine the design temperature of the vessel. The provisions of UG-20 shall apply except that pressure parts in vessel areas having joints other than Type Nos. (1) and (2) of Table UW-12, subject to direct radiation and/or the products of combustion, shall be designed for temperatures not less than the maximum surface metal temperatures expected under operating conditions.

UW-3 WELDED JOINT CATEGORY

The term "Category" as used herein defines the location of a joint in a vessel, but not the type of joint. The "Categories" established by this paragraph are for use elsewhere in this Division in specifying special requirements regarding joint type and degree of inspection for certain welded pressure 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 will apply to joints of a given category only when specifically so stated. The joints included in each category are designated as Category A, B, C, and D joints below. Figure UW-3 illustrates typical joint locations included in each category. Welded joints not defined by the category designations include but are not limited to Figure 5-1, sketches (a), (c), and (d) corner joints; Figure 9-5 jacket-closure-to-shell welds; and Figure 26-13 fillet welds. Unless limited elsewhere in this Division, the UW-9(a) permissible weld joint types may be used with welded joints that are not assigned a category.

(a) Category A. Longitudinal and spiral welded joints within the main shell, communicating chambers,[65] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[66] of a flat-sided vessel; any butt-welded joint within a flat tubesheet; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.[65]

(b) Category B. Circumferential welded joints within the main shell, communicating chambers,[65] nozzles, or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.[65] Circumferential welded joints are butt joints if the half-apex angle, α, is equal to or less than 30 deg and angle joints when α is greater than 30 deg. (See Figure UW-3.)

(c) Category C. Welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers[65] any welded joint connecting one side plate[66] to another side plate of a flat-sided vessel.

(d) Category D. Welded joints connecting communicating chambers[65] or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels, and those joints connecting nozzles to communicating chambers[65] (for nozzles at the small end of a transition in diameter, see Category B).

MATERIALS

UW-5 GENERAL

(a) Pressure Parts. Materials used in the construction of welded pressure vessels shall comply with the requirements for materials given in UG-4 through UG-15, and shall be proven of weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof.

(b) Nonpressure Parts. Materials used for nonpressure parts that are welded to the pressure vessel shall be proven of weldable quality as described below.

(1) For material identified in accordance with UG-10, UG-11, UG-15, or UG-93, satisfactory qualification of the welding procedure under Section IX is considered as proof of weldable quality.

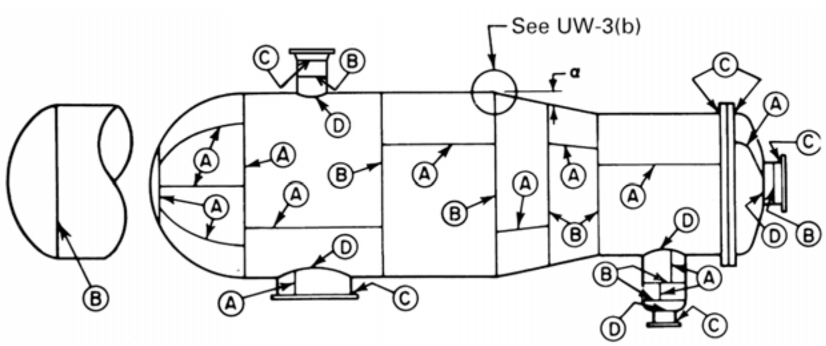
(2) For materials not identifiable in accordance with UG-10, UG-11, UG-15, or UG-93, but identifiable as to nominal chemical analysis and mechanical properties, P-Number under Section IX, Table QW/QB-422, or to a material specification not permitted in this Division, satisfactory qualification of the welding procedure under Section IX is considered as proof of weldable quality. For materials identified by P-Numbers, the provisions of Section IX, Table QW/QB-422 may be followed for welding procedure qualification. The welding procedure need only be qualified once for a given nominal chemical analysis and mechanical properties or material specification not permitted in this Division.

(3) Materials that cannot be identified are to be considered as unassigned material and qualified per the requirements of Section IX.

(c) Two materials of different specifications may be joined by welding provided the requirements of Section IX are met.

(d) Materials joined by the electroslag and electrogas welding processes shall be limited to ferritic steels and the following austenitic steels which are welded to

(19) **Figure UW-3**
Illustration of Welded Joint Locations Typical of Categories A, B, C, and D



produce a ferrite containing weld metal: SA-240 Types 304, 304L, 316, and 316L; SA-182 F304, F304L, F316, and F316L; SA-351 CF3, CF3A, CF3M, CF8, CF8A, and CF8M.

(e) Welding of SA-841 by the electroslag or electrogas welding process is prohibited.

(f) Materials joined by the inertia and continuous drive friction welding processes shall be limited to materials assigned P-Numbers in Section IX and shall not include rimmed or semikilled steel.

UW-6 NONMANDATORY GUIDELINES FOR WELDING MATERIAL SELECTIONS

The Manufacturer is responsible for the selection of welding consumables and welding processes. These nonmandatory guidelines for welding material selections are intended to achieve suitable vessel performance for the intended service conditions, but may not be appropriate for every condition in the absence of specific technical reasons to do otherwise. The user or his designated agent should inform the Manufacturer when a specific filler metal selection is necessary to achieve satisfactory vessel performance for the intended service conditions.

(a) The tensile strength of the weld should equal or exceed that of the base metals to be joined. When base metals of different strengths are to be joined by welding, the tensile strength of the weld metal should equal or exceed that of the weaker of the two base metals.

(b) When considerations such as corrosion resistance, toughness, or fatigue resistance require selecting welding consumables or processes that produce weld joints of a lesser strength than either of the base metals, the strength of the resulting joint should be reviewed and the design adjusted as appropriate for the intended service conditions.

(c) When welding materials of like composition, the nominal composition of the weld metal should be analogous to the nominal composition of the base metal, except when creep or corrosion performance is an overriding consideration.

(d) When welding materials of different nominal composition, the nominal composition of the weld metal should be analogous to one of the base metals, or be of an acceptable alternative composition.

(e) When joining nonferrous base metals, filler metal selections should follow the recommendations of the manufacturer of the nonferrous metal or applicable industry associations.

DESIGN

UW-8 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsection C that pertain to the class of material used.

UW-9 DESIGN OF WELDED JOINTS (19)

(a) Permissible Types. The types of welded joints permitted for Category A, B, C, and D joints are listed in Table UW-12, together with the limiting plate thickness permitted for each type. Other types of welded joints are specifically allowed in this Subsection. Only butt-type joints may be used with the permitted welding processes in UW-27 that include the application of pressure.

(b) Welding Grooves. The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration. Qualification of the welding procedure, as required in UW-28, is acceptable as proof that the welding groove is satisfactory.

(c) Tapered Transitions

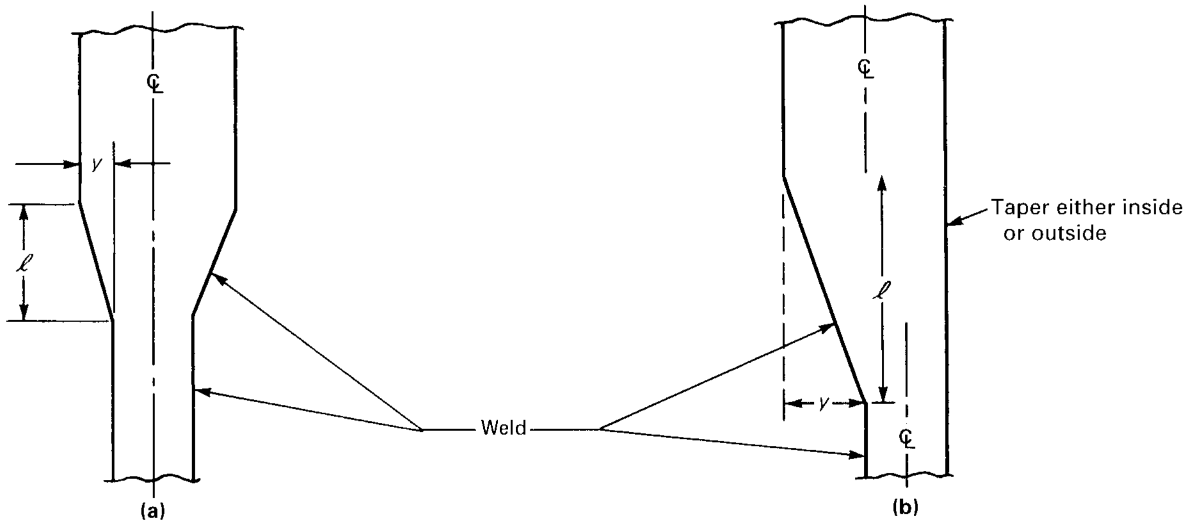
(1) A tapered transition having a length not less than *three* times the offset between the adjacent surfaces of abutting sections, as shown in Figure UW-9-1, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section, or by more than $^1\!/_8$ in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. When the transition is formed by removing material from the thicker section, the minimum thickness of that section, after the material is removed, shall not be less than that required by UG-23(c). When the transition is formed by adding additional weld metal beyond what would otherwise be the edge of the weld, such additional weld metal buildup shall be subject to the requirements of UW-42. The butt weld may be partly or entirely in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential, butt welded joints connecting formed heads to main shells are contained in UW-13.

(2) The centerline of a butt weld attaching a component (flange, pipe, etc.) to a thickened neck nozzle that has a taper transition angle, α, less than 71.5 deg shall be located a minimum of $1.5t_n$ from the taper (see Figure UW-9-2), where t_n is the nominal thickness of the nozzle wall at the butt weld.

(d) Except when the longitudinal joints are radiographed 4 in. (100 mm) each side of each circumferential welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

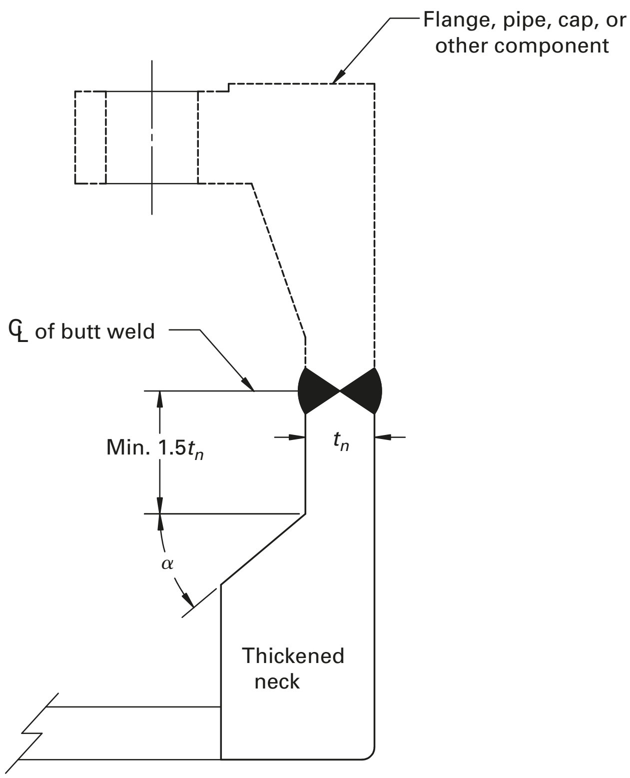
(e) Lap Joints. For lapped joints, the surface overlap shall be not less than four times the thickness of the inner plate except as otherwise provided for heads in UW-13.

Figure UW-9-1
Butt Welding of Plates of Unequal Thickness



GENERAL NOTES:
(a) $\ell \geq 3y$, where ℓ is the required length of taper and y is the offset between the adjacent surfaces of abutting sections.
(b) Length of required taper, ℓ, may include the width of the weld.
(c) In all cases, ℓ shall be not less than $3y$.

Figure UW-9-2
Butt Welding of Components to Thickened Neck Nozzles



(f) Welded Joints Subject to Bending Stresses. Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. Corner joints, with fillet welds only, shall not be used unless the plates forming the corner are properly supported independently of such welds. (See UW-18.)

(g) Minimum Weld Sizes. Sizing of fillet and partial penetration welds shall take into consideration the loading conditions in UG-22 but shall not be less than the minimum sizes specified elsewhere in this Division.

UW-10 POSTWELD HEAT TREATMENT

Pressure vessels and pressure vessel parts shall be postweld heat treated as prescribed in UW-40 when postweld heat treatment is required in the applicable part of Subsection C.

(19) UW-11 RADIOGRAPHIC AND ULTRASONIC EXAMINATION

(a) Full Radiography. The following welded joints shall be examined radiographically for their full length in the manner prescribed in UW-51:

(1) all butt welds in the shell and heads of vessels used to contain lethal substances [see UW-2(a)];

(2) all butt welds in the shell and heads of vessels in which the nominal thickness [see (g) below] at the welded joint exceeds $1^1/_2$ in. (38 mm), or exceeds the lesser thicknesses prescribed in UCS-57, UNF-57, UHA-33, UCL-35, or UCL-36 for the materials covered therein, or as otherwise prescribed in UHT-57, ULW-51, ULW-52(d), ULW-54, or ULT-57;

(3) all butt welds in the shell and heads of unfired steam boilers having design pressures

(-a) exceeding 50 psi (350 kPa) [see UW-2(c)];

(-b) not exceeding 50 psi (350 kPa) [see UW-2(c)] but with nominal thickness at the welded joint exceeding the thickness specified in (2) above;

(4) all butt welds in nozzles, communicating chambers, etc., with the nominal thickness at the welded joint that exceeds the thickness in (2) above or attached to the shell or heads of vessels under (1)or (3) above that are required to be fully radiographed; however, except as required by UHT-57(a), Category B and C butt welds in nozzles and communicating chambers that neither exceed NPS 10 (DN 250) nor $1^1/_8$ in. (29 mm) wall thickness do not require any radiographic examination;

(5) all Category A and D butt welds in the shell and heads of vessels where the design of the joint or part is based on a joint efficiency permitted by UW-12(a), in which case:

(-a) Category A and B welds connecting the shell or heads of vessels shall be of Type No. (1) or Type No. (2) of Table UW-12;

(-b) Category B or C butt welds [but not including those in nozzles and communicating chambers except as required in (4) above] which intersect the Category A butt welds in the shell or heads of vessels or connect seamless vessel shell or heads shall, as a minimum, meet the requirements for spot radiography in accordance with UW-52. Spot radiographs required by this paragraph shall not be used to satisfy the spot radiography rules as applied to any other weld increment.

(6) all butt welds joined by electrogas welding with any single pass greater than $1^1/_2$ in. (38 mm) and all butt welds joined by electroslag welding;

(7) all Category A welds in a tubesheet shall be of Type (1) of Table UW-12;

(8) exemptions from radiographic examination for certain welds in nozzles and communicating chambers as described in (2), (4), and (5) above take precedence over the radiographic requirements of Subsection C of this Division.

(b) Spot Radiography. Except when spot radiography is required for Category B or C butt welds by (a)(5)(-b) above, butt-welded joints made in accordance with Type No. (1) or (2) of Table UW-12 which are not required to be fully radiographed by (a) above, may be examined by spot radiography. Spot radiography shall be in accordance with UW-52. If spot radiography is specified for the entire vessel, radiographic examination is not required of Category B and C butt welds in nozzles and communicating chambers that exceed neither NPS 10 (DN 250) nor $1^1/_8$ in. (29 mm) wall thickness.

NOTE: This requirement specifies spot radiography for butt welds of Type No. (1) or No. (2) that are used in a vessel, but does not preclude the use of fillet and/or corner welds permitted by other paragraphs, such as for nozzle and manhole attachments, welded stays, flat heads, etc., which need not be spot radiographed.

(c) No Radiography. Except as required in (a) above, no radiographic examination of welded joints is required when the vessel or vessel part is designed for external pressure only, or when the joint design complies with UW-12(c).

(d) Electrogas welds in ferritic materials with any single pass greater than $1^1/_2$ in. (38 mm) and electroslag welds in ferritic materials shall be ultrasonically examined throughout their entire length in accordance with the requirements of Mandatory Appendix 12. This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment.

(e) In addition to the requirements in (a) and (b) above, all welds made by the electron beam or laser beam process shall be ultrasonically examined for their entire length in accordance with the requirements of Mandatory Appendix 12. Ultrasonic examination may be waived if the following conditions are met:

(1) The nominal thickness at the welded joint does not exceed $^1/_4$ in. (6 mm).

(2) For ferromagnetic materials, the welds are either examined by the magnetic particle examination technique in accordance with Mandatory Appendix 6 or examined by the liquid penetrant examination technique in accordance with Mandatory Appendix 8.

(3) For nonferromagnetic materials, the welds are examined by the liquid penetrant examination technique in accordance with Mandatory Appendix 8.

(f) When radiography is required for a welded joint in accordance with (a) and (b) above, and the weld is made by the inertia and continuous drive friction welding processes, the welded joints shall also be ultrasonically examined for their entire length in accordance with Mandatory Appendix 12.

(g) For radiographic and ultrasonic examination of butt welds, the definition of nominal thickness at the welded joint under consideration shall be the nominal thickness of the thinner of the two parts joined. Nominal thickness is defined in 3-2.

(19) UW-12 JOINT EFFICIENCIES

Table UW-12 gives the joint efficiencies, E, to be used in the equations of this Division for welded joints. Except as required by UW-11(a)(5), a joint efficiency depends only on the type of joint and on the extent of examination of the joint and does not depend on the extent of examination of any other joint. The user or his designated agent [see U-2(a)] shall establish the type of joint and the extent of examination when the rules of this Division do not mandate specific requirements. Rules for determining the applicability of the efficiencies are found in the various paragraphs covering design equations [for example, see UG-24(a) and UG-27]. For further guidance, see Nonmandatory Appendix L.

(a) A value of E not greater than that given in column (a) of Table UW-12 shall be used in the design calculations for fully radiographed butt joints [see UW-11(a)], except that when the requirements of UW-11(a)(5) are not met, a value of E not greater than that given in column (b) of Table UW-12 shall be used.

(b) A value of E not greater than that given in column (b) of Table UW-12 shall be used in the design calculations for spot radiographed butt-welded joints [see UW-11(b)].

(c) A value of E not greater than that given in column (c) of Table UW-12 shall be used in the design calculations for welded joints that are neither fully radiographed nor spot radiographed [see UW-11(c)].

(d) Seamless vessel sections or heads shall be considered equivalent to welded parts of the same geometry in which all Category A welds are Type No. 1. For calculations involving circumferential stress in seamless vessel sections or for thickness of seamless heads, E = 1.0 when the spot radiography requirements of UW-11(a)(5)(-b) are met. E = 0.85 when the spot radiography requirements of UW-11(a)(5)(-b) are not met, or when the Category A or B welds connecting seamless vessel sections or heads are Type No. 3, 4, 5, 6, or 8 of Table UW-12.

(e) Welded pipe or tubing shall be treated in the same manner as seamless, but with allowable tensile stress taken from the welded product values of the stress tables, and the requirements of (d) applied.

(f) A value of E not greater than 0.80 may be used in the equations of this Division for joints completed by any of the permitted welding processes in UW-27(b) that include the application of pressure, except for electric resistance welding, provided the welding process used is permitted by the rules in the applicable parts of Subsection C for the material being welded. The quality of such welds used in vessels or parts of vessels shall be proved as follows: Test specimens shall be representative of the production welding on each vessel. They may be removed from the shell itself or from a prolongation of the shell including the longitudinal joint, or, in the case of vessels not containing a longitudinal joint, from a test plate of the same material and thickness as the vessel and welded in accordance with the same procedure. One reduced-section tension test and two side-bend tests shall be made in accordance with, and shall meet the requirements of Section IX, QW-150 and QW-160.

UW-13 ATTACHMENT DETAILS

(a) Definitions

t_h = nominal thickness of head
t_p = minimum distance from outside surface of flat head to edge of weld preparation measured as shown in Figure UW-13.2
t_s = nominal thickness of shell

(See UG-27, UG-28, UG-32, UG-34, and other paragraphs for additional definitions.)

(b) See below.

(1) Ellipsoidal, torispherical, and other types of formed heads shall be attached to the shell with a butt weld, or as illustrated in the applicable Figure UW-13.1, sketches (a), (b), (c), (d), and (i). The construction shown in sketch (e) may also be used for end heads when the thickness of the shell section of the vessel does not exceed $^5/_8$ in. (16 mm) [see also (c) below]. Limitations relative to the use of these attachments shall be as given in the sketches and related notes and in Table UW-12. Figure UW-13.1, sketches (f), (g), and (h) are examples of attachment methods which are not permissible.

(2) Formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure UW-13.1, using the applicable sketch. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(3) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Figure UW-13.1, sketches (j) and (k) shall be provided at joints between formed

(19)

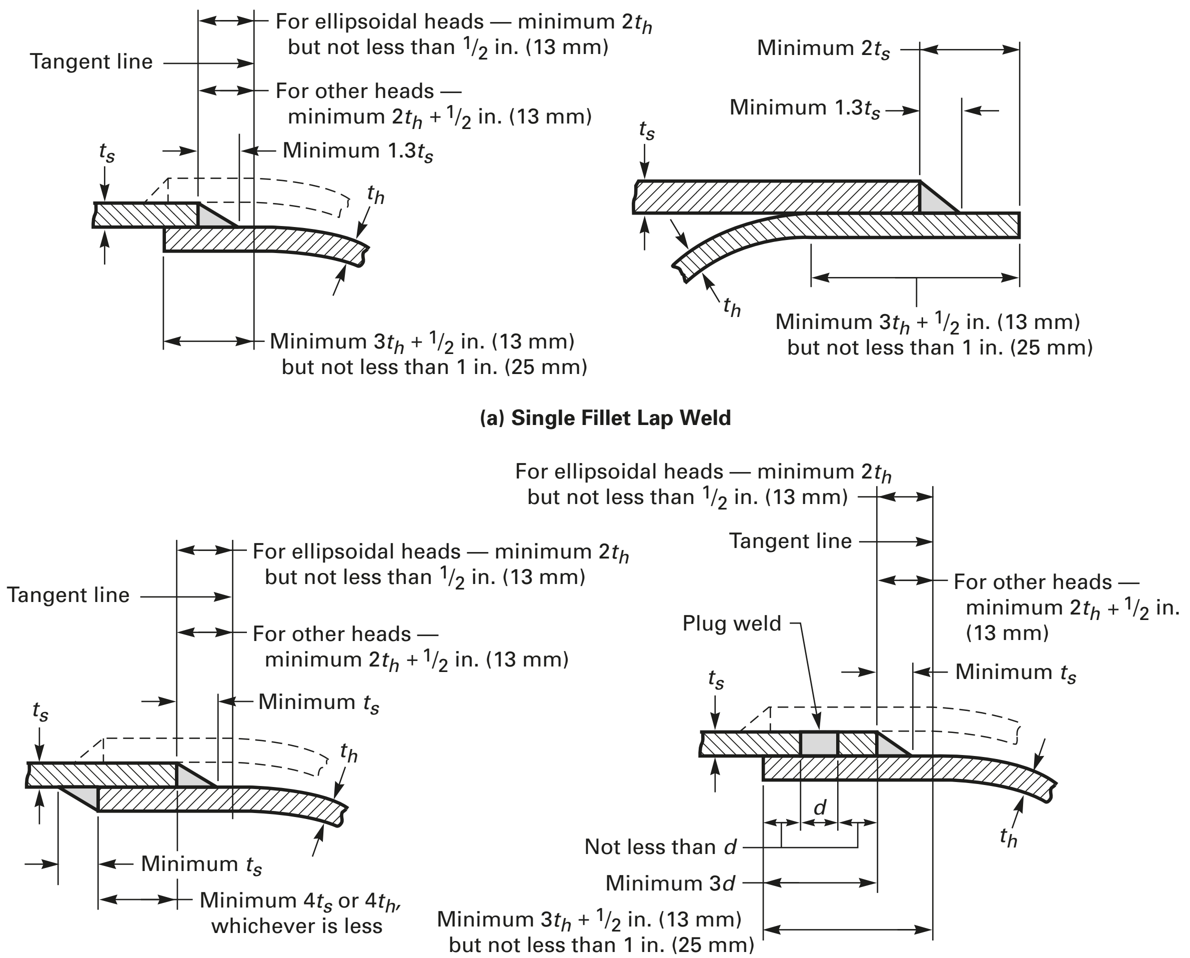
Table UW-12
Maximum Allowable Joint Efficiencies for Welded Joints

Type No.	Joint Description	Limitations	Joint Category	Extent of Radiographic or Ultrasonic Examination [Note (1), Note (2), Note (3)] (a) Full [Note (4)]	(b) Spot [Note (5)]	(c) None
(1)	Butt joints as attained by double-welding or by other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to agree with the requirements of UW-35. Welds using metal backing strips that remain in place are excluded.	None	A, B, C, and D	1.00	0.85	0.70
(2)	Single-welded butt joint with backing strip other than those included under (1)	*(a)* None except as in (b) below	A, B, C, and D	0.90	0.80	0.65
		(b) Circumferential butt joints with one plate offset; see UW-13(b)(4) and Figure UW-13.1, sketch (i)	A, B, and C	0.90	0.80	0.65
(3)	Single-welded butt joint without use of backing strip	Circumferential butt joints only, not over $^5/_8$ in. (16 mm) thick and not over 24 in. (600 mm) outside diameter	A, B, and C	NA	NA	0.60
(4)	Double full fillet lap joint	*(a)* Longitudinal joints not over $^3/_8$ in. (10 mm) thick	A	NA	NA	0.55
		(b) Circumferential joints not over $^5/_8$ in. (16 mm) thick	B and C [Note (6)]	NA	NA	0.55
(5)	Single full fillet lap joints with plug welds conforming to UW-17	*(a)* Circumferential joints [Note (7)] for attachment of heads not over 24 in. (600 mm) outside diameter to shells not over $^1/_2$ in. (13 mm) thick	B	NA	NA	0.50
		(b) Circumferential joints for the attachment to shells of jackets not over $^5/_8$ in. (16 mm) in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than $1^1/_2$ times the diameter of the hole for the plug.	C	NA	NA	0.50
(6)	Single full fillet lap joints without plug welds	*(a)* For the attachment of heads convex to pressure to shells not over $^5/_8$ in. (16 mm) required thickness, only with use of fillet weld on inside of shell; or	A and B	NA	NA	0.45
		(b) for attachment of heads having pressure on either side, to shells not over 24 in. (600 mm) inside diameter and not over $^1/_4$ in. (6 mm) required thickness with fillet weld on outside of head flange only	A and B	NA	NA	0.45
(7)	Corner joints, full penetration, partial penetration, and/or fillet welded	As limited by Figure UW-13.2 and Figure UW-16.1	C and D [Note (8)]	NA	NA	NA
(8)	Angle joints	Design per U-2(g) for Category B and C joints	B, C, and D	NA	NA	NA

GENERAL NOTE: E = 1.00 for butt joints in compression.

NOTES:
(1) Some welding processes require ultrasonic examination in addition to radiographic examination, and other processes require ultrasonic examination in lieu of radiographic examination. See UW-11 for some additional requirements and limitations that may apply.
(2) Joint efficiency assignment rules of UW-12(d) and UW-12(e) shall be considered and may further reduce the joint efficiencies to be used in the required thickness calculations.
(3) The rules of UW-12(f) may be used in lieu of the rules of this Table at the Manufacturer's option.
(4) See UW-12(a) and UW-51.
(5) See UW-12(b) and UW-52.
(6) For Type No. 4 Category C joint, limitation not applicable for bolted flange connections.
(7) Joints attaching hemispherical heads to shells are excluded.
(8) There is no joint efficiency E in the design equations of this Division for Category C and D corner joints. When needed, a value of E not greater than 1.00 may be used.

Figure UW-13.1
Heads Attached to Shells

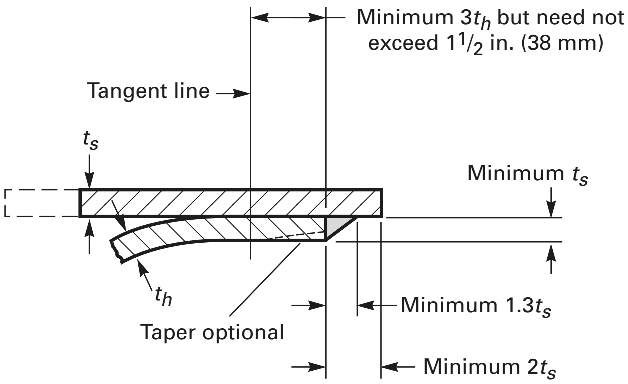


(a) Single Fillet Lap Weld

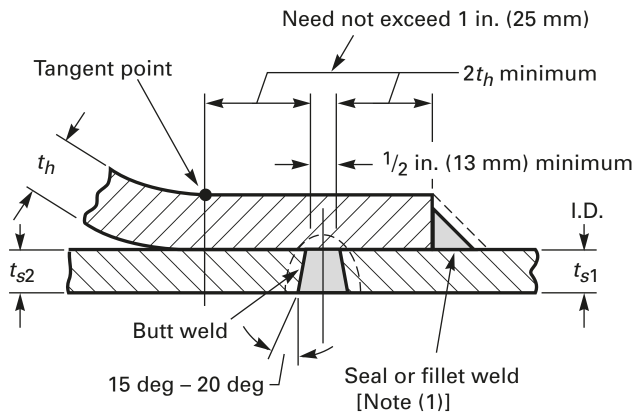
(b) Double Fillet Lap Weld

(c) Single Fillet Lap Weld With Plug Welds

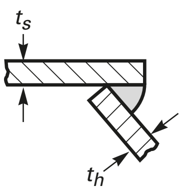
Figure UW-13.1
Heads Attached to Shells (Cont'd)



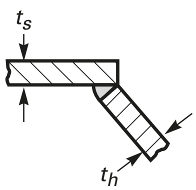
(d) Single Fillet Lap Weld



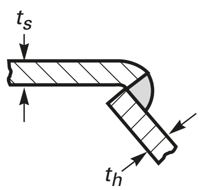
(e) Intermediate Head [See Notes (2) and (3)]



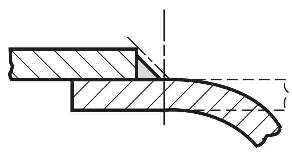
(f-1) Not Permissible



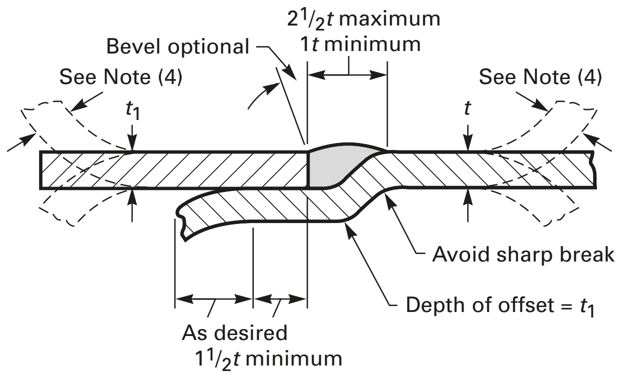
(f-2) Not Permissible



(g) Not Permissible



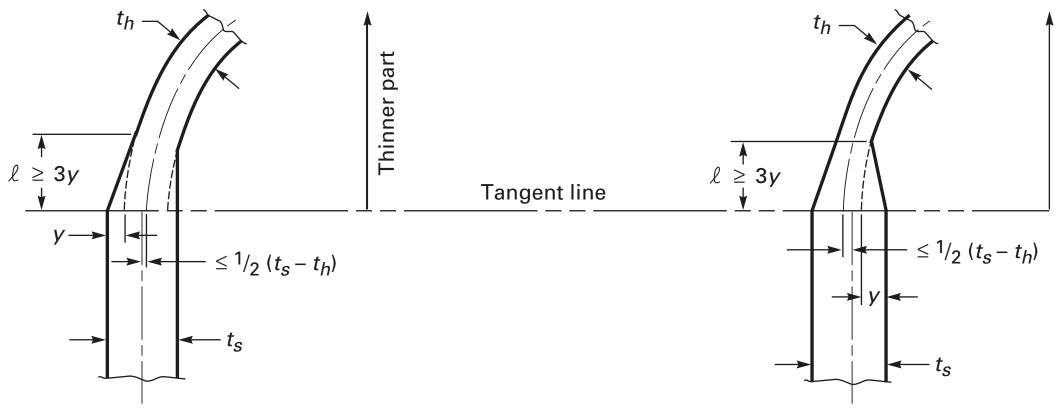
(h) Not Permissible



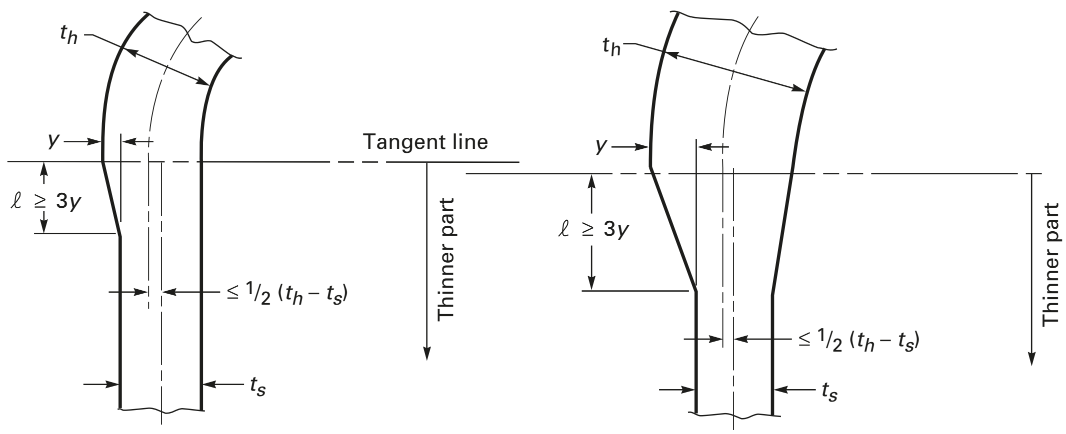
t or t_1 = $^5/_8$ maximum [see Note (5)]

(i) Butt Weld With One Plate Edge Offset

Figure UW-13.1
Heads Attached to Shells (Cont'd)



(j) [See Notes (6) and (7)] **(k) [See Notes (6) and (7)]**

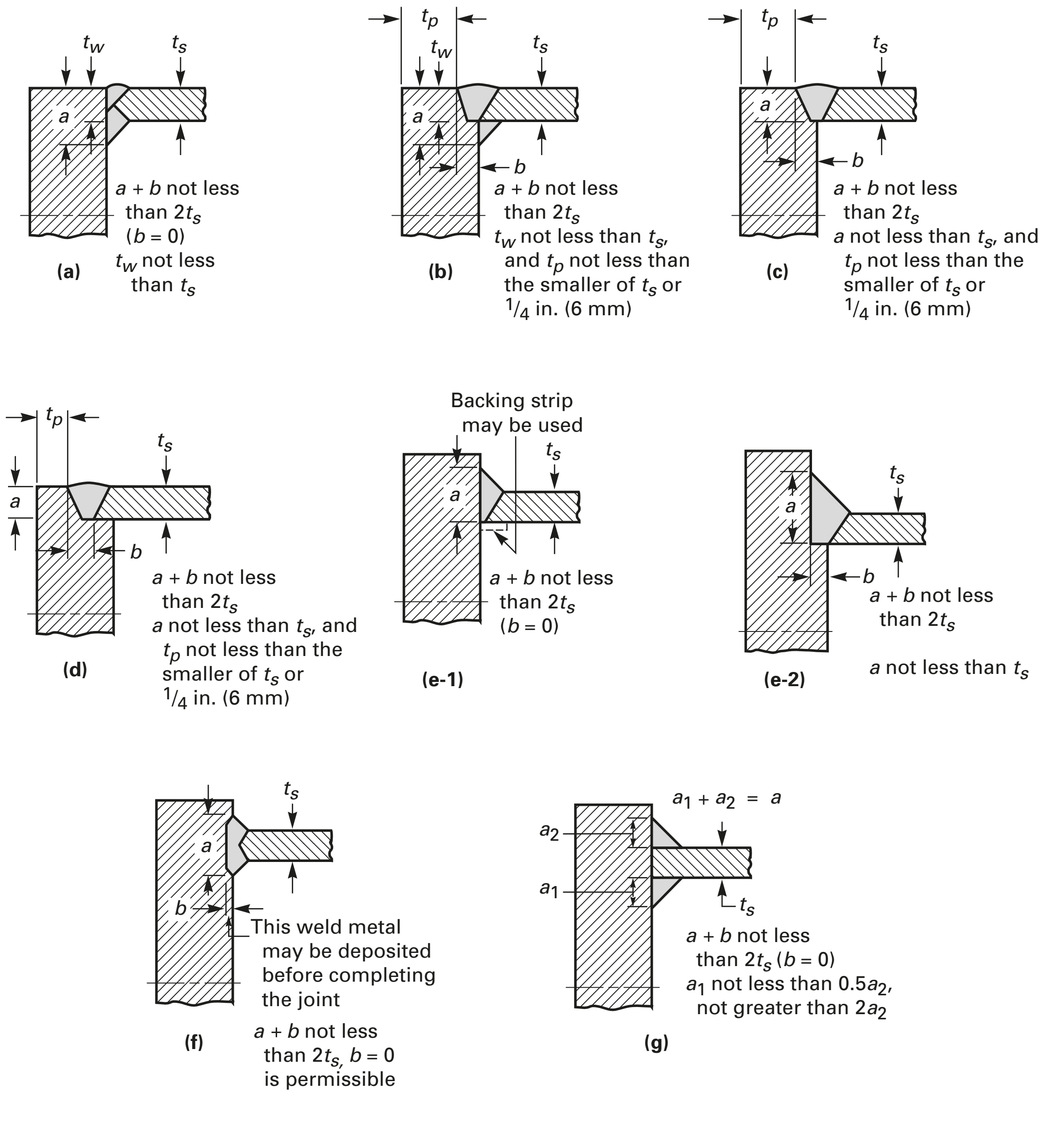


(l) [See Notes (7) and (8)] **(m) [See Notes (7) and (8)]**

GENERAL NOTE: See Table UW-12 for limitations.

NOTES:
(1) See UW-13(c)(2).
(2) Butt weld and fillet weld, if used, shall be designed to take shear at $1\frac{1}{2}$ times the differential pressure than can exist.
(3) t_{s1} and t_{s2} may be different.
(4) See UW-13(b)(4) for limitation when weld bead is deposited from inside.
(5) For joints connecting hemispherical heads to shells, the following shall apply:
(a) t or t_1 = $^3/_8$ in. (10 mm) maximum.
(b) Maximum difference in thickness between t or t_1 = $^3/_{32}$ in. (2.5 mm).
(c) Use of this figure for joints connecting hemispherical heads to shells shall be noted in the “Remarks” part of the Data Report Form.
(6) In all cases, the projected length of taper, ℓ, shall be not less than $3y$.
(7) Length of required taper, ℓ, may include the width of the weld. The shell plate centerline may be on either side of the head plate centerline.
(8) In all cases, ℓ shall be not less than $3y$ when t_h exceeds t_s. Minimum length of skirt is $3t_h$ but need not exceed $1\frac{1}{2}$ in. (38 mm) except when necessary to provide required length of taper. When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.

Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint



Typical Unstayed Flat Heads, Tubesheets Without a Bolting Flange, and Side Plates of Rectangular Vessels [See Note (1)]

Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint (Cont'd)

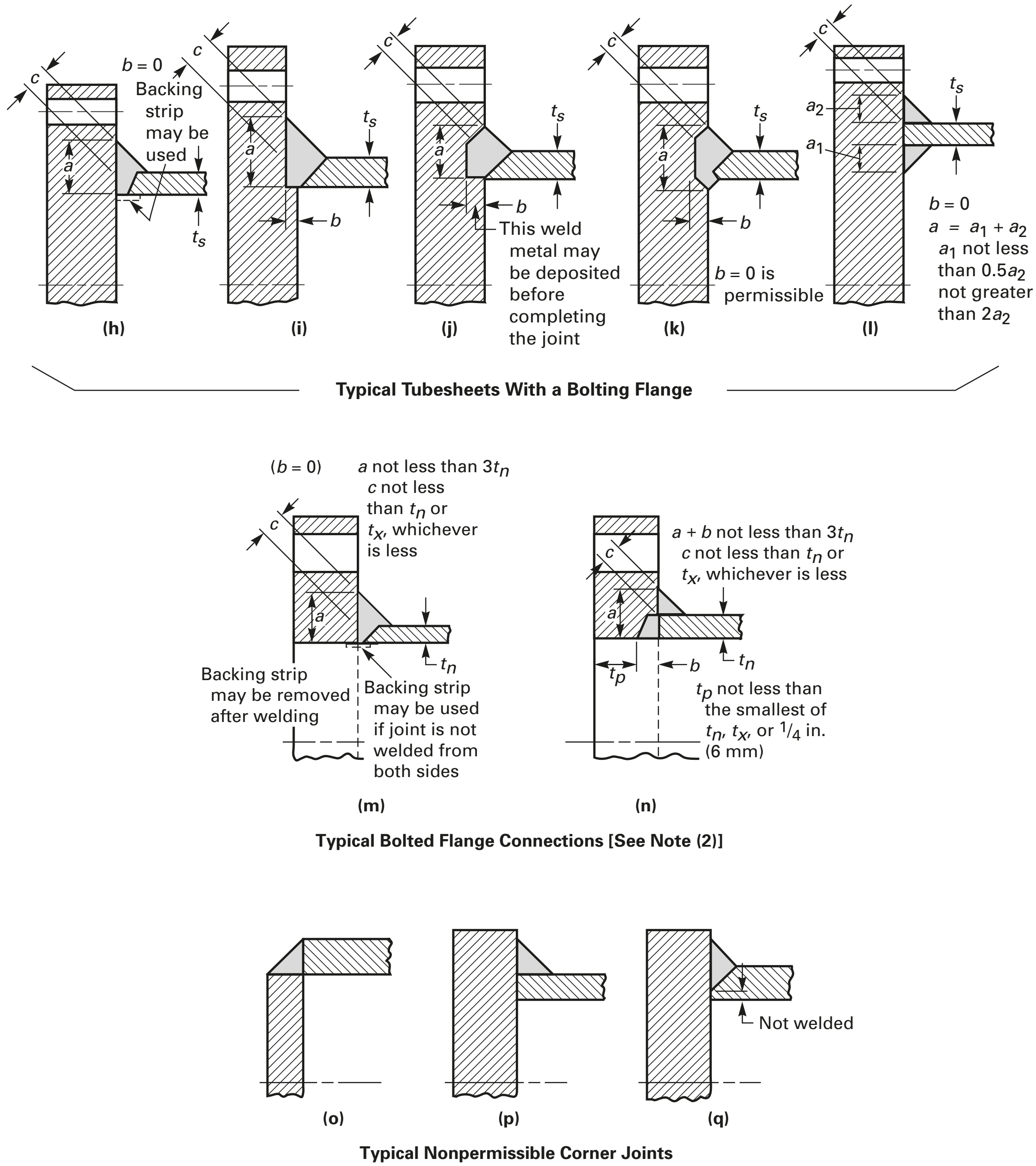
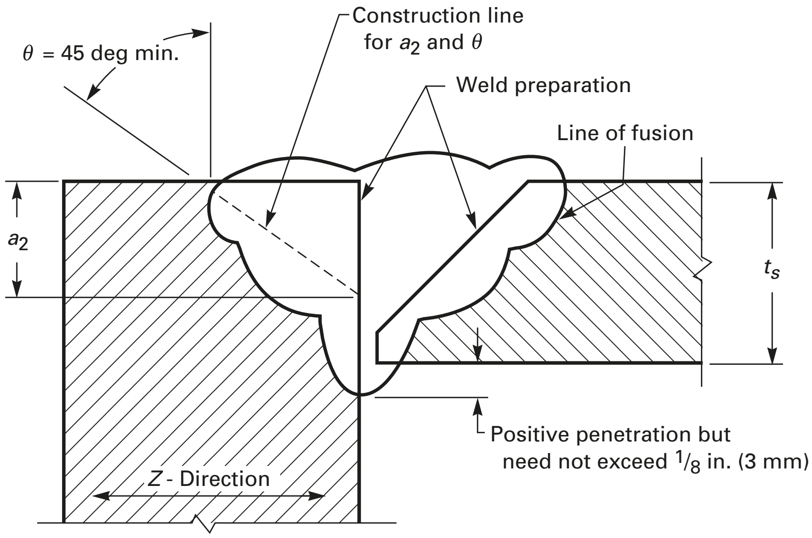
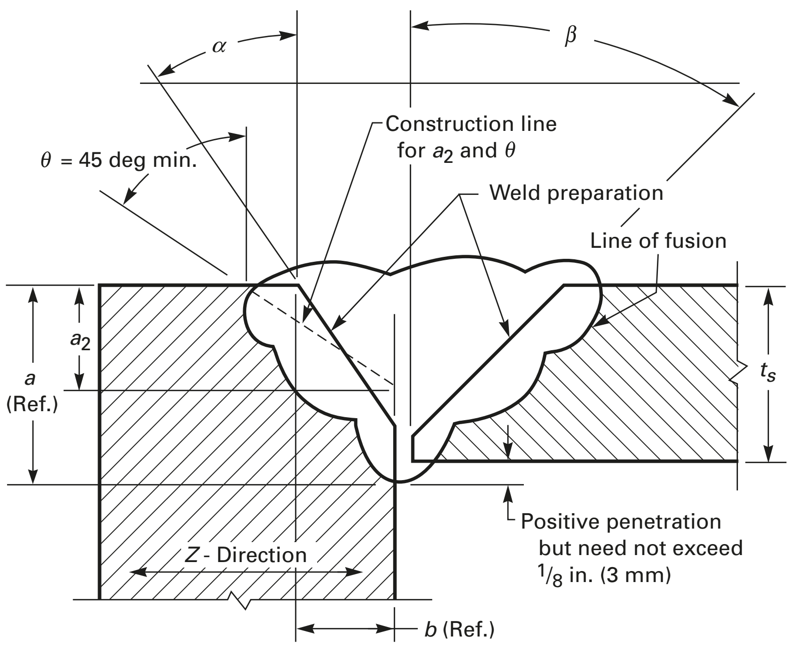


Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint (Cont'd)



K	a_2/t_s Not Less Than
0.6	0.29
0.7	0.23
0.8	0.17
0.9	0.09
1.0	0

(r) Details for One Member Beveled [See Note (3)]



K	Min. a_2/t_s for α Not Less Than 15 deg	Min. a_2/t_s for α Not Less Than 30 deg	Min. a_2/t_s for α Not Less Than 45 deg
0.6	0.85	0.55	0.29
0.7	0.81	0.47	0.23
0.8	0.74	0.38	0.17
0.9	0.58	0.23	0.09
1.0	0	0	0

See sketch (r) above for table with values of K and a_2/t_s

(s) Details for Both Members Beveled [See Note (3)]

GENERAL NOTES:
(a) $a + b$ not less than $2t_s$; c not less than $0.7t_s$ or $1.4t_r$, whichever is less.
(b) t_s and t_r are as defined in UG-34(b).
(c) Dimension b is produced by the weld preparation and shall be verified after fit up and before welding.

NOTES:
(1) For unstayed flat heads, see also UG-34.
(2) c, t_n, and t_x are as defined in 2-3.
(3) Interpolation of α and K is permitted.

heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $^1/_8$ in. (3 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt-welded attachment [Figure UW-13.1, sketches (l) and (m)], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line. When the transition is formed by removing material from the thicker section, the minimum thickness of that section, after the material is removed, shall not be less than that required by UG-23(c). When the transition is formed by adding additional weld metal beyond what would otherwise be the edge of the weld, such additional weld metal buildup shall be subject to the requirements of UW-42. The centerline misalignment between shell and head shall be no greater than one-half the difference between the actual shell and head thickness, as illustrated in Figure UW-13.1, sketches (j), (k), (l), and (m).

(4) Shells and heads may be attached to shells or heads using a butt weld with one plate offset as shown in Figure UW-13.1, sketch (i). The weld bead may be deposited on the inside of the vessel only when the weld is accessible for inspection after the vessel is completed. The offset shall be smooth and symmetrical and shall not be machined or otherwise reduced in thickness. There shall be a uniform force fit with the mating section at the root of the weld. Should the offset contain a longitudinal joint, the following shall apply:

(-a) The longitudinal weld within the area of the offset shall be ground substantially flush with the parent metal prior to the offsetting operation.

(-b) The longitudinal weld from the edge of the plate through the offset shall be examined by the magnetic particle method after the offsetting operation. Cracks and cracklike defects are unacceptable and shall be repaired or removed.

(-c) As an acceptable alternative to magnetic particle examination or when magnetic particle methods are not feasible because of the nonferromagnetic character of the weld deposit, a liquid penetrant method shall be used. Cracks and cracklike defects are unacceptable and shall be repaired or removed.

(5) Non-butt-welded bolting flanges shall be attached to formed heads as illustrated in Figure 1-6.

(c) See below.

(1) Intermediate heads, without limit to thickness, of the type shown in Figure UW-13.1, sketch (e) may be used for all types of vessels provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder.

(2) The butt weld and fillet weld shall be designed to take shear based on $1^1/_2$ times the maximum differential pressure that can exist. The allowable stress value for the butt weld shall be 70% of the stress value for the vessel material and that of the fillet 55%. The area of the butt weld in shear is the width at the root of the weld times the length of weld. The area of the fillet weld is the minimum leg dimension times the length of weld. The fillet weld may be omitted if the construction precludes access to make the weld, and the vessel is in noncorrosive service.

(d) The requirements for the attachment of welded unstayed flat heads to shells are given in UG-34 and in (e) and (f) hereunder.

(e) When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Figure UW-13.2, the joint shall meet the following requirements [see also UG-93(d)(3)]:

(1) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b, respectively (see Figure UW-13.2).

(2) For flange rings of bolted flanged connections, as shown in Figure UW-13.2, sketches (m) and (n), the sum of a and b shall be not less than three times the nominal wall thickness of the abutting pressure part. (**19**)

(3) For other components, the sum a and b shall be not less than two times the nominal wall thickness of the abutting pressure part unless the provisions of (f) are satisfied. Examples of such components are flat heads, tubesheets with or without a projection having holes for a bolted connection, and the side plates of a rectangular vessel.

(4) Other dimensions at the joint shall be in accordance with details as shown in Figure UW-13.2.

(5) Joint details that have a dimension through the joint less than the thickness of the shell, head or other pressure part, or that provide attachment eccentric thereto, are not permissible. See Figure UW-13.2, sketches (o), (p), and (q).

(f) When a multipass corner weld joint is constructed in accordance with Figure UW-13.2, sketch (r) or sketch (s), all rules in the Code pertaining to welded joints shall apply except that the requirement "$a + b$ not less than $2t_s$" of (e)(3) shall be replaced with the following requirements:

(1) A sample corner weld joint shall be prepared to qualify the weld procedure, and a sample corner weld joint shall be prepared to qualify each welder or welding operator. The Manufacturer shall prepare the sample corner weld joint with nominal thickness and configuration matching that to be employed with the following tolerances:

(-a) The sample thinner plate shall match the thickness of the production thinner plate within ±$^1/_4$ in. (±6 mm).

(-b) The sample thicker plate shall be at least 1.5 times the thickness of the sample thinner plate.

The sample shall be sectioned, polished, and etched to clearly delineate the line of fusion. Acceptability shall be determined by measurements of the line of fusion for use in the calculations for compliance with Figure

UW-13.2, sketch (r) or sketch (s). The sample shall be free from slag, cracks, and lack of fusion. A sample corner weld shall be prepared for each P-Number, except that a sample prepared to qualify a joint made from material with a given value for K [see (4)] may be used to qualify a joint made from material having an equal or higher value for K but not vice versa.

(2) This sample corner weld joint is an addition to the Welding Procedure Specification Qualification and the Welder and Welding Operator Performance Qualification requirements of Section IX. The following essential variables apply for both the procedure and performance qualification, in addition to those of Section IX:

(-a) a change in the nominal size of the electrode or electrodes used and listed in the PQR;

(-b) a change in the qualified root gap exceeding ±$^1/_{16}$ in. (±1.5 mm);

(-c) addition or deletion of nonmetallic retainers or nonfusing metal retainers;

(-d) a change in the SFA specification filler metal classification or to a weld metal or filler metal composition not covered in the specifications;

(-e) the addition of welding positions other than those qualified;

(-f) for fill passes, a change in amperage exceeding ±25 amp, change in voltage exceeding ±3 V;

(-g) a change in contact tube to work distance exceeding $^1/_4$ in. (6 mm);

(-h) a change from single electrode to multiple electrodes, or vice versa;

(-i) a change in the electrode spacing;

(-j) a change from manual or semiautomatic to machine or automatic welding or vice versa.

(3) After production welding, the back side of the weld shall be subjected to a visual examination to ensure that complete fusion and penetration have been achieved in the root, except where visual examination is locally prevented by an internal member covering the weld.

(4) K, the ratio of through-thickness (Z direction) tensile strength to the specified minimum tensile strength, shall be taken as 0.6. Higher values for K, but not higher than 1.0, may be used if through-thickness tensile strength is determined in accordance with Specification SA-770. The test results, including the UTS in addition to the reduction in area, shall be reported on the Material Test Report, in addition to the information required by Specification SA-20 when the testing in accordance with Specification SA-770 is performed by the material manufacturer. If the testing is performed by the vessel Manufacturer, the test result shall be reported on the Manufacturer's Data Report. See UG-93(b) and UG-93(c).

(5) The maximum value of t_s [see Figure UW-13.2, sketch (r) or sketch (s)] shall be limited to 3 in. (75 mm).

(6) Both members may be beveled as shown in Figure UW-13.2, sketch (s). When the bevel angle, α, is large enough to satisfy the (e)(3) requirements, these alternative rules do not apply. When the bevel angle, α, results in weld fusion dimensions that do not satisfy the (e)(3) requirement that $a + b$ is not less than $2t_s$, the following shall be satisfied:

(-a) The angle α shall be equal to or greater than 15 deg.

(-b) The dimension a_2 shall be measured from the projected surface of the plate being attached as shown in Figure UW-13.2, sketch (s).

(-c) The angle β shall be equal to or greater than 15 deg.

(-d) When a_2/t_s is equal to or exceeds the value corresponding to the K shown in the table in Figure UW-13.2, sketch (s), the requirements in (1) and (2) need not be satisfied. When a_2/t_s is less than this value, all other requirements of (f) shall be satisfied.

(g) When used, the hub of a tubesheet or flat head shall have minimum dimensions in accordance with Figure UW-13.3 and shall meet the following requirements:

(1) When the hub is integrally forged with the tubesheet or flat head, or is machined from a forging, the hub shall have the minimum tensile strength and elongation specified for the material, measured in the 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 practical.[67]

(2) When the hub is machined from plate, the requirements of Mandatory Appendix 20 shall be met.

(h) When the hub of a lap joint stub end is machined from plate with the hub length in the through thickness direction of the plate, the requirements of Mandatory Appendix 20 shall be met.

(i) In the case of nozzle necks which attach to piping [see U-1(e)(1)(-a)] of a lesser wall thickness, a tapered transition from the weld end of the nozzle may be provided to match the piping thickness although that thickness is less than otherwise required by the rules of this Division. This tapered transition shall meet the limitations as shown in Figure UW-13.4.

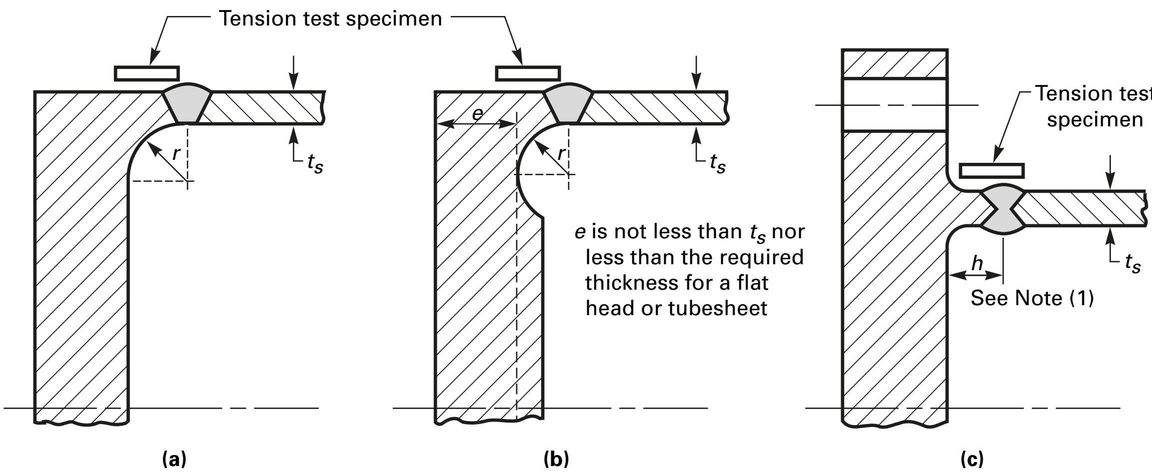
UW-14 OPENINGS IN OR ADJACENT TO WELDS

(a) Any type of opening that meets the requirements for reinforcement given in UG-37 or UG-39 may be located in a welded joint.

(b) Single openings meeting the requirements given in UG-36(c)(3) may be located in head-to-shell or Category B or C butt-welded joints, provided the weld meets the radiographic requirements in UW-51 for a length equal to three times the diameter of the opening with the center of the hole at midlength. Defects that are completely removed in cutting the hole shall not be considered in judging the acceptability of the weld.

(c) In addition to meeting the radiographic requirements of (b) above, when multiple openings meeting the requirements given in UG-36(c)(3) are in line in a

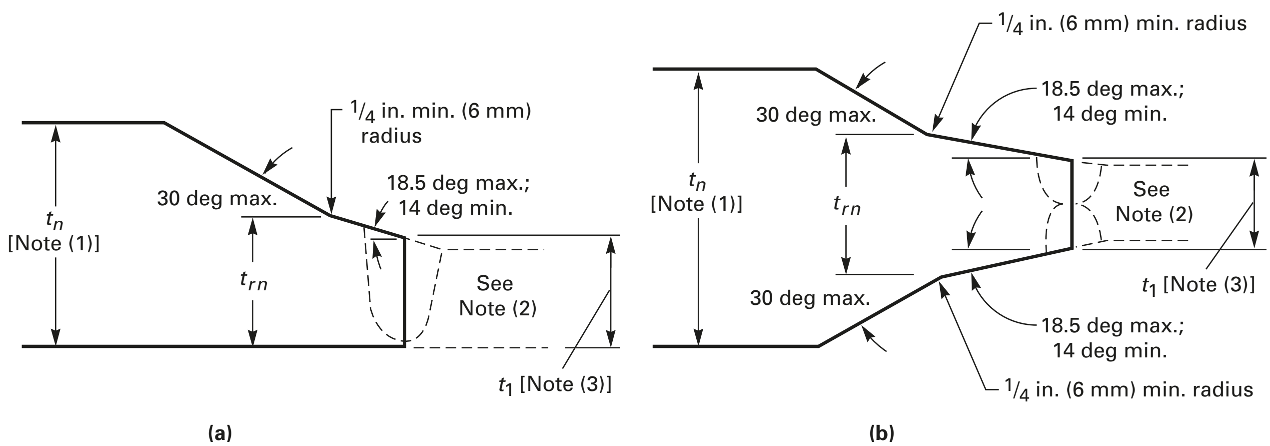
Figure UW-13.3
Typical Pressure Parts With Butt-Welded Hubs



GENERAL NOTES:
(a) Refer to Figure UG-34, sketch (b-2) for dimensional requirements.
(b) Not permissible if machined from rolled plate unless in accordance with Mandatory Appendix 20. See UW-13(g).
(c) Tension test specimen may be located inside or outside the hub.

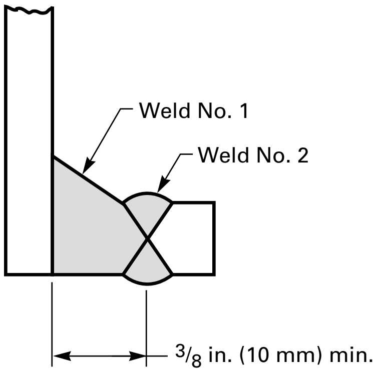
NOTE:
(1) h is the greater of $^3/_4$ in. (19 mm) or $1.5t_s$, but need not exceed 2 in. (50 mm).

Figure UW-13.4
Nozzle Necks Attached to Piping of Lesser Wall Thickness



NOTES:
(1) As defined in UG-40. t_n shall not be less than the thickness required by UG-45.
(2) Weld bevel is shown for illustration only.
(3) t_1 is not less than the greater of
  (a) $0.8t_{rn}$, where t_{rn} = required thickness of seamless nozzle wall
  (b) minimum wall thickness of connecting pipe

Figure UW-13.5
Fabricated Lap Joint Stub Ends for Lethal Service



head-to-shell or Category B or C butt-welded joint, the requirements of UG-53 shall be met or the openings shall be reinforced in accordance with UG-37 through UG-42.

(d) Except when the adjacent butt weld satisfies the requirement for radiography in (b) above, the edge of openings in solid plate meeting the requirements of UG-36(c)(3) shall not be placed closer than $^1/_2$ in. (13 mm) from the edge of a Category A, B, or C weld for material $1^1/_2$ in. (38 mm) thick or less.

(19) UW-15 WELDED CONNECTIONS

(a) Nozzles, other connections, and their reinforcements may be attached to pressure vessels by welding. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as prescribed in UG-41 through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear (computed on the minimum leg dimension). The inside diameter of a fillet weld shall be used in figuring its length.

(b) Strength calculations for nozzle attachment welds for pressure loading are not required for the following:

(1) Figure UW-16.1, sketches (a), (b), (c), (d), (e), (f-1), (f-2), (f-3), (f-4), (g), (x-1), (y-1), and (z-1), and all the sketches in Figures UHT-18.1 and UHT-18.2

(2) openings that are exempt from the reinforcement requirements by UG-36(c)(3)

(3) openings designed in accordance with the rules for ligaments in UG-53

(c) The allowable stress values for groove and fillet welds in percentages of stress values for the vessel material, which are used with UG-41 calculations, are as follows:

(1) groove-weld tension, 74%

(2) groove-weld shear, 60%

(3) fillet-weld shear, 49%

NOTE: These values are obtained by combining the following factors: $87^1/_2$% for combined end and side loading, 80% for shear strength, and the applicable joint efficiency factors.

UW-16 MINIMUM REQUIREMENTS FOR ATTACHMENT WELDS AT OPENINGS

(a) General

(1) The terms: nozzles, connections, reinforcements, necks, tubes, fittings, pads, and other similar terms used in this paragraph define essentially the same type construction and form a Category D weld joint between the nozzle (or other term) and the shell, head, etc., as defined in UW-3(d).

(2) The location and minimum size of attachment welds for nozzles and other connections shall conform to the requirements of this paragraph in addition to the strength calculations required in UW-15.

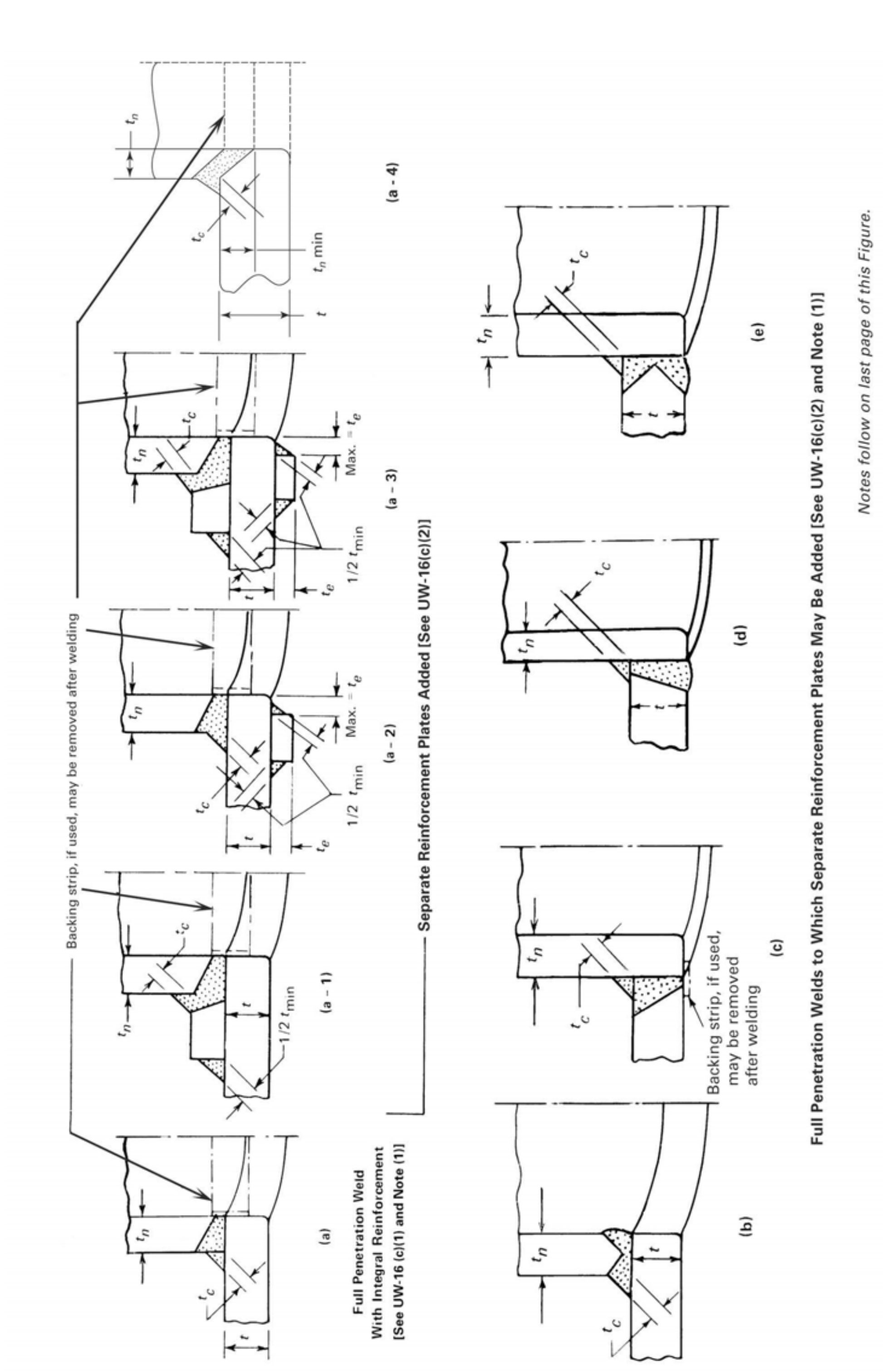
(b) Symbols. The symbols used in this paragraph and in Figures UW-16.1 and UW-16.2 are defined as follows:

D_o = outside diameter of neck or tube attached by welding on inside of vessel shell only
G = radial clearance between hole in vessel wall and outside diameter of nozzle neck or tube
r_1 = minimum inside corner radius, the lesser of $^1/_4 t$ or $^1/_8$ in. (3 mm)
Radius = $^1/_8$ in. (3 mm) minimum blend radius
t = nominal thickness of vessel shell or head,
t_1 *or* t_2 = not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_{\text{min}}$
t_c = not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_{\text{min}}$ (inside corner welds may be further limited by a lesser length of projection of the nozzle wall beyond the inside face of the vessel wall)
t_e = thickness of reinforcing plate, as defined in UG-40
t_{min} = the smaller of $^3/_4$ in. (19 mm) or the thickness of the thinner of the parts joined by a fillet, single-bevel, or single-J weld
t_n = nominal thickness of nozzle wall
t_w = dimension of attachment welds (fillet, single-bevel, or single-J), measured as shown in Figure UW-16.1

(c) Necks Attached by a Full Penetration Weld. Necks abutting a vessel wall shall be attached by a full penetration groove weld. See Figure UW-16.1, sketches (a) and (b) for examples. Necks inserted through the vessel wall may be attached by a full penetration groove weld. See Figure UW-16.1, sketches (c), (d), and (e). When complete joint penetration cannot be verified by visual inspection or other means permitted in this Division, backing strips or equivalent shall be used with full penetration welds deposited from one side.

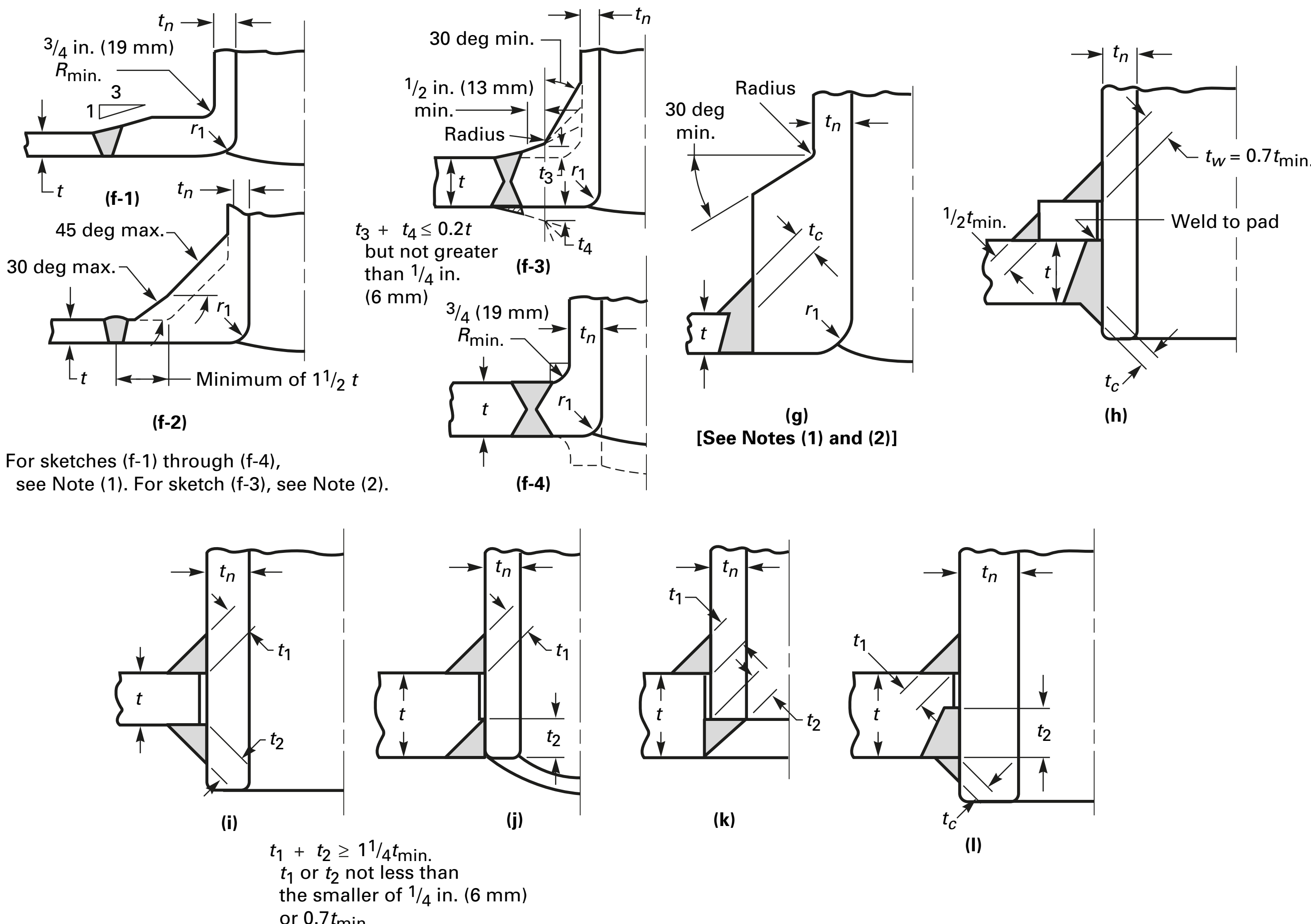
(19)

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc.



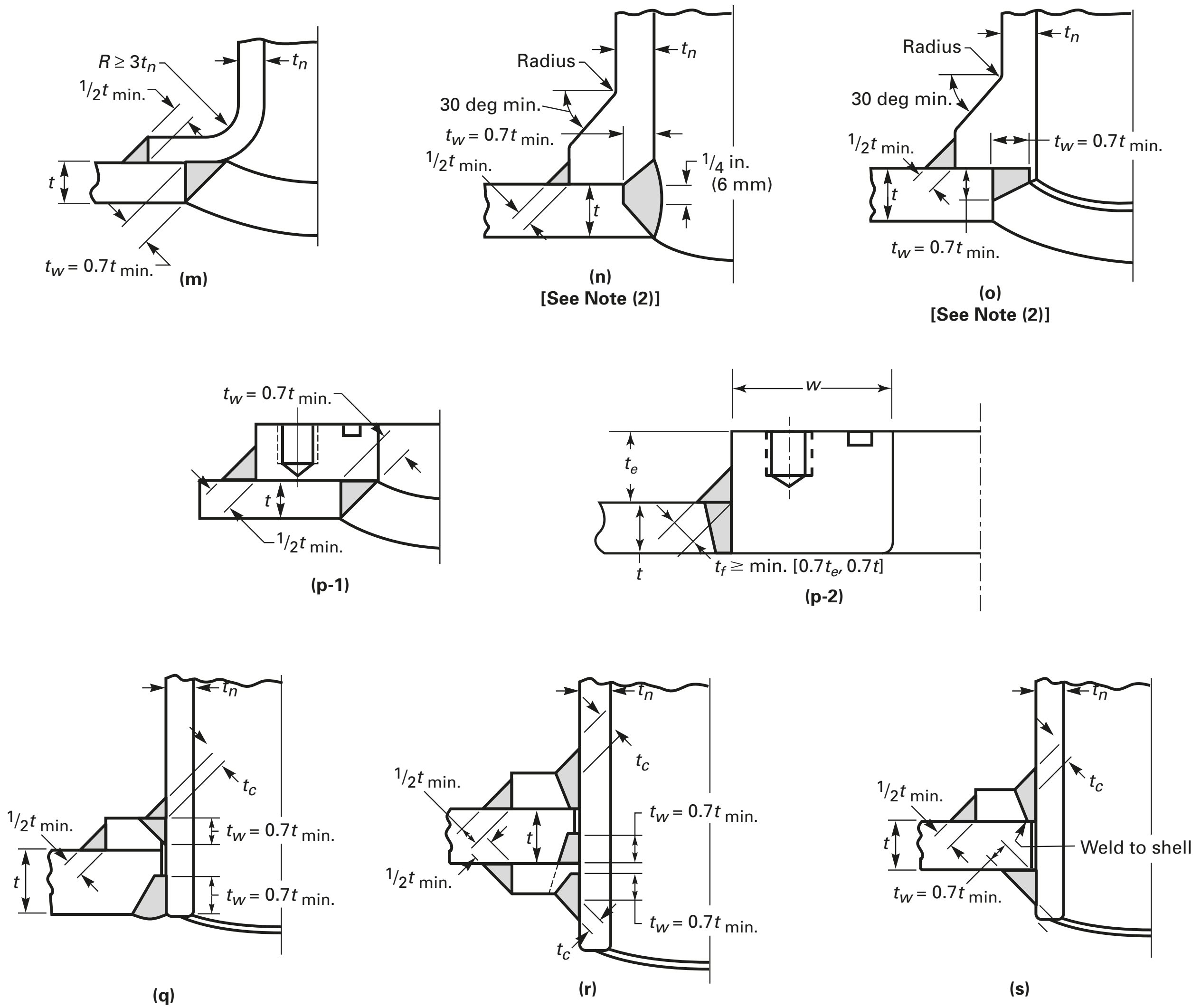
Notes follow on last page of this Figure.

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



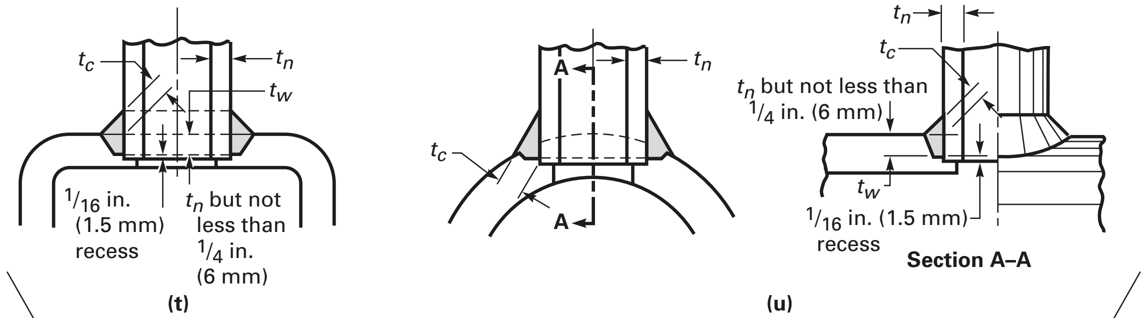
Notes follow on last page of this Figure

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



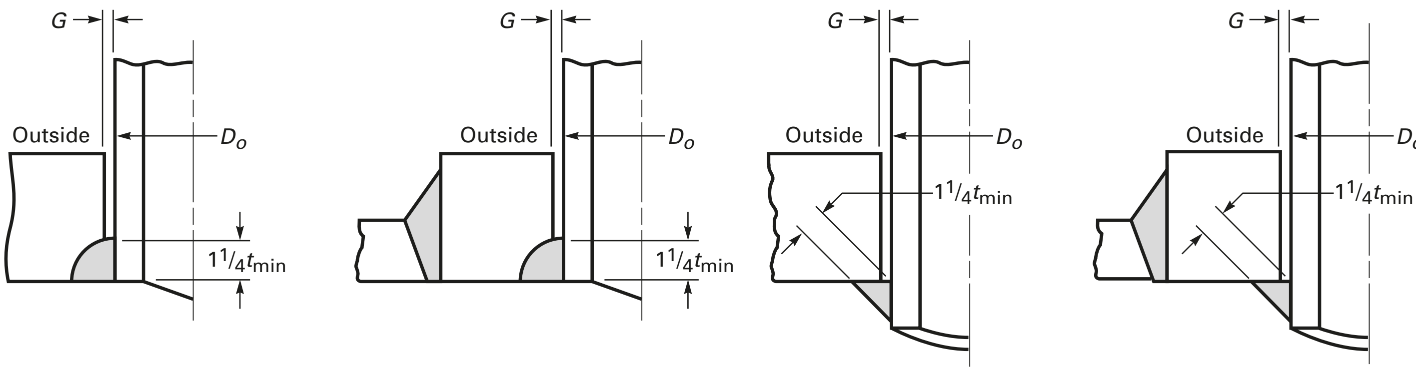
Notes follow on last page of this Figure

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



Typical Tube Connections

(When used for other than square, round, or oval headers, round off corners)



(v-1)
[See Note (3)]

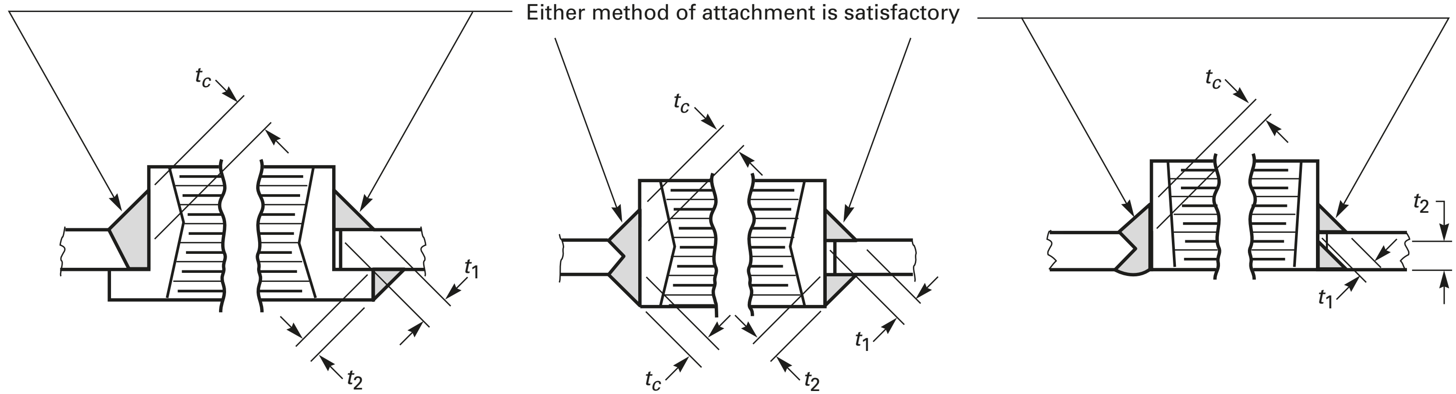
(v-2)
[See Note (3)]

(w-1)
[See Note (3)]

(w-2)
[See Note (3)]

Notes follow on last page of this Figure.

Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc. (Cont'd)



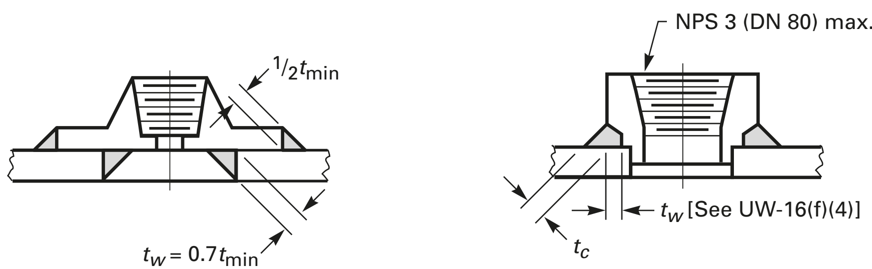
(x-1) (x-2)
[See Notes (1) and (4)]

(y-1) (y-2)
[See Notes (1) and (4)]

(z-1) (z-2)
[See Notes (1) and (4)]

$t_1 + t_2 \geq 1^1/_4 t_{min}$

t_1 or t_2 not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_{min}$



(aa)
[See Note (4)]

(bb)
[See Note (4)]

NOTES:
(1) Sketches (a), (b), (c), (d), (e), (f-1) through (f-4), (g), (x-1), (y-1), and (z-1) are examples of nozzles with integral reinforcement.
(2) Where the term *Radius* appears, provide a $^1/_8$ in. (3 mm) minimum blend radius.
(3) For sketches (v-1) through (w-2):
 (a) For applications where there are no external loads, G = $^1/_8$ in. (3 mm) max.
 (b) With external loads
 G = 0.005 for $D_o \leq$ 1 in. (25 mm); G = 0.010 for 1 in. (25 mm) < $D_o \leq$ 4 in. (100 mm); G = 0.015 for 4 in. (100 mm) < $D_o \leq 6^5/_8$ in. (170 mm)
(4) For NPS 3 (DN 80) and smaller, see exemptions in UW-16(f)(2).

If additional reinforcement is required, it shall be provided as integral reinforcement as described in (1) below, or by the addition of separate reinforcement elements (plates) attached by welding as described in (2) below.

(1) Integral reinforcement is that reinforcement provided in the form of extended or thickened necks, thickened shell plates, forging type inserts, or weld buildup which is an integral part of the shell or nozzle wall and, where required, is attached by full penetration welds. See Figure UW-16.1, sketches (a), (b), (c), (d), (e), (f-1), (f-2), (f-3), (f-4), (g), (x-1), (y-1), and (z-1) for examples of nozzles with integral reinforcement where the F factor in Figure UG-37 may be used.

(2) Separate reinforcement elements (plates) may be added to the outside surface of the shell wall, the inside surface of the shell wall, or to both surfaces of the shell wall. When this is done, the nozzle and reinforcement is no longer considered a nozzle with integral reinforcement and the F factor in UG-37(a) shall be F = 1.0. Figure UW-16.1, sketches (a-1), (a-2), and (a-3) depict various applications of reinforcement elements added to sketch (a). Any of these applications of reinforcement elements may be used with necks of the types shown in Figure UW-16.1, sketches (b), (c), (d), and (e) or any other integral reinforcement types listed in (1) above. The reinforcement plates shall be attached by welds at the outer edge of the plate, and at the nozzle neck periphery or inner edge of the plate if no nozzle neck is adjacent to the plate.

(-a) The weld at the outer edge of the reinforcement plate shall be a continuous fillet weld with a minimum throat dimension of $^1/_2 t_{min}$.

(-b) The weld at the inner edge of the reinforcement plate which does not abut a nozzle neck shall be a continuous fillet weld with a minimum throat dimension $^1/_2 t_{min}$ [see Figure UW-16.1, sketches (a-2) and (a-3)].

(-c) The weld at the inner edge of the reinforcement plate when the reinforcement plate is full penetration welded to the nozzle neck shall be a continuous fillet weld with a minimum throat dimension of t_c [see Figure UW-16.1, sketches (a-1) and (a-3)].

(-d) The weld at the inner edge of the reinforcement plate when the reinforcement plate is not full penetration welded to the nozzle neck shall be a continuous fillet weld with a minimum throat dimension of $t_w = 0.7t_{min}$ [see Figure UW-16.1, sketch (h)].

(d) Neck Attached by Fillet or Partial Penetration Welds

(1) Necks inserted into or through the vessel wall may be attached by fillet or partial penetration welds, one on each face of the vessel wall. The welds may be any desired combination of fillet, single-bevel, and single-J welds. The dimension of t_1 or t_2 for each weld shall be not less than the smaller of $^1/_4$ in. (6 mm) or $0.7t_{min}$, and their sum shall be not less than $1^1/_4 t_{min}$. See Figure UW-16.1, sketches (i), (j), (k), and (l).

If additional reinforcement is required, it may be provided in the form of extended or thickened necks, thickened shell plates, forgings, and/or separate reinforcement elements (plates) attached by welding. Weld requirements shall be the same as given in (c)(2) above, except as follows. The welds attaching the neck to the vessel wall or to the reinforcement plate shall consist of one of the following:

(-a) a single-bevel or single-J weld in the shell plate, and a single-bevel or single-J weld in each reinforcement plate. The dimension t_w of each weld shall be not less than $0.7t_{min}$. See Figure UW-16.1, sketches (q) and (r).

(-b) a full penetration groove weld in each reinforcement plate, and a fillet, single-bevel, or single-J weld with a weld dimension t_w not less than $0.7t_{min}$ in the shell plate. See Figure UW-16.1, sketch (s).

(2) Nozzle necks, flared necks, and studding outlet type flanges may be attached by fillet welds or partial penetration welds between the outside diameter or the attachment and the outside surface of the shell and at the inside of the opening in the shell. The throat dimension of the outer attachment weld shall not be less than $^1/_2 t_{min}$. The dimension t_w of the weld at the inside of the shell cutout shall not be less than $0.7t_{min}$. See Figure UW-16.1, sketches (m), (n), (o), and (p-1). Studding-outlet-type flanges may also be attached by full-penetration welds as shown in Figure UW-16.1, sketch (p-2). (**19**)

(e) Necks and Tubes Up to and Including NPS 6 (DN 150) Attached From One Side Only. Necks and tubes not exceeding NPS 6 (DN 150) may be attached from one side only on either the outside or inside surface of the vessel.

(1) The depth of the welding groove or the throat of the fillet weld shall be at least equal to $1^1/_4 t_{min}$. The radial clearance between the vessel hole and the nozzle outside diameter at the unwelded side shall not exceed the tolerances given in Figure UW-16.1, sketches (v-1), (v-2), (w-1), and (w-2). When welded from the outside only, the neck or tube shall extend to be at least flush to the inside surface of the vessel wall. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the nozzle neck shall be counted as reinforcement.

(2) As an alternative to (1) above, when the neck or tube is attached from the outside only, a welding groove shall be cut into the surface to a depth of not less than t_n on the longitudinal axis of the opening. It is recommended that a recess $^1/_{16}$ in. (1.5 mm) deep be provided at the bottom of the groove, in which to center the nozzle. The dimension t_w of the attachment weld shall be not less than t_n nor less than $^1/_4$ in. (6 mm). See Figure UW-16.1, sketches (t) and (u).

(f) Standard Fittings: ASME/ANSI or Manufacturer's Standard. The attachment of standard fittings shall meet the following requirements; see (g) for the attachment of bolting pads:

(1) Except as provided for in (2), (3), (4), (5), and (6) below, fittings shall be attached by a full penetration groove weld or by two fillet or partial penetration welds, one on each face of the vessel wall. The minimum weld dimensions shall be as shown in Figure UW-16.1, sketches (x), (y), (z), and (aa).

(2) Fittings not exceeding NPS 3 (DN 80) shown on Figure UW-16.1, sketches (x), (y), (z), (aa), and (bb) may be attached by welds that are exempt from size requirements with the following limitations:

(-a) UW-15(a) requirements shall be satisfied for UG-22 loadings.

(-b) For partial penetration welds or fillet welds, t_1 or t_2 shall not be less than the smaller of $^3/_{32}$ in. (2.5 mm) or $0.7t_{\min}$.

(3) See below.

(-a) Fittings not exceeding NPS 3 (DN 80), as shown in Figure UW-16.2, may be attached to vessels that are not subject to rapid fluctuations in pressure by a fillet weld deposited from the outside only without additional reinforcement other than is inherent in the fitting and its attachment to the vessel wall provided all of the following conditions are met

(-1) maximum vessel wall thickness of $^3/_8$ in. (10 mm);

(-2) the maximum size of the opening in the vessel is limited to the outside diameter of the attached pipe plus $^3/_4$ in. (19 mm), but not greater than one-half of the vessel inside diameter;

(-3) the attachment weld throat shall be the greater of the following:

(+a) the minimum nozzle neck thickness required by UG-45 for the same nominal size connection; or

(+b) that necessary to satisfy the requirements of UW-18 for the applicable loadings of UG-22.

(-4) the typical fitting dimension t_f as shown in Figure UW-16.2, sketch (p) shall be sufficient to accommodate a weld leg which will provide a weld throat dimension as required in (-3) above.

(-5) The openings shall meet the requirements provided in UG-36(c)(3)(-c) and UG-36(c)(3)(-d).

(-6) In lieu of the thickness requirements in UG-45, the minimum wall thickness for fittings shall not be less than that shown in Table UW-16.1 for the nearest equivalent nominal pipe size.

(-b) If the opening does not meet the requirements of (-a)(-5) or exceeds the requirements of (-a)(-2) above or (5)(-d) below in any direction, or is greater than one-half the vessel inside diameter, the part of the vessel affected shall be subjected to a proof test as required in UG-36(a)(2), or the opening shall be reinforced in accordance with UG-37 and the nozzle or other connection attached, using a suitable detail in Figure UW-16.1, if welded. In satisfying the rules for reinforcement of openings, no material in the nozzle neck shall be counted as reinforcement.

(4) Fittings not exceeding NPS 3 (DN 80) may be attached by a fillet groove weld from the outside only as shown in Figure UW-16.1, sketch (bb). The groove weld t_w shall not be less than the thickness of Schedule 160 pipe (ASME B36.10M) for the nearest equivalent pipe size. [For fittings smaller than NPS ½ (DN 15), use Schedule 160 taken from Table 8 of ASME B16.11.]

(5) Flange-type fittings not exceeding NPS 2 (DN 50), with some acceptable types such as those shown in Figure UW-16.2, may be attached without additional reinforcement other than that in the fitting and its attachment to the vessel wall. The construction satisfies the requirements of this Division without further calculation or proof test as permitted in UG-36(c)(3) provided all of the following conditions are met:

(-a) Maximum vessel wall thickness shall not exceed $^3/_8$ in. (10 mm).

(-b) Maximum design pressure shall not exceed 350 psi (2.5 MPa).

(-c) Minimum fillet leg t_f is $^3/_{32}$ in. (2.45 mm).

(-d) The finished opening, defined as the hole in the vessel wall, shall not exceed the outside diameter of the nominal pipe size plus $^3/_4$ in. (19 mm).

(6) Fittings conforming to Figure UW-16.2, sketch (k) not exceeding NPS 3 (DN 80) may be attached by a single fillet weld on the inside of the vessel only, provided the criteria of Figure UW-16.1, sketch (w) and (e)(1) are met.

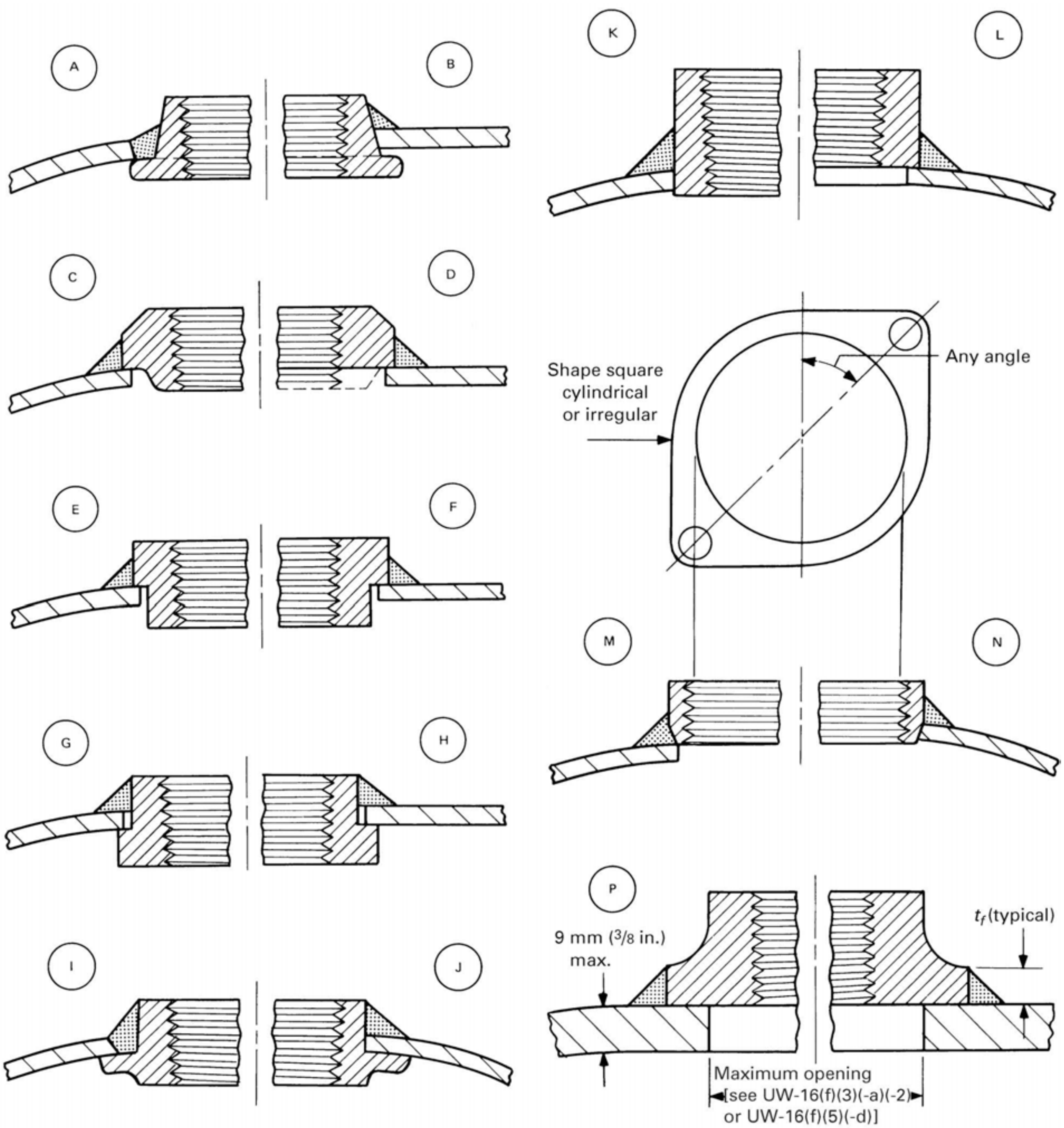
(g) Bolting Pads: Manufacturer's Standard. The attachment of standard bolting pads shall meet the following requirements:

(1) Except as provided for in (2) and (3), bolting pads shall be attached by a full penetration groove weld or by two fillet or partial penetration welds, one on each face of

Table UW-16.1
Minimum Thickness Requirements for Fittings

NPS	in.	mm
$^1/_8$	0.11	2.7
$^1/_4$	0.11	2.7
$^3/_8$	0.11	2.7
$^1/_2$	0.14	3.6
$^3/_4$	0.16	4.2
1	0.22	5.5
$1^1/_4$	0.30	7.5
$1^1/_2$	0.30	7.5
2	0.31	7.9
$2^1/_2$	0.37	9.5
3	0.38	9.5

Figure UW-16.2
Some Acceptable Types of Small Standard Fittings



GENERAL NOTE: See UW-16(f) for limitations.

the vessel wall. The minimum weld dimensions shall be as shown in Figure UW-16.1, sketches (p), (x), (y), (z), and (aa).

(2) Bolting pads as shown in Figure UW-16.3, sketches (a) and (b) may be attached to vessels by a fillet weld deposited from the outside only with the following limitations:

(-a) The maximum vessel wall thickness is $^3/_8$ in. (10 mm), and the bolting pad outside the diameter is not greater than $4^3/_4$ in. (120 mm).

(-b) The maximum size of the opening in the vessel is limited to the following:

(-1) $4^3/_4$ in. (120 mm) for bolting pads that are installed through wall; see Figure UW-16.3, sketch (a)

(-2) $^1/_4$ in. (6 mm) less than the bolting pad diameter for those that are attached to the outside of the vessel; see Figure UW-16.3, sketch (b)

(-c) The attachment weld throat shall be the greatest of the following:

(-1) the minimum nozzle neck thickness required by UG-45 for the same nominal size connection

(-2) $1.0t_{\min}$

(-3) that necessary to satisfy the requirements of UW-18 for the applicable loadings of UG-22

(-d) The typical bolting pad dimension, t_f, as shown in Figure UW-16.3, sketch (a), shall be sufficient to accommodate a weld leg that will provide a weld throat dimension.

(-e) In satisfying the rules for reinforcement of openings, no material in the bolting pad shall be counted as reinforcement.

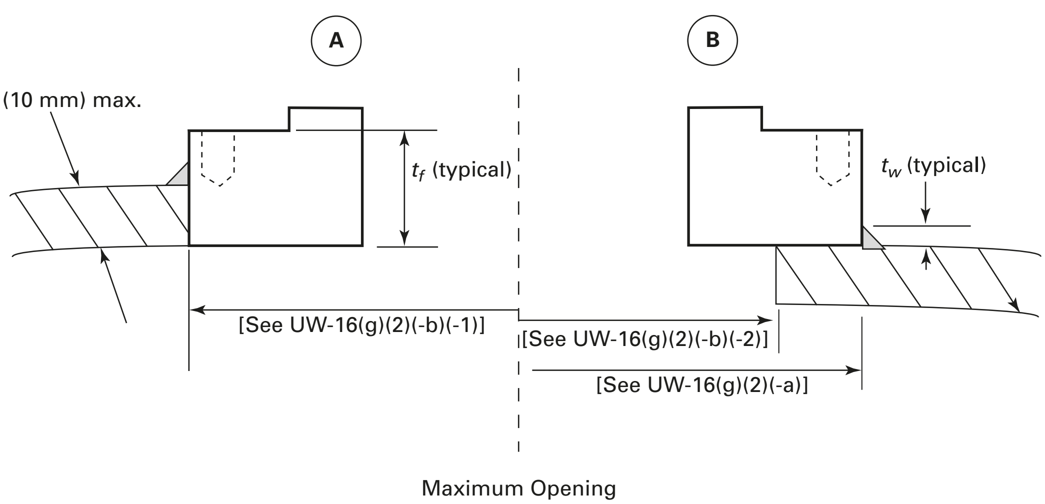
(3) If the opening exceeds the requirements of (2)(-b) above, or is greater than one-half the vessel inside diameter, the part of the vessel affected shall be subjected to a proof test as required in UG-36(a)(2), or the opening shall be reinforced in accordance with UG-37 and the nozzle or other connection attached, using a suitable detail in Figure UW-16.1, if welded.

(h) The minimum throat dimensions of fillet welds defined in UW-16.1 shall be maintained around the circumference of the attachment, except as provided below. (**19**)

(1) For a radial nozzle attachment on a cylindrical shell as shown in Figure UW-16.1, sketches (a) through (e), the fillet weld leg dimensions that meet the minimum throat dimensions shall be determined at the plane through the longitudinal axis of the cylindrical shell (other planes need not be considered), and these fillet weld leg dimensions shall be used around the circumference of the attachment.

(2) For a radial nozzle attachment on a cylindrical shell as shown in Figure UW-16.1, sketches (a) through (e), where the outside diameter of the nozzle is the same as the outside diameter of the cylindrical shell or when the outside diameter of the nozzle is too large to make a fillet weld, the fillet weld leg dimensions that meet the minimum throat dimensions shall be determined at the plane through the longitudinal axis of the cylindrical shell (other planes need not be considered), and these fillet weld leg dimensions shall be used around the circumference of the attachment to the maximum extent possible, and from that point, the fillet weld may be transitioned into the full-penetration weld.

Figure UW-16.3
Some Acceptable Types of Small Bolting Pads



GENERAL NOTE: See UW-16(g)(2) for limitations.

UW-17 PLUG WELDS

(a) Plug welds may be used in lap joints, in reinforcements around openings and in nonpressure structural attachments. They shall be properly spaced to carry their proportion of the load, but shall not be considered to take more than 30% of the total load to be transmitted.

(b) Plug weld holes shall have a diameter not less than $t + {}^1\!/_4$ in. (6 mm) and not more than $2t + {}^1\!/_4$ in. (6 mm), where t is the thickness in inches of the plate or attached part in which the hole is made.

(c) Plug weld holes shall be completely filled with weld metal when the thickness of the plate, or attached part, in which the weld is made is ${}^5\!/_{16}$ in. (8 mm) or less; for thicker plates or attached parts the holes shall be filled to a depth of at least half the plate thickness or ${}^5\!/_{16}$ of the hole diameter, whichever is larger, but in no case less than ${}^5\!/_{16}$ in. (8 mm).

(d) The allowable working load on a plug weld in either shear or tension shall be computed by the following formula:

(U.S. Customary Units)

$$P = 0.63S\left(d - \frac{1}{4}\right)^2$$

(SI Units)

$$P = 0.63S(d - 6)^2$$

where

d = the bottom diameter of the hole in which the weld is made
P = total allowable working load on the plug weld
S = maximum allowable stress value for the material in which the weld is made (see UG-23)

UW-18 FILLET WELDS

(a) Fillet welds may be employed as strength welds for pressure parts within the limitations given elsewhere in this Division. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for the purposes enumerated in UG-55.

(c) Figures UW-13.1 and UW-13.2 show several construction details that are not permissible.

(d) Unless the sizing basis is given elsewhere in this Division, the maximum allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the maximum allowable stress value in tension of the material being welded, and a joint efficiency of 55%.

UW-19 WELDED STAYED CONSTRUCTION (19)

(a) Welded-in staybolts shall meet the following requirements:

(1) the arrangement shall substantially conform to one of those illustrated in Figure UW-19.1;

(2) the required thickness of the plate shall not exceed $1^1\!/_2$ in. (38 mm), except for Figure UW-19.1, sketches (e), (g), and (h). For plate thicknesses greater than ${}^3\!/_4$ in. (19 mm), the staybolt pitch shall not exceed the smaller of 20 in. (500 mm) or the limits established in UG-47(f).

(3) the provisions of UG-47 and UG-49 shall be followed; and

(4) the required area of the staybolt shall be determined in accordance with the requirements in UG-50.

(b) Welded stays, substantially as shown in Figure UW-19.2, may be used to stay jacketed pressure vessels provided:

(1) the pressure does not exceed 300 psi (2 MPa);

(2) the required thickness of the plate does not exceed ${}^1\!/_2$ in. (13 mm);

(3) the size of the fillet welds is not less than the plate thickness;

(4) the inside welds are properly inspected before the closing plates are attached;

(5) the allowable load on the fillet welds is computed in accordance with UW-18(d);

(6) the maximum diameter or width of the hole in the plate does not exceed $1^1\!/_4$ in. (32 mm);

(7) the welders are qualified under the rules of Section IX;

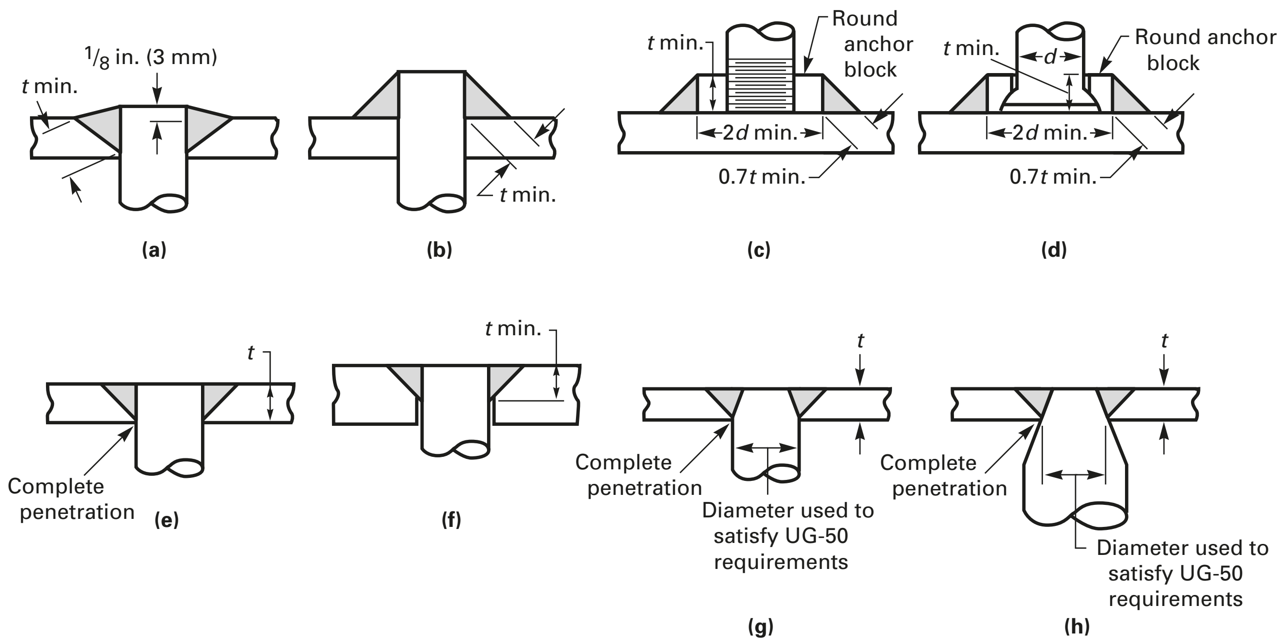
(8) the maximum spacing of stays is determined by the formula in UG-47(a), using C = 2.1 if either plate is not over ${}^7\!/_{16}$ in. (11 mm) thick, C = 2.2 if both plates are over ${}^7\!/_{16}$ in. (11 mm) thick.

(c) Welded stayed construction, as shown in Figure UW-19.2 or consisting of a dimpled or embossed plate welded to another like plate or to a plain plate, may be used, provided

(1) the welded attachment is made by fillet welds around holes or slots as shown in Figure UW-19.2 or if the thickness of the plate having the hole or slot is ${}^1\!/_2$ in. (12 mm) or less, and the hole is 1 in. (25 mm) or less in diameter, the holes may be completely filled with weld metal. The allowable load on the weld shall equal the product of the thickness of the plate having the hole or slot, the circumference or perimeter of the hole or slot, the allowable stress value in tension of the weaker of the materials being joined and a joint efficiency of 55%.

(2) the maximum allowable working pressure of the dimpled or embossed components is established in accordance with the requirements of UG-101. The joint efficiency, E, used in UG-101 to calculate the MAWP of the dimpled panel shall be taken as 0.80. This proof test may be carried out on a representative panel. If a representative panel is used, it shall be rectangular in shape and at least 5 pitches in each direction, but not less than

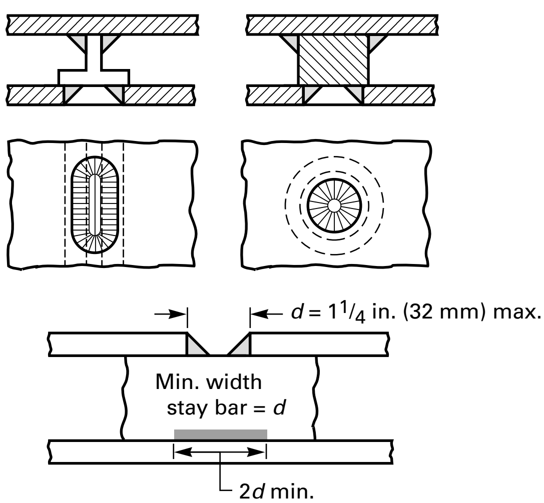
Figure UW-19.1
Typical Forms of Welded Staybolts



Legend:

t = nominal thickness of the thinner stayed plate

Figure UW-19.2
Use of Plug and Slot Welds for Staying Plates



24 in. (600 mm) in either direction. The representative panel shall utilize the same weld details as will be used in the final construction.

(3) the plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(d) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel or vessel part in which they occur is required to be postweld heat treated.

UW-20 TUBE-TO-TUBESHEET WELDS

UW-20.1 Scope. These rules provide a basis for establishing weld sizes and allowable joint loads for full strength and partial strength tube-to-tubesheet welds.

UW-20.2 Definitions.

(a) Full Strength Weld. A full strength tube-to-tubesheet weld is one in which the design strength is equal to or greater than the axial tube strength, F_t. When the weld in a tube-to-tubesheet joint meets the requirements of UW-20.4, it is a full strength weld and the joint does not require qualification by shear load testing. Such a weld also provides tube joint leak tightness.

(b) Partial Strength Weld. A partial strength weld is one in which the design strength is based on the mechanical and thermal axial tube loads (in either direction) that are determined from the actual design conditions. The maximum allowable axial load of this weld may be determined in accordance with UW-20.5, Nonmandatory Appendix A, or UW-18(d). When the weld in a tube-to-tubesheet joint meets the requirements of UW-20.5 or UW-18(d), it is a partial strength weld and the joint does not require qualification by shear load testing. Such a weld also provides tube joint leak tightness.

(c) Seal Weld. A tube-to-tubesheet seal weld is one used to supplement an expanded tube joint to ensure leak tightness. Its size has not been determined based on axial tube loading.

(19) **UW-20.3 Nomenclature.** The symbols described below are used for the design of tube-to-tubesheet welds.

a_c = length of the combined weld legs measured parallel to the longitudinal axis of the tube at its outside diameter

a_f = fillet weld leg

a_g = groove weld leg

a_r = minimum required length of the weld leg(s) under consideration

d_o = tube outside diameter

F_d = design strength, but not greater than F_t

f_d = ratio of the design strength to the tube strength
= 1.0 for full strength welds
= F_d/F_t for partial strength welds

F_f = fillet weld strength, but not greater than F_t
= $0.55\pi a_f (d_o + 0.67a_f) S_w$

f_f = ratio of the fillet weld strength to the design strength
= $1 - F_g/(f_d F_t)$

F_g = groove weld strength, but not greater than F_t
= $0.85\pi a_g (d_o + 0.67a_g) S_w$

F_t = axial tube strength
= $\pi t (d_o - t) S_a$

f_w = weld strength factor
= S_a/S_w

$L_{\max}$ = maximum allowable axial load in either direction on the tube-to-tubesheet joint

S = allowable stress value at the design temperature as given in the applicable part of Section II, Part D

S_a = allowable stress in tube (see S, above)

S_t = allowable stress of the material to which the tube is welded (see S, above). See UW-20.7(d)

S_w = allowable stress in weld (lesser of S_a or S_t, above)

t = nominal tube thickness

NOTE: For a welded tube or pipe, use the allowable stress for the equivalent seamless product. When the allowable stress for the equivalent seamless product is not available, divide the allowable stress of the welded product by 0.85.

UW-20.4 Full Strength Welds. Full strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a full strength weld shall be determined in accordance with UW-20.6.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a full strength weld shall be determined as follows:

(1) For loads due to pressure-induced axial forces, $L_{\max} = F_t$.

(2) For loads due to thermally induced or pressure plus thermally induced axial forces:

(-a) $L_{\max} = F_t$ for welded only tube-to-tubesheet joints, where the thickness through the weld throat is less than the nominal tube thickness t;

(-b) $L_{\max} = 2F_t$ for all other welded tube-to-tubesheet joints.

UW-20.5 Partial Strength Welds. Partial strength welds shown in Figure UW-20.1 shall conform to the following requirements:

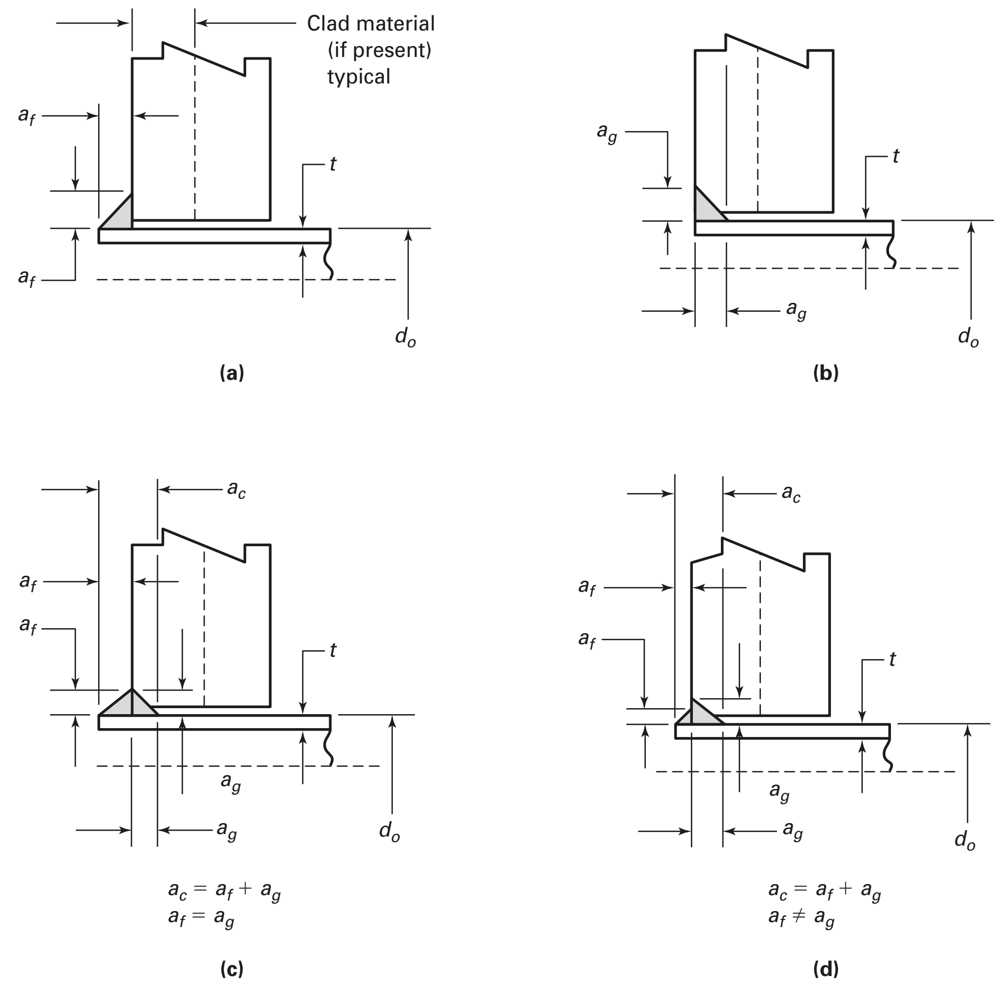
(a) The size of a partial strength weld shall be determined in accordance UW-20.6.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a partial strength weld shall be determined as follows:

(1) For loads due to pressure-induced axial forces, $L_{\max} = F_f + F_g$, but not greater than F_t.

(2) For loads due to thermally induced or pressure plus thermally induced axial forces:

Figure UW-20.1
Some Acceptable Types of Tube-to-Tubesheet Strength Welds



(-a) $L_{max} = F_f + F_g$, but not greater than F_t, for welded only tube-to-tubesheet joints, where the thickness through the weld throat is less than the nominal tube thickness t;

(-b) $L_{max} = 2(F_f + F_g)$, but not greater than $2F_t$, for all other welded tube-to-tubesheet joints.

UW-20.6 Weld Size Design Formulas. The size of tube-to-tubesheet strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) For fillet welds shown in sketch (a),

$$a_r = \sqrt{(0.75d_o)^2 + 2.73t(d_o - t)f_w f_d} - 0.75d_o$$

(1) For full strength welds, a_f shall not be less than the greater of a_r or t.

(2) For partial strength welds, a_f shall not be less than a_r.

(b) For groove welds shown in sketch (b),

$$a_r = \sqrt{(0.75d_o)^2 + 1.76t(d_o - t)f_w f_d} - 0.75d_o$$

(1) For full strength welds, a_g shall not be less than the greater of a_r or t.

(2) For partial strength welds, a_g shall not be less than a_r.

(c) For combined groove and fillet welds shown in sketch (c), where a_f is equal to a_g,

$$a_r = 2\left[\sqrt{(0.75d_o)^2 + 1.07t(d_o - t)f_w f_d} - 0.75d_o\right]$$

(1) For full strength welds, a_c shall not be less than the greater of a_r or t.

(2) For partial strength welds, a_c shall not be less than a_r.

Calculate a_f and a_g: $a_f = a_c/2$ and $a_g = a_c/2$.

(d) For combined groove and fillet welds shown in sketch (d), where a_f is not equal to a_g, a_r shall be determined as follows: Choose a_g. Calculate a_r:

$$a_r = \sqrt{(0.75d_o)^2 + 2.73t(d_o - t)f_w f_d f_f} - 0.75d_o$$

(1) For full strength welds, a_c shall not be less than the greater of ($a_r + a_g$) or t.

(2) For partial strength welds, a_c shall not be less than ($a_r + a_g$).

Calculate a_f : $a_f = a_c - a_g$.

(19) **UW-20.7 Clad Tubesheets.**

(a) Tube-to-tubesheet welds in the cladding of either integral or weld metal overlay clad tubesheets may be considered strength welds (full or partial), provided the welds meet the design requirements of UW-20. In addition, when the strength welds are to be made in the clad material of integral clad tubesheets, the integral clad material to be used for tubesheets shall meet the requirements in (1) and (2) for any combination of clad and base materials. The shear strength test and ultrasonic examination specified in (1) and (2) are not required for weld metal overlay clad tubesheets.

(1) Integral clad material shall be shear strength tested in accordance with SA-263. One shear test shall be made on each integral clad plate or forging and the results shall be reported on the material test report.

(2) Integral clad material shall be ultrasonically examined for bond integrity in accordance with SA-578, including Supplementary Requirement S1, and shall meet the acceptance criteria given in SA-263 for Quality Level Class 1.

(b) When the design calculations for clad tubesheets are based on the total thickness including the cladding, the clad material shall meet any additional requirements specified in Part UCL.

(c) When tubesheets are constructed using linings, or integral cladding that does not meet the requirements of (a)(1) and (a)(2), the strength of the tube-to-tubesheet joint shall not be dependent upon the connection between the tubes and the lining or integral cladding, as applicable.

(d) When the tubes are strength welded (full or partial) to integral or weld metal overlay clad tubesheets, S_t shall be the allowable stress value of the integral cladding or the wrought material whose chemistry most closely approximates that of the weld metal overlay cladding. The thickness of the integral or weld metal clad overlay material shall be sufficient to prevent any of the strength weld from extending into the base material.

UW-21 ASME B16.5 SOCKET AND SLIP-ON FLANGE WELDS

(a) ASME B16.5 socket weld flanges shall be welded using an external fillet weld. See Figure UW-21, sketch (4).

(b) ASME B16.5 slip-on flanges shall be welded using an internal and an external weld. See Figure UW-21, sketches (1), (2), and (3).

(c) Nomenclature

t_n = nominal thickness of the shell or nozzle
X_{min} = the lesser of $1.4t_n$ or the thickness of the hub

(d) When ASME B16.5 slip-on flanges are shown to comply with all the requirements provided in Mandatory Appendix 2 of this Division, the weld sizes in Mandatory Appendix 2 may be used as an alternative to the requirements in (b).

FABRICATION

UW-26 GENERAL

(a) The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection C that pertain to the class of material used.

(b) Each Manufacturer or parts Manufacturer shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding procedure to determine its suitability to ensure welds that will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly.

(c) No production 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 Section IX shall be used in production.

(d) The Manufacturer (Certificate Holder) may engage individuals by contract or agreement for their services as welders[68] at the shop location shown on the Certificate of Authorization and at field sites (if allowed by the Certificate of Authorization) for the construction of pressure vessels or vessel parts, provided all of the following conditions are met:

(1) All Code construction shall be the responsibility of the Manufacturer.

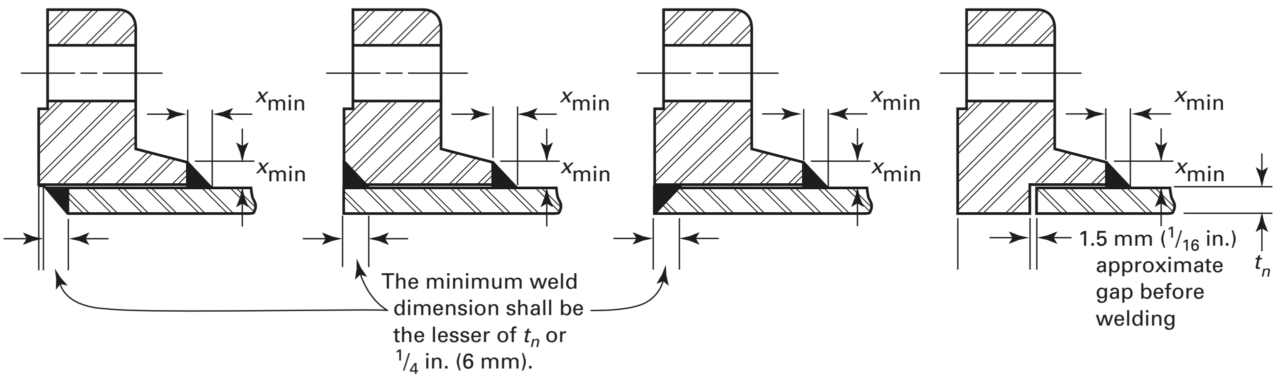
(2) All welding shall be performed in accordance with the Manufacturer's welding procedure specifications in accordance with the requirements of Section IX.

(3) All welders shall be qualified by the Manufacturer in accordance with the requirements of Section IX.

(4) The Manufacturer's Quality Control System shall include as a minimum:

(-a) a requirement for complete and exclusive administrative and technical supervision of all welders by the Manufacturer;

Figure UW-21
Welds of Socket Weld Flanges to Nozzle Necks



(-b) evidence of the Manufacturer's authority to assign and remove welders at his discretion without involvement of any other organization;

(-c) a requirement for assignment of welder identification symbols;

(-d) evidence that this program has been accepted by the Manufacturer's Authorized Inspection Agency which provides the inspection service.

(5) The Manufacturer shall be responsible for Code compliance of the vessel or part, including Certification Mark stamping and providing Data Report Forms properly executed and countersigned by the Inspector.

(19) UW-27 WELDING PROCESSES

The welding processes that may be used in the construction of vessels under this Part of this Division are limited to those listed in Section IX, Article II with the following additional restrictions:

(a) Other than pressure inherent to the welding processes, no mechanical pressure or blows shall be applied except as permitted for peening in UW-39.

(b) Arc stud welding and resistance stud welding may be used only for non-pressure-bearing attachments having a load- or non-load-carrying function, except for material listed in Table UHT-23, provided that, in the case of ferrous materials, the heat treatment requirements of UCS-56 are complied with and the requirements of UW-28(b) and UW-29(a) are met prior to start of production welding. Studs shall be limited to 1 in. (25 mm) diameter maximum for round studs and an equivalent cross-sectional area for studs with other shapes.

(c) The electroslag welding process may be used for butt welds only in ferritic steels and austenitic stainless steels of types listed in UW-5(d), provided the requirements of UW-11(a)(6) and UW-11(d) are satisfied. [See UW-5(e).]

(d) The electrogas welding process may be used for butt welds only in ferritic steels and austenitic stainless steels of types listed in UW-5(d), provided the requirements of UW-11(a)(6) are satisfied. When a single pass is greater than $1\frac{1}{2}$ in. (38 mm) in ferritic materials, the joint shall be given a grain refining (austenitizing) heat treatment. [See UW-5(e).]

(e) Welding processes accepted under Section IX Code Cases shall not be used unless those Code Cases are explicitly accepted by this Division.

UW-28 QUALIFICATION OF WELDING PROCEDURE

(a) Each procedure of welding that is to be followed in construction shall be recorded in detail by the manufacturer.

(b) The procedure used in welding pressure parts and in joining load-carrying nonpressure parts, such as all permanent or temporary clips and lugs, to pressure parts shall be qualified in accordance with Section IX.

(c) The procedure used in welding non-pressure-bearing attachments which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall meet the following requirements.

(1) When the welding process is manual, machine, or semiautomatic, procedure qualification is required in accordance with Section IX.

(2) When the welding is any automatic welding process performed in accordance with a Welding Procedure Specification (in compliance with Section IX as far as applicable), procedure qualification testing is not required.

(d) Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. Alternatively, AWS Standard Welding Procedure Specifications that have been accepted by Section IX may be used provided they meet all other requirements of this Division.

Qualification of a welding procedure by one Manufacturer shall not qualify that procedure for any other Manufacturer except as provided in Section IX, QG-106.

UW-29 TESTS OF WELDERS AND WELDING OPERATORS

(a) The welders and welding operators used in welding pressure parts and in joining load-carrying nonpressure parts (attachments) to pressure parts shall be qualified in accordance with Section IX.

(1) The qualification test for welding operators of machine welding equipment shall be performed on a separate test plate prior to the start of welding or on the first workpiece.

(2) When stud welding is used to attach load-carrying studs, a production stud weld test of each welder or welding operator shall be performed on a separate test plate or tube prior to the start of welding on each work shift. This weld test shall consist of five studs, welded and tested by the bend or torque stud weld testing procedure described in Section IX.

(b) The welders and welding operators used in welding non-pressure-bearing attachments, which have essentially no load-carrying function (such as extended heat transfer surfaces, insulation support pins, etc.), to pressure parts shall comply with the following:

(1) When the welding process is manual, machine, or semiautomatic, qualification in accordance with Section IX is required.

(2) When welding is done by any automatic welding process, performance qualification testing is not required.

(3) When stud welding is used, a production stud weld test, appropriate to the end use application requirements, shall be specified by the Manufacturer and carried out on a separate test plate or tube at the start of each shift.

(c) Each welder and welding operator shall be assigned an identifying number, letter, or symbol by the manufacturer which shall be used to identify the work of that welder or welding operator in accordance with UW-37(f).

(d) The Manufacturer shall maintain a record of the welders and welding operators showing the date and result of tests and the identification mark assigned to each. These records shall be maintained in accordance with Section IX.

(e) Welding of all test coupons shall be conducted by the Manufacturer. Testing of all test coupons shall be the responsibility of the Manufacturer. A performance qualification test conducted by one Manufacturer shall not qualify a welder or welding operator to do work for any other Manufacturer except as provided in Section IX, QG-106.

UW-30 LOWEST PERMISSIBLE TEMPERATURES FOR WELDING

It is recommended that no welding of any kind be done when the temperature of the base metal is lower than 0°F (−20°C). At temperatures between 32°F (0°C) and 0°F (−20°C), the surface of all areas within 3 in. (75 mm) of the point where a weld is to be started should be heated to a temperature at least warm to the hand [estimated to be above 60°F (15°C)] before welding is started. It is recommended also that no welding be done when surfaces are wet or covered with ice, when snow is falling on the surfaces to be welded, or during periods of high wind, unless the welders or welding operators and the work are properly protected.

UW-31 CUTTING, FITTING, AND ALIGNMENT

(a) When plates are shaped by oxygen or arc cutting, the edges to be welded shall be uniform and smooth and shall be freed of all loose scale and slag accumulations before welding (see UG-76 and UCS-5).

(b) Plates that are being welded shall be fitted, aligned, and retained in position during the welding operation.

(c) Bars, jacks, clamps, tack welds, or other appropriate means may be used to hold the edges of parts in alignment. 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, whether removed or left in place, shall be made using a fillet weld or butt weld procedure qualified in accordance with Section IX. Tack welds to be left in place shall be made by welders qualified in accordance with Section IX, and shall be examined visually for defects, and if found to be defective shall be removed.

Provided that the work is done under the provisions of U-2(b), it is not necessary that a subcontractor making such tack welds for a vessel or parts manufacturer be a holder of a Code Certificate of Authorization. The requirements of UW-26(d) do not apply to such tack welds.

(d) The edges of butt joints shall be held during welding so that the tolerances of UW-33 are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerances, the head or shell ring, whichever is out-of-true, shall be reformed until the errors are within the limits specified. Where fillet welds are used, the lapped plates shall fit closely and be kept in contact during welding.

(e) When joining two parts by the inertia and continuous drive friction welding processes, one of the two parts must be held in a fixed position and the other part rotated. The two faces to be joined must be essentially symmetrical with respect to the axis of rotation. Some of the basic types of applicable joints are solid round to solid round, tube to tube, solid round to tube, solid round to plate, and tube to plate.

UW-32 CLEANING OF SURFACES TO BE WELDED

(a) The surfaces to be welded shall be clean and free of scale, rust, oil, grease, slag, detrimental oxides, and other deleterious foreign material. The method and extent of cleaning should be determined based on the material to be welded and the contaminants to be removed. When weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel, chipping hammer, or other suitable means so as to prevent inclusion of impurities in the weld metal.

(b) Cast surfaces to be welded shall be machined, chipped, or ground to remove foundry scale and to expose sound metal.

(c) The requirements in (a) and (b) above are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the weld remains free from defects.

UW-33 ALIGNMENT TOLERANCE

(a) Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than the applicable amount for the welded joint category (see UW-3) under consideration, as listed in Table UW-33. The section thickness t is the nominal thickness of the thinner section at the joint.

(b) Any offset within the allowable tolerance provided above shall be faired at a three to one 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. Such additional weld metal buildup shall be subject to the requirements of UW-42.

UW-34 SPIN-HOLES

Spin-holes are permitted within heads or segments thereof to facilitate forming. Spin-holes not exceeding the size limitations of UG-36(c)(3)(-a) may be closed with a full-penetration weld using either a welded plug or weld metal. The weld and plug shall be no thinner than the head material adjacent to the spin-hole.

The finished weld shall be examined[69] and shall meet the acceptance requirements of Mandatory Appendix 6 or Mandatory Appendix 8 of this Division. Radiographic examination, if required by UW-11(a), and additional inspections, if required by the material specification, shall be performed.

Table UW-33

Customary Units

Section Thickness, in.	Joint Category A	Joint Category B, C, and D
Up to $^1/_2$, incl.	$^1/_4 t$	$^1/_4 t$
Over $^1/_2$ to $^3/_4$, incl.	$^1/_8$ in.	$^1/_4 t$
Over $^3/_4$ to $1^1/_2$, incl.	$^1/_8$ in.	$^3/_{16}$ in.
Over $1^1/_2$ to 2, incl.	$^1/_8$ in.	$^1/_8 t$
Over 2	Lesser of $^1/_{16} t$ or $^3/_8$ in.	Lesser of $^1/_8 t$ or $^3/_4$ in.

SI Units

Section Thickness, mm	Joint Category A	Joint Category B, C, and D
Up to 13, incl.	$^1/_4 t$	$^1/_4 t$
Over 13 to 19, incl.	3 mm	$^1/_4 t$
Over 19 to 38, incl.	3 mm	5 mm
Over 38 to 51, incl.	3 mm	$^1/_8 t$
Over 51	Lesser of $^1/_{16} t$ or 10 mm	Lesser of $^1/_8 t$ or 19 mm

This weld is a butt weld, but it is not categorized. It shall not be considered in establishing the joint efficiency of any part of the head or of the head-to-shell weld.

UW-35 FINISHED LONGITUDINAL AND CIRCUMFERENTIAL JOINTS

(a) Butt-welded joints shall have complete penetration and full fusion. 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 permit proper interpretation of radiographic and other required nondestructive examinations. If there is a question regarding the surface condition of the weld when interpreting a radiographic film, the film shall be compared to the actual weld surface for determination of acceptability.

(b) A reduction in thickness due to the welding process is acceptable provided all of the following conditions are met:

(1) The reduction in thickness shall not reduce the material of the adjoining surfaces below the design thickness at any point.

(2) The reduction in thickness shall not exceed $^1/_{32}$ in. (1 mm) or 10% of the nominal thickness of the adjoining surface, whichever is less.[70]

(c) When a single-welded butt joint is made by using a backing strip which is left in place [Type No. (2) of Table UW-12], the requirement for reinforcement applies only to the side opposite the backing strip.

(d) To assure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining base

materials,[71] weld metal may be added as reinforcement on each face of the weld. The thickness of the weld reinforcement on each face shall not exceed the following:

Customary Units		
	Maximum Reinforcement, in.	
Material Nominal Thickness, in.	Category B and C Butt Welds	Other Welds
Less than $^3/_{32}$	$^3/_{32}$	$^1/_{32}$
$^3/_{32}$ to $^3/_{16}$, incl.	$^1/_8$	$^1/_{16}$
Over $^3/_{16}$ to $^1/_2$, incl.	$^5/_{32}$	$^3/_{32}$
Over $^1/_2$ to 1, incl.	$^3/_{16}$	$^3/_{32}$
Over 1 to 2, incl.	$^1/_4$	$^1/_8$
Over 2 to 3, incl.	$^1/_4$	$^5/_{32}$
Over 3 to 4, incl.	$^1/_4$	$^7/_{32}$
Over 4 to 5, incl.	$^1/_4$	$^1/_4$
Over 5	$^5/_{16}$	$^5/_{16}$

SI Units		
	Maximum Reinforcement, mm	
Material Nominal Thickness, mm	Category B and C Butt Welds	Other Welds
Less than 2.4	2.5	0.8
2.4 to 4.8, incl.	3	1.5
Over 4.8 to 13, incl.	4	2.5
Over 13 to 25, incl.	5	2.5
Over 25 to 51, incl.	6	3
Over 51 to 76, incl.	6	4
Over 76 to 102, incl.	6	5.5
Over 102 to 127, incl.	6	6
Over 127	8	8

UW-36 FILLET WELDS

In making fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is secured. The reduction of the thickness of the base metal due to the welding process at the edges of the fillet weld shall meet the same requirements as for butt welds [see UW-35(b)].

UW-37 MISCELLANEOUS WELDING REQUIREMENTS

(a) The reverse side of double-welded joints shall be prepared by chipping, grinding, or melting out, so as to secure sound metal at the base of weld metal first deposited, before applying weld metal from the reverse side.

(b) The requirements in (a) above are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the base of the weld remains free from defects.

(c) 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.

(d) 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.

(e) In welding plug welds, a fillet around the bottom of the hole shall be deposited first.

(f) *Welder and Welding Operator Identification*

(1) Each welder and welding operator shall stamp the identifying number, letter, or symbol assigned by the Manufacturer, on or adjacent to and at intervals of not more than 3 ft (1 m) along the welds which he makes in steel plates $^1/_4$ in. (6 mm) and over in thickness and in nonferrous plates $^1/_2$ in. (13 mm) and over in thickness; or a record shall be kept by the Manufacturer of welders and welding operators employed on each joint which shall be available to the Inspector. For identifying welds on vessels in which the wall thickness is less than $^1/_4$ in. (6 mm) for steel material and less than $^1/_2$ in. (13 mm) for nonferrous material, suitable stencil or other surface markings shall be used; or a record shall be kept by the Manufacturer of welders and welding operators employed on each joint which shall be available to the Inspector; or a stamp may be used provided the vessel part is not deformed and the following additional requirements are met:

(-a) for ferrous materials:

(-1) the materials shall be limited to P-No. 1 Gr. Nos. 1 and 2;

(-2) the minimum nominal plate thickness shall be $^3/_{16}$ in. (5 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (3.91 mm);

(-3) the minimum design metal temperature shall be no colder than −20°F (−29°C);

(-b) for nonferrous materials:

(-1) the materials shall be limited to aluminum as follows: SB-209 Alloys 3003, 5083, 5454, and 6061; SB-241 Alloys 3003, 5083, 5086, 5454, 6061, and 6063; and SB-247 Alloys 3003, 5083, and 6061;

(-2) the minimum nominal plate thickness shall be 0.249 in. (6.32 mm), or the minimum nominal pipe thickness shall be 0.133 in. (3.37 mm).

(2) When a multiple number of permanent nonpressure part load bearing attachment welds, nonload-bearing welds such as stud welds, or special welds such as tube-to-tubesheet welds are made on a vessel, the Manufacturer need not identify the welder or welding operator that welded each individual joint provided:

(-a) the Manufacturer's Quality Control System includes a procedure that will identify the welders or welding operators that made such welds on each vessel so that the Inspector can verify that the welders or welding operators were all properly qualified;

(-b) the welds in each category are all of the same type and configuration and are welded with the same welding procedure specification.

(3) Permanent identification of welders or welding operators making tack welds that become part of the final pressure weld is not required provided the Manufacturer's Quality Control System includes a procedure to permit the Inspector to verify that such tack welds were made by qualified welders or welding operators.

(g) The welded joint between two members joined by the inertia and continuous drive friction welding processes shall be a full penetration weld. Visual examination of the as-welded flash roll of each weld shall be made as an in-process check. The weld upset shall meet the specified amount within ±10%. The flash shall be removed to sound metal.

(h) Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments without postweld heat treatment, provided the following requirements are met:

(1) A welding procedure specification shall be prepared in accordance with Section IX, insofar as possible 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.

(2) The energy output shall be limited to 125 W-sec.

UW-38 REPAIR OF WELD DEFECTS

Defects, such as cracks, pinholes, and incomplete fusion, detected visually or by the hydrostatic or pneumatic test or by the examinations prescribed in UW-11 shall be removed by mechanical means or by thermal gouging processes, after which the joint shall be rewelded [see UW-40(e)].

UW-39 PEENING

(a) Weld metal and heat-affected zones may be peened by manual, electric, or pneumatic means when it is deemed necessary or helpful to control distortion, to relieve residual stresses, or to improve the quality of the weld. Peening shall not be used on the initial (root) layer of weld metal nor on the final (face) layer unless the weld is subsequently postweld heat treated. In no case, however, is peening to be performed in lieu of any postweld heat treatment required by these rules.

(b) Controlled shot peening and other similar methods which are intended only to enhance surface properties of the vessel or vessel parts shall be performed after any nondestructive examinations and pressure tests required by these rules.

UW-40 PROCEDURES FOR POSTWELD HEAT TREATMENT

(a) The operation of postweld heat treatment shall be performed in accordance with the requirements given in the applicable Part in Subsection C using one of the following procedures. In the procedures that follow, the soak band is defined as the volume of metal required to meet or exceed the minimum PWHT temperatures listed in Tables UCS-56-1 through UCS-56-11. As a minimum, the soak band shall contain the weld, heat-affected zone, and a portion of base metal adjacent to the weld being heat treated. The minimum width of this volume is the widest width of weld plus 1t or 2 in. (50 mm), whichever is less, on each side or end of the weld. The term t is the nominal thickness as defined in (f) below. For additional detailed recommendations regarding implementation and performance of these procedures, refer to Welding Research Council (WRC) Bulletin 452, June 2000, "Recommended Practices for Local Heating of Welds in Pressure Vessels."

(1) heating the vessel as a whole in an enclosed furnace. This procedure is preferable and should be used whenever practicable.

(2) heating the vessel in more than one heat in a furnace, provided the overlap of the heated sections of the vessel is at least 5 ft (1.5 m). When this procedure is used, the portion outside of the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the vessel projects from the furnace shall not intersect a nozzle or other structural discontinuity.

(3) heating of shell sections and/or portions of vessels to postweld heat treat longitudinal joints or complicated welded details before joining to make the completed vessel. When the vessel is required to be postweld heat treated, and it is not practicable to postweld heat treat the completed vessel as a whole or in two or more heats as provided in (2) above, any circumferential joints not previously postweld heat treated may be thereafter locally postweld heat treated by heating such joints by any appropriate means that will assure the required uniformity. For such local heating, the soak band shall extend around the full circumference. The portion outside the soak band shall be protected so that the temperature gradient is not harmful. This procedure may also be used to postweld heat treat portions of new vessels after repairs.

(4) heating the vessel 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 vessel wall. Previous to this operation, the vessel should be fully enclosed with insulating material, or the permanent insulation may be installed provided it is suitable for the required temperature. In this procedure the internal pressure should be kept as low as practicable, but shall not exceed 50% of the maximum allowable working pressure at the highest metal temperature expected during the postweld heat treatment period.

(5) heating a circumferential band containing nozzles or other welded attachments that require postweld heat treatment in such a manner that the entire band shall be brought up uniformly to the required temperature and held for the specified time. Except as modified in this paragraph below, the soak band shall extend around the entire vessel, and shall include the nozzle or welded attachment. The circumferential soak band width may be varied away from the nozzle or attachment weld requiring PWHT, provided the required soak band around the nozzle or attachment weld is heated to the required temperature and held for the required time. As an alternative

to varying the soak band width, the temperature within the circumferential band away from the nozzle or attachment may be varied and need not reach the required temperature, provided the required soak band around the nozzle or attachment weld is heated to the required temperature, held for the required time, and the temperature gradient is not harmful throughout the heating and cooling cycle. The portion of the vessel outside of the circumferential soak band shall be protected so that the temperature gradient is not harmful. This procedure may also be used to postweld heat treat portions of vessels after repairs.

(6) heating the circumferential joints of pipe or tubing by any appropriate means using a soak band that extends around the entire circumference. The portion outside the soak band shall be protected so that the temperature gradient is not harmful. The proximity to the shell increases thermal restraint, and the designer should provide adequate length to permit heat treatment without harmful gradients at the nozzle attachment or heat a full circumferential band around the shell, including the nozzle.

(7) heating a local area around nozzles or welded attachments in the larger radius sections of a double curvature head or a spherical shell or head in such a manner that the area is brought up uniformly to the required temperature and held for the specified time. The soak band shall include the nozzle or welded attachment. The soak band shall include a circle that extends beyond the edges of the attachment weld in all directions by a minimum of t or 2 in. (50 mm), whichever is less. The portion of the vessel outside of the soak band shall be protected so that the temperature gradient is not harmful.

(8) heating of other configurations. Local area heating of other configurations such as “spots” or “bulls eye” local heating not addressed in (1) through (7) above is permitted, provided that other measures (based upon sufficiently similar, documented experience or evaluation) are taken that consider the effect of thermal gradients, all significant structural discontinuities (such as nozzles, attachments, head to shell junctures), and any mechanical loads which may be present during PWHT. The portion of the vessel or component outside the soak band shall be protected so that the temperature gradient is not harmful.

(b) The temperatures and rates of heating and cooling to be used in postweld heat treatment of vessels constructed of materials for which postweld heat treatment may be required are given in UCS-56, UHT-56, UNF-56, and UHA-32.

(c) The minimum temperature for postweld heat treatment given in Tables UCS-56-1 through UCS-56-11, Table UHT-56, and Tables UHA-32-1 through UHA-32-7, and in UNF-56, shall be the minimum temperature of the plate material of the shell or head of any vessel. Where more than one pressure vessel or pressure vessel part are postweld heat treated in one furnace charge, thermocouples shall be placed on vessels at the bottom, center, and top of the charge, or in other zones of possible temperature variation so that the temperature indicated shall be true temperature for all vessels or parts in those zones.[72]

(d) It is recognized that some postweld heat treatments may have detrimental effects on the properties of some materials. When pressure parts of two different P-Numbers are joined by welding, engineering judgment shall be applied when selecting the postweld heat treatment temperature and holding time to produce material properties suitable for the intended service. Alternatives such as welding with buttering as described in Section IX, QW-283 may be considered.

(e) Postweld heat treatment, when required, shall be done before the hydrostatic test and after any welded repairs except as permitted by UCS-56(f). A preliminary hydrostatic test to reveal leaks prior to postweld heat treatment is permissible.

(f) The term nominal thickness as used in Tables UCS-56-1 through UCS-56-11, UCS-56.1, UHA-32-1 through UHA-32-7, and UHT-56, is the thickness of the welded joint as defined below. For pressure vessels or parts of pressure vessels being postweld heat treated in a furnace charge, it is the greatest weld thickness for all weld types as defined in (1) through (6) below in any vessel or vessel part that has not previously been postweld heat treated.

(1) When the welded joint connects parts of the same thickness, using a full penetration buttweld, the nominal thickness is the total depth of the weld exclusive of any permitted weld reinforcement.

(2) For groove welds, the nominal thickness is the depth of the groove. For single- or double-sided groove welds, the nominal thickness is the total depth of the groove.

(3) For fillet welds, the nominal thickness is the throat dimension. If a fillet weld is used in conjunction with a groove weld, the nominal thickness is the depth of the groove or the throat dimension, whichever is greater.

(4) For stud welds, the nominal thickness shall be the diameter of the stud.

(5) When a welded joint connects parts of unequal thicknesses, the nominal thickness shall be the following:

(-a) the thinner of two adjacent butt-welded parts including head to shell connections

(-b) the thickness of the shell or the fillet weld, whichever is greater, in connections to intermediate heads of the type shown in Figure UW-13.1, sketch (e);

(-c) the thickness of the shell in connections to tubesheets, flat heads, covers, flanges (except for welded parts depicted in Figure 2-4, sketch (7), where the thickness of the weld shall govern), or similar constructions;

(-d) in Figures UW-16.1 and UW-16.2, the thickness of the weld across the nozzle neck or shell or head or reinforcing pad or attachment fillet weld, whichever is the greater;

(-e) the thickness of the nozzle neck at the joint in nozzle neck to flange connections;

(-f) the thickness of the weld at the point of attachment when a nonpressure part is welded to a pressure part;

(-g) the thickness of the tube in tube-to-tubesheet connections.

(-h) the thickness of the weld metal overlay when weld metal overlay is the only welding applied

(6) For repairs, the nominal thickness is the depth of the repair weld.

(7) The thickness of the head, shell, nozzle neck, or other parts as used in (1) through (6) above shall be the wall thickness of the part at the welded joint under consideration. For plate material, the thickness as shown on the Material Test Report or material Certificate of Compliance before forming may be used, at the Manufacturer's option, in lieu of measuring the wall thickness at the welded joint.

UW-41 SECTIONING OF WELDED JOINTS

Welded joints may be examined by sectioning when agreed to by user and Manufacturer, but this examination shall not be considered a substitute for spot radiographic examination. This type of examination has no effect on the joint factors in Table UW-12. The method of closing the hole by welding is subject to acceptance by the Inspector. Some acceptable methods are given in Nonmandatory Appendix K.

UW-42 SURFACE WELD METAL BUILDUP

(a) Construction in which deposits of weld metal are applied to the surface of base metal for the purpose of restoring the thickness of the base metal for strength consideration; or modifying the configuration of weld joints in order to provide the tapered transition requirements of UW-9(c) and UW-33(b) shall be performed in accordance with the rules in (b) and (c).

(b) Procedure Qualification. A butt welding procedure qualification in accordance with provisions of Section IX shall be performed for the thickness of weld metal deposited, prior to production welding.

(c) Examination Requirements

(1) All weld metal buildup shall be examined over the full surface of the deposit by either magnetic particle examination to the requirements of Mandatory Appendix 6, or by liquid penetrant examination to the requirements of Mandatory Appendix 8.

(2) When such surface weld metal buildup is used in welded joints which require full or spot radiographic examination, the weld metal buildup shall be included in the examination.

INSPECTION AND TESTS

UW-46 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsection C that pertain to the class of material used. [For tests on reinforcing plates, see UG-37(g).]

UW-47 CHECK OF WELDING PROCEDURE

The Inspector shall assure himself that the welding procedure employed in the construction of a vessel has been qualified under the provisions of Section IX. The Manufacturer shall submit evidence to the Inspector that the requirements have been met.

UW-48 CHECK OF WELDER AND WELDING OPERATOR QUALIFICATIONS

(a) The Manufacturer shall certify that the welding on a vessel has been done only by welders and welding operators who have been qualified under the requirements of Section IX and the Inspector shall assure himself that only qualified welders and welding operators have been used.

(b) The Manufacturer shall make available to the Inspector the record of the qualification tests of each welder and welding operator. The Inspector shall have the right at any time to call for and witness tests of the welding procedure or of the ability of any welder and welding operator.

UW-49 CHECK OF POSTWELD HEAT TREATMENT PRACTICE

The Inspector shall satisfy himself that all postweld heat treatment has been correctly performed and that the temperature readings conform to the requirements.

UW-50 NONDESTRUCTIVE EXAMINATION OF WELDS ON PNEUMATICALLY TESTED VESSELS (19)

(a) On welded pressure vessels to be pneumatically tested in accordance with UG-100, the full length of the following welds shall be examined[69] before the pneumatic test is performed, for the purpose of detecting cracks:

(1) all welds around openings

(2) all attachment welds having a throat thickness greater than $\frac{1}{4}$ in. (6 mm), including welds attaching nonpressure parts to pressure parts

(b) The weld joint examination requirements given in (a) may be waived when the maximum allowable working pressure of the vessel is no greater than 500 psi (3.5 MPa) and the following applicable requirement is met:

(1) For Part UCS materials, the governing thickness as defined in UCS-66(a) shall be limited to a maximum governing thickness of $^1/_2$ in. (13 mm) for materials assigned to Curve A, and 1 in. (25 mm) for materials assigned to Curve B, C, or D in Figure UCS-66.

(2) For austenitic chromium–nickel stainless steels 304, 304L, 316, 316L, 321, and 347 in Part UHA, the maximum nominal material thickness shall be $^3/_4$ in. (19 mm).

(3) For aluminum, aluminum alloy 3000 series, aluminum alloy 5000 series, and aluminum alloy 6061-T6 in Part UNF, the maximum nominal material thickness shall be 1 in. (25 mm).

(19) UW-51 RADIOGRAPHIC EXAMINATION OF WELDED JOINTS

(a) All welded joints to be radiographed shall be examined in accordance with Section V, Article 2, except as specified below.

(1) A complete set of radiographic images and examination records, as described in Section V, Article 2, for each vessel or vessel part shall be retained by the Manufacturer, as follows:

(-a) radiographic images until the Manufacturer's Data Report has been signed by the Inspector

(-b) examination records as required by this Division (10-13)

(2) Demonstration of acceptable density on radiographic films and the ability to see the prescribed image quality indicator (IQI) image and the specified hole or the designated wire of a wire IQI shall be considered satisfactory evidence of compliance with Section V, Article 2.

(3) The requirements of Section V, Article 2, T-274.2, are to be used only as a guide for film-based radiography.

(4) As an alternative to the radiographic examination requirements above, all welds in which the thinner of the members joined is $^1/_4$ in. (6 mm) thick and greater may be examined using the ultrasonic (UT) method specified by UW-53(b).

(b) Indications revealed by radiography within a weld that exceed the following criteria are unacceptable and therefore are defects. Defects shall be repaired as provided in UW-38, and the repaired area shall be reexamined. In lieu of reexamination by radiography, the repaired weld may be ultrasonically examined in accordance with Mandatory Appendix 12 at the Manufacturer's option. For material thicknesses in excess of 1 in. (25 mm), the concurrence of the user shall be obtained. This ultrasonic examination shall be noted under Remarks on the Manufacturer's Data Report Form:

(1) any indication characterized as a crack or zone of incomplete fusion or penetration;

(2) any other elongated indication on the radiograph which has length greater than:

(-a) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm)

(-b) $^1/_3 t$ for t from $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm)

(-c) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where

t = the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

(3) any group of aligned indications that have an aggregate length greater than t in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group;

(4) rounded indications in excess of that specified by the acceptance standards given in Mandatory Appendix 4.

UW-52 SPOT EXAMINATION OF WELDED JOINTS

NOTE: Spot radiographing of a welded joint is recognized as an effective inspection tool. The spot radiography rules are also considered to be an aid to quality control. Spot radiographs made directly after a welder or an operator has completed a unit of weld proves that the work is or is not being done in accordance with a satisfactory procedure. If the work is unsatisfactory, corrective steps can then be taken to improve the welding in the subsequent units, which unquestionably will improve the weld quality.

Spot radiography in accordance with these rules will not ensure a fabrication product of predetermined quality level throughout. It must be realized that an accepted vessel under these spot radiography rules may still contain defects which might be disclosed on further examination. If all radiographically disclosed weld defects must be eliminated from a vessel, then 100% radiography must be employed.

(a) Butt-welded joints that are to be spot radiographed shall be examined locally as provided herein.

(b) Minimum Extent of Spot Radiographic Examination

(1) One spot shall be examined on each vessel for each 50 ft (15 m) increment of weld or fraction thereof for which a joint efficiency from column (b) of Table UW-12 is selected. However, for identical vessels or parts, each with less than 50 ft (15 m) of weld for which a joint efficiency from column (b) of Table UW-12 is selected, 50 ft (15 m) increments of weld may be represented by one spot examination.

(2) For each increment of weld to be examined, a sufficient number of spot radiographs shall be taken to examine the welding of each welder or welding operator. Under conditions where two or more welders or welding operators make weld layers in a joint, or on the two sides of a double-welded butt joint, one spot may represent the work of all welders or welding operators.

(3) Each spot examination shall be made as soon as practicable after completion of the increment of weld to be examined. The location of the spot shall be chosen by the Inspector after completion of the increment of welding to be examined, except that when the Inspector has been notified in advance and cannot be present or otherwise make the selection, the Manufacturer may exercise his own judgment in selecting the spots.

(4) Radiographs required at specific locations to satisfy the rules of other paragraphs, such as UW-9(d), UW-11(a)(5)(-b), and UW-14(b), shall not be used to satisfy the requirements for spot radiography.

(c) Standards for Spot Radiographic Examination. Spot examination by radiography shall be made in accordance with the technique prescribed in UW-51(a). The minimum length of spot radiograph shall be 6 in. (150 mm). Spot radiographs may be retained or be discarded by the Manufacturer after acceptance of the vessel by the Inspector. The acceptability of welds examined by spot radiography shall be judged by the following standards:

(1) Welds in which indications are characterized as cracks or zones of incomplete fusion or penetration shall be unacceptable.

(2) Welds having indications characterized as slag inclusions or cavities are unacceptable when the indication length exceeds $^2/_3t$, where t is defined as shown in UW-51(b)(2). For all thicknesses, indications less than $^1/_4$ in. (6 mm) are acceptable, and indications greater than $^3/_4$ in. (19 mm) are unacceptable. Multiple aligned indications meeting these acceptance criteria are acceptable when the sum of their longest dimensions indications does not exceed t within a length of $6t$ (or proportionally for radiographs shorter than $6t$), and when the longest length L for each indication is separated by a distance not less than $3L$ from adjacent indications.

(3) Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.

(d) Evaluation and Retests

(1) When a spot, radiographed as required in (b)(1) or (b)(2) above, is acceptable in accordance with (c)(1) and (c)(2) above, the entire weld increment represented by this radiograph is acceptable.

(2) When a spot, radiographed as required in (b)(1) or (b)(2) above, has been examined and the radiograph discloses welding which does not comply with the minimum quality requirements of (c)(1) or (c)(2) above, two additional spots shall be radiographically examined in the same weld increment at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination in (b)(3) above.

(-a) If the two additional spots examined show welding which meets the minimum quality requirements of (c)(1) and (c)(2) above, the entire weld increment represented by the three radiographs is acceptable provided the defects disclosed by the first of the three radiographs are removed and the area repaired by welding. The weld repaired area shall be radiographically examined in accordance with the foregoing requirements of UW-52.

(-b) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of (c)(1) or (c)(2) above, the entire increment of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire increment of weld represented shall be completely radiographed and only defects need be corrected.

(-c) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint, or the weld repaired areas, shall be spot radiographically examined at one location in accordance with the foregoing requirements of UW-52.

UW-53 ULTRASONIC EXAMINATION OF WELDED JOINTS

(a) Ultrasonic examination of welded joints whose joint efficiency is not determined by ultrasonic examinations may be performed and evaluated in accordance with Mandatory Appendix 12.

(b) Ultrasonic examination of welds per UW-51(a)(4) shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, 7.5.5.

UW-54 QUALIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL (19)

Personnel performing nondestructive examinations in accordance with UW-51, UW-52, or UW-53 shall be qualified and certified in accordance with the requirements of Section V, Article 1, T-120(e), T-120(f), T-120(g), T-120(i), T-120(j), or T-120(k), as applicable.

MARKING AND REPORTS

UW-60 GENERAL

The provisions for marking and reports, UG-115 through UG-120, shall apply without supplement to welded pressure vessels.

PART UF
REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY FORGING

GENERAL

UF-1 SCOPE

The rules in Part UF are applicable to forged pressure vessels without longitudinal joints, including their component parts that are fabricated of carbon and low alloy steels or of high alloy steels within the limitations of Part UHA. These rules shall be used in conjunction with the applicable requirements in Subsection A, and with the specific requirements in Subsection C that pertain to the respective classes of all materials used.

MATERIALS

(19) UF-5 GENERAL

(a) Materials used in the construction of forged pressure vessels shall comply with the requirements for materials given in UG-4 through UG-14, except as specifically limited or extended in (b) and (c) below, and in UF-6.

(b) The heat analysis of forgings to be fabricated by welding shall not exceed carbon 0.35%. However, when the welding involves only minor nonpressure attachments as limited in UF-32, seal welding of threaded connections as permitted in UF-43, or repairs as limited by UF-37, the carbon content shall not exceed 0.50% by heat analysis. When by heat analysis the carbon analysis exceeds 0.50% no welding is permitted.

(c) SA-372 materials that are subjected to liquid quench and temper heat treatment and that have a specified minimum tensile strength exceeding 95 ksi (655 MPa) may be subjected to accelerated cooling or may be quenched and tempered to attain their specified minimum properties provided

(1) after heat treatment, inspection for injurious defects shall be performed according to UF-31(b)(1);

(2) tensile strength shall not be greater than 20,000 psi (140 MPa) above their specified minimum tensile strength.

(d) For vessels constructed of SA-372 Grade J, Class 110 or Grade L material, transverse impact tests shall be made at the minimum allowable temperature in accordance with Part UHT of this Division, except in no case shall the test temperature be higher than −20°F (−29°C). Certification is required. An ultrasonic examination shall be made in accordance with UF-55.

UF-6 FORGINGS

All materials subject to stress due to pressure shall conform to one of the specifications given in Section II and limited to those listed in Tables UCS-23 and UHA-23 for forgings or to plates, and seamless pipe and tube when such material is further processed by a forging operation.

UF-7 FORGED STEEL ROLLS USED FOR CORRUGATING PAPER MACHINERY

Materials and rules of construction to be applied in the manufacture of forged steel corrugating and pressure rolls used in machinery for producing corrugated paper are covered in Section II, Part A, SA-649.

DESIGN

UF-12 GENERAL

The rules in the following paragraphs apply specifically to vessels or main sections of vessels that are forged from ingots, slabs, billets, plate, pipe, or tubes, and shall be used to supplement the requirements for design which are applicable, as given in UG-16 through UG-55, and those given in UCS-16 through UCS-67, and UHA-20 through UHA-34. Sections of vessels may be joined by any method permitted in the several parts of this Division except as limited in UF-5(b) and UF-5(c).

Vessels constructed of SA-372 Grade A, B, C, or D; Grade E, Class 55, 65, or 70; Grade F, Class 55, 65, or 70; Grade G, Class 55, 65, or 70; Grade H, Class 55, 65, or 70; Grade J, Class 55, 65, 70, or 110; Grade L; or Grade M, Class A or B must be of streamlined design, and stress raisers, such as abrupt changes in section, shall be minimized. Openings in vessels constructed of liquid quenched and tempered materials, other than austenitic steel, shall be reinforced in accordance with UG-37; UG-36(c)(3) shall not apply.

The nominal wall thickness of the cylindrical shell of vessels constructed of SA-372 Grade J, Class 110 shall not exceed 2 in. (50 mm).

UF-13 HEAD DESIGN

(a) The minimum required thickness of forged heads shall be computed using the equations of UG-32. When heads are made separate from the body forging they

may be attached by any method permitted in the several parts of this Division except as limited in UF-5(b) and UF-5(c).

(b) The juncture of a forged conical head with the body shall be a knuckle, the inside radius of which shall be not less than 6% of the internal diameter of the vessel. The thickness at the knuckle shall be not less than that of the cylinder and shall be faired into that of the head at the base of the cone.

(c) Except for the $3t$ requirements in UG-32(i) the design of the head shall comply with the applicable provisions of UG-32, UG-33, UG-34, and 1-6.

UF-25 CORROSION ALLOWANCE

Provision shall be made for corrosion in accordance with the requirements in UG-25.

FABRICATION

(19) UF-26 GENERAL

The rules in the following paragraphs supplement the applicable requirements for fabrication given in UG-75 through UG-84 and UCS-79. For high alloy steel forged vessels, the applicable paragraphs of Part UHA shall also apply.

UF-27 TOLERANCES ON BODY FORGINGS

(a) The inner surface of the body shall be true-to-round to the degree that the maximum difference between any two diameters at 90 deg to each other, determined for any critical cross section, does not exceed 1% of the mean diameter at that section. Chip marks and minor depressions in the inner surface may be filled by welding to meet these tolerances when the welding is done as permitted in UF-32.

(b) If out-of-roundness exceeds the limit in (a) and the condition cannot be corrected, the forging shall be rejected except that if the out-of-roundness does not exceed 3%, the forging may be certified for a lower pressure in the formula:

$$\text{Reduced pressure } P' = P\left(\frac{1.25}{\frac{S_b}{S} + 1}\right)$$

and in which

$$S_b = \frac{1.5PR_1t(D_1 - D_2)}{t^3 + 3\frac{P}{E}R_1R_a^{\,2}}$$

where

D_1, D_2 = the inside diameters maximum and minimum, respectively, as measured for the critical section, and for one additional section in each direction therefrom at a distance not exceeding $0.2D_2$. The average of the three readings for D_1 and D_2, respectively, shall be inserted in the formula.

E = modulus of elasticity of material at design temperature

P = maximum allowable working pressure for forging meeting the requirements of (a)

R_1 = average inside radius at critical section
= $^1/_4\,(D_1 + D_2)$

R_a = average radius to middle of shell wall at critical section
= $^1/_4\,(D_1 + D_2) + t/2$

S = design stress value, psi (kPa), at metal service temperature

S_b = bending stress at metal service temperature

t = the average (mean) thickness

NOTES:

(1) Use $P' = P$ when S_b is less than $0.25S$.

(2) In all measurements, correct for corrosion allowance if specified.

UF-28 METHODS OF FORMING FORGED HEADS

Forged heads shall be made either by closing in extensions of the body of such shape and dimensions as may be required to produce the final form desired, or by separate forgings [see UF-13(a)].

UF-29 TOLERANCE ON FORGED HEADS

Forged heads shall be as true as it is practicable to make them to the shape shown on the design drawings. Any deviations therefrom shall merge smoothly into the general shape of the head and shall not evidence a decrease of strength for the sections as required by the equations for design.

UF-30 LOCALIZED THIN AREAS

Forgings are permitted to have small areas thinner than required if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in UG-40.

UF-31 HEAT TREATMENT (19)

(a) Normalized or Annealed Material

(1) After all forging is completed, each vessel or forged part fabricated without welding shall be heat treated in accordance with the applicable material specification. When defects are repaired by welding, subsequent heat treatment may be necessary in accordance with UF-37(b).

(2) Vessels fabricated by welding of forged parts requiring heat treatment shall be heat treated in accordance with the applicable material specification as follows:

(-a) after all welding is completed; or

(-b) prior to welding, followed by postweld heat treatment of the finished weld in accordance with UW-40;

(-c) when the welding involves only minor nonpressure attachments to vessels having carbon content exceeding 0.35% but not exceeding 0.50% by ladle analysis, requirements of UF-32(b) shall govern.

In the case of austenitic steels, the heat treatment procedures followed shall be in accordance with UHA-32.

(b) *Liquid Quenched SA-372*. Vessels fabricated from SA-372 forging material to be liquid quenched and tempered shall be subjected to this heat treatment in accordance with the applicable material specifications after the completion of all forging, welding of nonpressure attachments as permitted by UF-32, and repair welding as limited by UF-37. Seal welding of threaded connections, as permitted in UF-43, may be performed either before or after this heat treatment.

(1) After final heat treatment, such vessels shall be examined for the presence of cracks on the outside surface of the shell portion and on the inside surface where practicable. This examination shall be made by liquid penetrant when the material is nonferromagnetic and by liquid penetrant or magnetic particle examination when the material is ferromagnetic.

(2) After final heat treatment, liquid quenched and tempered vessels, except as provided in (3) below, shall be subjected to Brinell hardness tests at 5 ft (1.5 m) intervals with a minimum of four readings at each of not less than three different sections representing approximately the center and each end of the heat-treated shell. The average of the individual Brinell hardness numbers at each section shall be not less than 10% below, nor more than 25% above the number obtained by dividing 500 into the specified minimum tensile strength of the material, and the highest average hardness number shall not exceed the lowest average value on an individual vessel by more than 40. Reheat treatment is permitted.

NOTE: Other hardness testing methods may be used and converted to Brinell numbers by means of the Table in ASTM E140.

(3) For vessels which are integrally forged, having an overall length less than 5 ft (1.5 m) and a nominal thickness not exceeding $^1/_2$ in. (13 mm), the requirements of (2) above may be modified by taking a minimum of two hardness readings at each end of the vessel. These four hardness readings shall satisfy the requirements of (2) above as if the four hardnesses were applicable to one section.

(c) *Non-Heat-Treated Material*. Postweld heat treatment of vessels fabricated by welding of forged parts not requiring heat treatment shall meet with the requirements of UCS-56.

UF-32 WELDING FOR FABRICATION

(a) All welding used in connection with the fabrication of forged vessels or components shall comply with the applicable requirements of Parts UW, UCS, and UHA and UF-5(b) except as modified in (b) and (c) below. Procedure qualification in accordance with Section IX shall be performed with the heat treatment condition of the base metal and weld metal as in UF-31 as contemplated for the actual work.

(b) When the carbon content of the material exceeds 0.35% by ladle analysis, the vessel or part shall be fabricated without welding of any kind, except for repairs [see UF-37(b)], for seal welding of threaded connections as permitted in UF-43, and for minor nonpressure attachments. Minor nonpressure attachments shall be joined by fillet welds of not over $^1/_4$ in. (6 mm) throat dimensions. Such welding shall be allowed under the following conditions:

(1) The suitability of the electrode and procedure shall be established by making a groove weld specimen as shown in Section IX, Figure QW-461.2 in material of the same analysis and of thickness in conformance with Section IX, QW-451. The specimen before welding shall be in the same condition of heat treatment as the work it represents, and after welding the specimen shall be subjected to heat treatment equivalent to that contemplated for the work. Tensile and bend tests, as shown in Section IX, Figures QW-462.1(a) through QW-462.1(e) and Figures QW-462.2 and QW-462.3(a), shall be made. These tests shall meet the requirements of Section IX, QW-150 and QW-160. The radius of the mandrel used in the guided bend test shall be as follows:

Specimen Thickness	Radius of Mandrel, *B* [Note (1)]	Radius of Die, *D* [Note (1)]
$^3/_8$ in. (10 mm)	$1^1/_2$ in. (38 mm)	$1^{11}/_{16}$ in. (42 mm)
t	$3^1/_3t$	$4^1/_3t$ + $^1/_{16}$ in. (1.5 mm)

NOTE:
(1) Corresponds to dimensions *B* and *D* in Section IX, Figure QW-466.1, and other dimensions to be in proportion.

Any cutting and gouging processes used in the repair work shall be included as part of the procedure qualification.

(2) Welders shall be qualified for fillet welding specified by making and testing a specimen in accordance with Section IX, QW-180 and Figure QW-462.4(b). Welders shall be qualified for repair welding by making a test plate in accordance with Section IX, Figure QW-461.3 from which the bend tests outlined in Section IX, QW-452 shall be made. The electrode used in making these tests shall be of the same classification number as that specified in the procedure. The material for these tests can be carbon steel plate or pipe provided the test specimens are preheated, welded and postheated in accordance with the procedure specification for the type of electrode involved.

(3) The finished weld shall be postweld heat treated or given a further heat treatment as required by the applicable material specification. The types of welding permitted in (b) shall be performed prior to final heat treatment except for seal welding of threaded openings which may be performed either before or after final heat treatment.

(4) The finished welds shall be examined after postweld heat treatment by liquid penetrant when the material is nonferromagnetic and by liquid penetrant or magnetic particle examination using the prod method when the material is ferromagnetic.

(c) The following requirements shall be used to qualify welding procedure and welder performance for seal welding of threaded connections in seamless forged pressure vessels of SA-372 Grades A, B, C, D, E, F, G, H, and J materials:

(1) The suitability of the welding procedure, including electrode, and the welder performance shall be established by making a seal weld in the welding position to be used for the actual work and in a full-size prototype of the vessel neck, including at least some portion of the integrally forged head, conforming to the requirements of UF-43 and the same geometry, thickness, vessel material type, threaded-plug material type, and heat treatment as that for the production vessel it represents.

(2) The seal weld in the prototype at the threaded connection of the neck and plug shall be cross sectioned to provide four macro-test specimens taken 90 deg apart.

(3) One face of each cross section shall be smoothed and etched with suitable etchant (see Section IX, QW-470) to give a clear definition of the weld metal and heat-affected zone. Visual examination of the cross sections of the weld metal and heat-affected zone shall show complete fusion and freedom from cracks.

(4) All production welding shall be done in accordance with the procedure qualification of (1) above, including the preheat and the electrode of the same classification as that specified in the procedure, and with welders qualified using that procedure.

(5) Seal welding of threaded connections may be performed either before or after final heat treatment.

(6) The finished weld shall be examined by liquid penetrant or magnetic particle examination using the prod method.

UF-37 REPAIR OF DEFECTS IN MATERIAL

(a) Surface defects, such as chip marks, blemishes, or other irregularities, shall be removed by grinding or machining and the surface exposed shall be blended smoothly into the adjacent area where sufficient wall thickness permits thin areas in compliance with the requirements of UF-30.

(b) Thinning to remove imperfections beyond those permitted in UF-30 may be repaired by welding only after acceptance by the Inspector. Defects shall be removed to sound metal as shown by acid etch or any other suitable method of examination. The welding shall be as outlined below.

(1) Material Having Carbon Content of 0.35% or Less (by Ladle Analysis)

(-a) The welding procedure and welders shall be qualified in accordance with Section IX.

(-b) Postweld heat treatment after welding shall be governed as follows.

(-1) All welding shall be postweld heat treated if UCS-56 requires postweld heat treatment, for all thicknesses of material of the analysis being used.

(-2) Fillet welds need not be postweld heat treated unless required by (-1) above or unless the fillet welds exceed the limits given in UCS-56.

(-3) Repair welding shall be postweld heat treated when required by (-1) above or if it exceeds 6 in.^{2} (4 000 mm^2) at any spot or if the maximum depth exceeds $^1/_4$ in. (6 mm).

(-c) Repair welding shall be radiographed if the maximum depth exceeds $^3/_8$ in. (10 mm). Repair welds $^3/_8$ in. (10 mm) and under in depth which exceed 6 in.^{2} (4 000 mm^2) at any spot and those made in materials requiring postweld heat treatment shall be examined by radiographing, magnetic particle or liquid penetrant examination, or any alternative method suitable for revealing cracks.

(-d) For liquid quenched and tempered steels, other than austenitic steels, welding repairs shall be in accordance with (3).

(2) Material Having Carbon Content Over 0.35% (by Ladle Analysis)

(-a) Welding repairs shall conform with UF-32(b) except that if the maximum weld depth exceeds $^1/_4$ in. (6 mm), radiography, in addition to magnetic particle or liquid penetrant examination, shall be used.

(-b) For liquid quenched and tempered steels, other than austenitic steel, welding repair shall be in accordance with (3) below.

(3) Welding repairs of materials which are to be or have been liquid quenched and tempered, regardless of depth or area of repairs, shall have the repaired area radiographed and examined by magnetic particle or liquid penetrant examination.

UF-38 REPAIR OF WELD DEFECTS

The repair of welds of forgings having carbon content not exceeding 0.35% by ladle analysis shall follow the requirements of UW-38.

UF-43 ATTACHMENT OF THREADED NOZZLES TO INTEGRALLY FORGED NECKS AND THICKENED HEADS ON VESSELS

Threaded openings, over NPS 3 (DN 80), but not exceeding the smaller of one-half of the vessel diameter or NPS 8, may be used in the heads of vessels having integrally forged heads and necks that are so shaped and thickened as to provide a center opening, which shall meet the rules governing openings and reinforcements contained elsewhere in the Code. Length of thread shall be calculated for the opening design, but shall not be less than shown in Table UG-43. Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means.

When seal welding is employed in the installation of a threaded nozzle, the work shall be performed and inspected in the shop of the vessel manufacturer. Seal welding shall comply with UF-32.

INSPECTION AND TESTS

(19) UF-45 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of forged vessels and their component parts. These rules shall be used to supplement the applicable requirements for inspection and tests given throughout this Part and in UG-90 through UG-102. All forged vessels shall be examined as manufacture proceeds, to assure freedom from loose scale, gouges or grooves, and cracks or seams that are visible. After fabrication has passed the machining stage, the vessel body shall be measured at suitable intervals along its length to get a record of variations in wall thickness, and the nozzles for connecting piping and other important details shall be checked for conformity to the design dimensions.

UF-46 ACCEPTANCE BY INSPECTOR

Surfaces which are not to be machined shall be carefully inspected for visible defects such as seams, laps, or folds. On surfaces to be machined the inspection shall be made after machining. Regions from which defective material has been removed shall be inspected after removal and again after any necessary repair.

UF-47 PARTS FORGING

(a) When welding is used in the fabrication of parts forgings completed elsewhere, the parts forging manufacturer shall furnish a Form U-2 Partial Data Report.

(b) All parts forgings completed elsewhere shall be marked with the manufacturer's name and the forging identification, including material designation. Should identifying marks be obliterated in the fabrication process, and for small parts, other means of identification shall be used. The forging manufacturer shall furnish reports of chemical and mechanical properties of the material and certification that each forging conforms to all requirements of Part UF.

(c) Parts forgings furnished as material for which parts Data Reports are not required need not be inspected at the plant of the forging manufacturer, but the manufacturer shall furnish a report of the extent and location of any repairs together with certification that they were made in accordance with all other requirements of UF-37 and UF-38. If desired, welding repairs of such forgings may be made, inspected, and tested at the shop of the pressure vessel manufacturer.

UF-52 CHECK OF HEAT TREATMENT AND POSTWELD HEAT TREATMENT

The Inspector shall check the provisions made for heat treatment to assure himself that the heat treatment is carried out in accordance with provisions of UF-31 and UF-32. He shall also assure himself that postweld heat treatment is done after repair welding when required under the rules of UF-37.

UF-53 TEST SPECIMENS

When test specimens are to be taken under the applicable specification, the Inspector shall be allowed to witness the selection, place the identifying stamping on them, and witness the testing of these specimens.

UF-54 TESTS AND RETESTS

Tests and retests shall be made in accordance with the requirements of the material specification.

UF-55 ULTRASONIC EXAMINATION

(a) For vessels constructed of SA-372 Grade J, Class 110 material, the completed vessel after heat treatment shall be examined ultrasonically in accordance with SA-388. The reference specimen shall have the same nominal thickness, composition, and heat treatment as the vessel it represents. Angle beam examination shall be calibrated with a notch of a depth equal to 5% of the nominal section thickness, a length of approximately 1 in. (25 mm), and a width not greater than twice its depth.

(b) A vessel is unacceptable if examination results show one or more imperfections which produce indications exceeding in amplitude the indication from the calibrated notch. Round bottom surface imperfections, such as pits, scores, and conditioned areas, producing indications exceeding the amplitude of the calibrated notch shall be acceptable if the thickness below the indication is not less than the design wall thickness of the vessel, and its sides are faired to a ratio of not less than three to one.

MARKING AND REPORTS

UF-115 GENERAL

The rules of UG-115 through UG-120 shall apply to forged vessels as far as practicable. Vessels constructed of liquid quenched and tempered material, other than austenitic steels, shall be marked on the thickened head, unless a nameplate is used.

SUBSECTION C
REQUIREMENTS PERTAINING TO CLASSES OF MATERIALS

PART UCS
REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CARBON AND LOW ALLOY STEELS[74]

GENERAL

UCS-1 SCOPE

The rules in Part UCS are applicable to pressure vessels and vessel parts that are constructed of carbon and low alloy steels and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection B that pertain to the method of fabrication used.

MATERIALS

UCS-5 GENERAL

(a) All carbon and low alloy steel material subject to stress due to pressure shall conform to one of the Specifications given in Section II and shall be limited to those listed in Table UCS-23 except as otherwise provided in UG-10 and UG-11.

(b) In addition to the requirements of UG-4(a), backing strips which remain in place need not conform to a material specification permitted by this Division if all of the following are met:

(1) The specification maximum composition limits or certificate values for the backing strip material shall not exceed those of the material specification for the pressure part to which it is attached.

(2) Either of the following requirements shall be met:

(-a) The backing strip base metal, and its associated HAZ, and the weld metal shall be impact tested in accordance with UG-84 at the MDMT shown on the nameplate with a butt weld test specimen to the pressure part material or to a material with the same P-No. and Group No. as the pressure part.

(-b) The material is assigned to Curve A and is exempt from impact testing at the MDMT shown on the nameplate by Figure UCS-66 alone (i.e., MDMT reduction per Figure UCS-66.1 is not permitted), and both of the following apply:

(-1) The backing strip material specification minimum tensile strength shall not exceed that of the pressure part material specification.

(-2) The backing strip material specification minimum percent elongation shall be at least equal to that for the pressure part material specification.

(c) Carbon or low alloy steel having a carbon content of more than 0.35% by heat analysis shall not be used in welded construction or be shaped by oxygen cutting (except as provided in Part UF in this Division).

(d) Small parts used under the provisions of UG-11(a)(2) in welded construction shall be of good weldable quality.

UCS-6 STEEL PLATES

(a) Approved specifications for carbon and low alloy steel plates are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A (see UG-5).

(b) Steel plates conforming to SA-36, SA/CSA-G40.21 38W, and SA-283 Grades A, B, C, and D may be used for pressure parts in pressure vessels provided all of the following requirements are met:

(1) The vessels are not used to contain lethal substances, either liquid or gaseous.

(2) The material is not used in the construction of unfired steam boilers [see U-1(g)(1)].

(3) With the exception of flanges, flat bolted covers, and stiffening rings, the thickness of plates on which strength welding is applied does not exceed $^5/_8$ in. (16 mm).

(c) Except for local heating, such as cutting and welding, heating of SA-841 above 1,200°F (649°C) during fabrication is prohibited.

UCS-7 STEEL FORGINGS

Approved specifications for forgings of carbon and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A (see UG-6).

UCS-8 STEEL CASTINGS

Approved specifications for castings of carbon and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of weldable grade.

UCS-9 STEEL PIPE AND TUBES

Approved specifications for pipe and tubes of carbon and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values of the materials from which the pipe or tubes are manufactured are given in Section II, Part D, Subpart 1, Table 1A. Net allowable stress values for pipe or tubes of welded manufacture are given in Section II, Part D, Subpart 1, Table 1A.

UCS-10 BOLT MATERIALS

(a) Approved specifications for bolt materials of carbon steel and low alloy steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures (see UG-12) are given in Section II, Part D, Subpart 1, Table 3.

(b) Nonferrous and high alloy steel bolts, studs, and nuts may be used provided they are suitable for the application. They shall conform to the requirements of Part UNF or UHA, as applicable.

(19) UCS-11 NUTS AND WASHERS

(a) Except as otherwise provided in (b)(4) below, materials for nuts shall conform to SA-194, SA-563, or to the requirements for nuts in the specification for the bolting material with which they are to be used. Nuts of special design, such as wing nuts, may be made of any suitable wrought material listed in Table UCS-23 or Table UHA-23 and shall be either: hot or cold forged; or machined from hot-forged, hot-rolled, or cold-drawn bars. Washers may be made from any suitable material listed in Table UCS-23 and Table UHA-23.

(b) Materials for nuts and washers shall be selected as follows:

(1) Carbon steel nuts and carbon steel washers may be used with carbon steel bolts or studs.

(2) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used with alloy steel bolts or studs for metal temperatures not exceeding 900°F (480°C).

(3) Alloy steel nuts shall be used with alloy steel studs or bolts for metal temperatures exceeding 900°F (480°C). Washers, if used, shall be of alloy steel equivalent to the nut material.

(4) Nonferrous nuts and washers may be used with ferrous bolts and studs provided they are suitable for the application. Consideration shall be given to the differences in thermal expansion and possible corrosion resulting from the combination of dissimilar metals. Nonferrous nuts and washers shall conform to the requirements of UNF-13.

(c) Nuts shall be semifinished, chamfered, and trimmed. Nuts shall be threaded to Class 2B or finer tolerances according to ASME B1.1. For use with flanges conforming to the standards listed in UG-44(a), nuts shall conform at least to the dimensions given in ASME B18.2.2 for Heavy Series nuts. For use with connections designed in accordance with the rules in Mandatory Appendix 2, nuts may be of the ANSI Heavy Series, or they may be of other dimensions as permitted in (d) below.

(d) Nuts of special design or of dimensions other than ANSI Heavy Series may be used provided their strength is equal to that of the bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class of fit, thread shear, and radial thrust from threads [see U-2(g)].

UCS-12 BARS AND SHAPES

(a) Approved specifications for bar and shape materials of carbon steel are given in Table UCS-23. A tabulation of allowable stress values at different temperatures are given in Section II, Part D, Subpart 1, Table 1A.

(b) Bolt materials as described in UCS-10 may be used as bar materials.

(c) Parts made from bars, on which welding is done, shall be of material for which a P-Number for procedure qualification is given in Section IX, Table QW/QB-422 (see UW-5).

DESIGN

UCS-16 GENERAL

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of carbon and low alloy steel and shall be used in conjunction with the general requirements for *Design* in Subsection A and with the specific requirements for *Design* in Subsection B that pertain to the method of fabrication used.

UCS-19 WELDED JOINTS

When radiographic examination is required for butt-welded joints by UCS-57, Category A and B joints (see UW-3) shall be of Type No. (1) or No. (2) of Table UW-12.

UCS-23 MAXIMUM ALLOWABLE STRESS VALUES

Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other materials give the maximum allowable stress values at the temperature indicated for materials conforming to the specifications listed therein.[75] Values may be interpolated for intermediate temperatures. (See UG-23.) For vessels designed to operate at a temperature below −20°F (−29°C), the allowable stress values to be used in design shall not exceed those given in Section II, Part D, Subpart 1, Table 1A or Table 3 for 100°F (40°C).

UCS-27 SHELLS MADE FROM PIPE

(a) Shells of pressure vessels may be made from seamless pipe or tubing listed in Section II, Part D, Subpart 1, Table 1A, provided the material of the pipe is manufactured by the open-hearth, basic oxygen, or electric-furnace process.

(b) Shells of pressure vessels may be made from electric resistance-welded pipe or tubing listed in Section II, Part D, Subpart 1, Table 1A in nominal diameters up to 30 in. (750 mm)provided the material is manufactured by the open-hearth, basic oxygen, or electric-furnace process [see UG-16(d)].

Table UCS-23
Carbon and Low Alloy Steel

Spec. No.	Type/Grade
SA-36	...
SA-53	E/A, E/B, S/A, S/B
SA-105	...
SA-106	A, B, C
SA-135	A, B
SA-178	A, C
SA-179	...
SA-181	...
SA-182	FR, F1, F2, F3V, F3VCb, F5, F5a, F9, F11 Cl. 1 & 2, F12 Cl. 1 & 2, F21, F22 Cl. 1 & 3, F22V, F91
SA-192	...
SA-193	B5, B7, B7M, B16
SA-203	A, B, D, E, F
SA-204	A, B, C
SA-209	T1, T1a, T1b
SA-210	A-1, C
SA-213	T2, T5, T5b, T5c, T9, T11, T12, T17, T21, T22, T91
SA-214	...
SA-216	WCA, WCB, WCC
SA-217	C12, C5, WC1, WC4, WC5, WC6, WC9
SA-225	C
SA-234	WPB, WPC, WPR, WP1, WP5, WP9, WP11 Cl. 1, WP12 Cl. 1, WP22 Cl. 1
SA-250	T1, T1a, T1b
SA-266	1, 2, 3, 4
SA-283	A, B, C, D
SA-285	A, B, C
SA-299	A, B
SA-302	A, B, C, D
SA-307	A, B
SA-320	L7, L7A, L7M, L43
SA-325	1

Spec. No.	Type/Grade
SA-333	1, 3, 4, 6, 7, 9
SA-334	1, 3, 6, 7, 9
SA-335	P1, P2, P5, P5b, P5c, P9, P11, P12, P15, P21, P22, P91
SA-336	F1, F3V, F3VCb, F5, F5A, F9, F11 Cl. 2 & 3, F12, F21 Cl. 1 & 3, F22 Cl. 1 & 3, F22V, F91
SA-350	LF1, LF2, LF3, LF5, LF9
SA-352	LCB, LC1, LC2, LC3
SA-354	BC, BD
SA-369	FP1, FP2, FP5, FP9, FP11, FP12, FP21, FP22
SA-372	A; B; C; D; E Cl. 55, 65, & 70; F Cl. 55, 65, & 70; G Cl. 55, 65, & 70; H Cl. 55, 65, & 70; J Cl. 55, 65, 70, & 110; L; M Cl. 85 & 100
SA-387	2, 5, 11, 12, 21, 22, 91
SA-414	A, B, C, D, E, F, G
SA-420	WPL 3, WPL 6, WPL 9
SA-423	1, 2
SA-437	B4B, B4C
SA-449	...
SA-455	...
SA-487	1 Cl. A & B, 2 Cl. A & B, 4 Cl. A, 8 Cl. A
SA-508	1, 1A, 2 Cl. 1, 2 Cl. 2, 3 Cl. 1, 3 Cl. 2, 3V, 3VCb, 4N Cl. 3, 22 Cl. 3
SA-515	60, 65, 70
SA-516	55, 60, 65, 70
SA-524	I, II
SA-533	A Cl. 1 & 2, B Cl. 1 & 2, C Cl. 1 & 2, D Cl. 2, E Cl. 1 & 2
SA-537	Cl. 1, 2, & 3
SA-540	B21, B22, B23, B24, B24V
SA-541	1, 1A, 2 Cl. 1, 2 Cl. 2, 3 Cl. 1, 3 Cl. 2, 3V, 3VCb, 22 Cl. 3, 22V

Spec. No.	Type/Grade
SA-542	B Cl. 4, C Cl. 4a, D Cl. 4a, E Cl. 4a
SA-556	A2, B2, C2
SA-557	A2, B2, C2
SA-562	...
SA-574	4037, 4042, 4140, 4340, 5137M, 51B37M
SA-587	...
SA-612	...
SA-662	A, B, C
SA-675	45, 50, 55, 60, 65, 70
SA-727	...
SA-737	B, C
SA-738	A, B, C
SA-739	B11, B22
SA-765	I, II, III, IV
SA-832	21V, 22V, 23V
SA-836	...
SA-841	A Cl. 1, B Cl. 2
SA-1008	CS-A, CS-B
SA/AS 1548	PT430, PT460, PT490
SA/CSA-G40.21	38W, 44W, 50W
SA/EN 10028-2	P235GH, P265GH, P295GH, P355GH, 13CrMo4–5, 10CrMo9–10
SA/EN 10028-3	P275NH
SA/EN 10216-2	P235GH, P265GH, 16Mo3, 13CrMo4–5, 10CrMo9–10
SA/EN 10222-2	P280GH, P305GH, 13CrMo4–5, 11CrMo9–10
SA/GB 713	Q345R

GENERAL NOTE: Maximum allowable stress values in tension for the materials listed in the above table are contained in Section II, Part D, Subpart 1 (see UG-23).

UCS-28 THICKNESS OF SHELLS UNDER EXTERNAL PRESSURE

(a) Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figures in Section II, Part D, Subpart 3 and the temperature limits of UG-20(c).

(b) Corrugated shells subject to external pressure may be used in pressure vessels in accordance with Section I, PFT-19.

UCS-29 STIFFENING RINGS FOR SHELLS UNDER EXTERNAL PRESSURE

Rules covering the design of stiffening rings are given in UG-29.

UCS-30 ATTACHMENT OF STIFFENING RINGS TO SHELL

Rules covering the attachment of stiffening rings are given in UG-30.

(19) UCS-33 FORMED HEADS, PRESSURE ON CONVEX SIDE

Ellipsoidal, torispherical, hemispherical, and conical heads having pressure on the convex side (minus heads) shall be designed by the rules of UG-33, using the applicable figures in Section II, Part D, Subpart 3.

(19) UCS-56 REQUIREMENTS FOR POSTWELD HEAT TREATMENT

(a) Before applying the detailed requirements and exemptions in these paragraphs, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all the essential variables of Section IX including conditions of postweld heat treatment or lack of postweld heat treatment and including other restrictions listed below.

Except as otherwise specifically provided in the notes to Tables UCS-56-1 through UCS-56-11 and Table UCS-56.1, all welds in pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than specified in those Tables when the nominal thickness, as defined in UW-40(f), including corrosion allowance, exceeds the limits in those Tables. The exemptions provided in Tables UCS-56-1 through UCS-56-11 or Table UCS-56.1 are not permitted when postweld heat treatment is a service requirement as set forth in UCS-68, when welding ferritic materials greater than $^1/_8$ in. (3 mm) thick with the electron beam welding process, or when welding P-No. 3, P-No. 4, P-Nos. 5A, 5B, and 5C, P-No. 10, and P-No. 15E materials of any thickness using the inertia and continuous drive friction welding processes. Electroslag welds in ferritic materials over $1^1/_2$ in. (38 mm) thickness at the joint shall be given a grain refining (austenitizing) heat treatment. Electrogas welds in ferritic materials with any single pass greater than $1^1/_2$ in. (38 mm) shall be given a grain refining (austenitizing) heat treatment. For P-No. 1 materials only, the heating and cooling rate restrictions of (d)(2) and (d)(5) below do not apply when the heat treatment following welding is in the austenitizing range.

The materials in Tables UCS-56-1 through UCS-56-11 are listed in accordance with Section IX P-Number material groupings of Section IX, Table QW/QB-422 and also listed in Table UCS-23. When there is a conflict in P-Number or Group Number, the numbers in Section IX govern.

(b) Except where prohibited in Tables UCS-56-1 through UCS-56-11, holding temperatures and/or holding times in excess of the minimum values given in Tables UCS-56-1 through UCS-56-11 may be used. Intermediate postweld heat treatments need not conform to the requirements of Tables UCS-56-1 through UCS-56-11. The holding time at temperature as specified in Tables UCS-56-1 through UCS-56-11 need not be continuous. It may be an accumulation of time of multiple postweld heat treatment cycles.

(c) When pressure parts of two different P-Number groups are joined by welding, engineering judgment shall be applied when selecting the postweld heat treatment temperature and holding time to produce material properties suitable for the intended service. Alternatives such as welding with buttering as described in Section IX, QW-283 may be considered. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control.

(d) The operation of postweld heat treatment shall be carried out by one of the procedures given in UW-40 in accordance with the following requirements:

(1) The temperature of the furnace shall not exceed 800°F (425°C) at the time the vessel or part is placed in it.

(2) Above 800°F (425°C), the rate[76] of heating shall be not more than 400°F/hr (222°C/h) divided by the maximum metal thickness of the shell or head plate in inches, but in no case more than 400°F/hr (222°C/h). During the heating period there shall not be a greater variation in temperature throughout the portion of the vessel being heated than 250°F (140°C) within any 15 ft (4.6 m) interval.

(3) The vessel or vessel part shall be held at or above the temperature specified in Tables UCS-56-1 through UCS-56-11 or Table UCS-56.1 for the period of time specified in the Tables. During the holding period, there shall not be a greater difference than 150°F (83°C) between the highest and lowest temperature throughout the portion of the vessel being heated, except where the range is further limited in Tables UCS-56-1 through UCS-56-11.

(4) During the heating and holding periods, the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface of the vessel. The furnace shall be of such design as to prevent direct impingement of the flame on the vessel.

(5) Above 800°F (425°C), cooling shall be done in a closed furnace or cooling chamber at a rate[76] not greater than 500°F/hr (280°C/h) divided by the maximum metal thickness of the shell or head plate in inches, but in no case more than 500°F/hr (280°C/h). At temperatures above 800°F (425°C), temperature variations within the heated portion during the cooling phase shall not be greater than 250°F (140°C) within any 15 ft (4.6 m) interval. From 800°F (425°C), the vessel may be cooled in still air.

(e) Except as permitted in (f) below, vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after welded repairs have been made.

(f) Weld repairs to P-No. 1 Group Nos. 1, 2, and 3 materials and to P-No. 3 Group Nos. 1, 2, and 3 materials and to the weld metals used to join these materials may be made after the final PWHT but prior to the final hydrostatic test, without additional PWHT, provided that PWHT is not required as a service requirement in accordance with UW-2(a), except for the exemptions in Tables UCS-56-1 through UCS-56-11, or as a service requirement in accordance with UCS-68. The welded repairs shall meet the requirements of (1) through (6) below. These requirements do not apply when the welded repairs are minor restorations of the material surface, such as those required after removal of construction fixtures, and provided that the surface is not exposed to the vessel contents.

(1) The Manufacturer shall give prior notification of the repair to the user or to his designated agent and shall not proceed until acceptance has been obtained. Such repairs shall be recorded on the Data Report.

(2) The total repair depth shall not exceed $1^1/_2$ in. (38 mm) for P-No. 1 Group Nos. 1, 2, and 3 materials and $^5/_8$ in. (16 mm) for P-No. 3 Group Nos. 1, 2, and 3 materials. The total depth of a weld repair shall be taken as the sum of the depths for repairs made from both sides of a weld at a given location.

(3) After removal of the defect, the groove shall be examined, using either the magnetic particle or the liquid penetrant examination methods, in accordance with Mandatory Appendix 6 for MT and Mandatory Appendix 8 for PT.

(4) In addition to the requirements of Section IX for qualification of Welding Procedure Specifications for groove welds, the following requirements shall apply:

(-a) The weld metal shall be deposited by the manual shielded metal arc process using low hydrogen electrodes. The electrodes shall be properly conditioned in accordance with Section II, Part C, SFA-5.1, Annex A, A6.11; and SFA-5.5, Annex A, A6.12. The maximum bead width shall be four times the electrode core diameter.

(-b) For P-No. 1 Group Nos. 1, 2, and 3 materials, the repair area shall be preheated and maintained at a minimum temperature of 200°F (95°C) during welding.

(-c) For P-No. 3 Group Nos. 1, 2, and 3 materials, the repair weld method shall be limited to the half bead weld repair and weld temper bead reinforcement technique. The repair area 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). The initial layer of weld metal shall be deposited over the entire area using $^1/_8$ in. (3 mm) maximum diameter electrodes. Approximately one-half the thickness of this layer shall be removed by grinding before depositing subsequent layers. The subsequent weld layers shall be deposited using $^5/_{32}$ in. (4 mm) maximum diameter electrodes in such a manner as to assure tempering of the prior weld beads and their heat-affected zones. A final temper bead weld shall be applied to a level above the surface being repaired without contacting the base material but close enough to the edge of the underlying weld bead to assure tempering of the base material heat-affected zone. After completing all welding, the repair area shall be maintained at a temperature of 400°F to 500°F (205°C to 260°C) for a minimum period of 4 hr. The final temper bead reinforcement layer shall be removed substantially flush with the surface of the base material.

(5) After the finished repair weld has reached ambient temperature, it shall be inspected using the same nondestructive examination that was used in (3) above, except that for P-No. 3, Group No. 3 materials, the examination shall be made after the material has been at ambient temperature for a minimum period of 48 hr to determine the presence of possible delayed cracking of the weld. If the examination is by the magnetic particle method, only the alternating current yoke type is acceptable. In addition, welded repairs greater than $^3/_8$ in. (10 mm) deep in materials and in welds that are required to be radiographed by the rules of this Division, shall be radiographically examined to the requirements of UW-51.

(6) The vessel shall be hydrostatically tested after making the welded repair.

(g) Capacitor discharge or electric resistance welding may be used for attaching bare-wire thermocouples, without subsequent postweld heat treatment, provided the energy output for welding is limited to 125 W-sec max. and any requirements specified in the applicable notes as found in Tables UCS-56-1 through UCS-56-11 shall apply. A welding procedure specification shall be prepared, and the content shall describe, as a minimum, the capacitor discharge equipment, the combination of materials to be joined, and the technique of application. Qualification of the welding procedure is not required.

(19)

Table UCS-56-1
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 1

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]		
		Up to 2 in. (50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
P-No. 1 Gr. Nos. 1, 2, 3	1,100 (595)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)
Gr. No. 4	NA	None	None	None

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56.1.

(b) Postweld heat treatment is mandatory under the following conditions:

(1) for welded joints over $1\frac{1}{2}$ in. (38 mm) nominal thickness;

(2) for welded joints over $1\frac{1}{4}$ in. (32 mm) nominal thickness through $1\frac{1}{2}$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (95°C) during welding. This preheat need not be applied to SA-841 Grades A and B, provided that the carbon content and carbon equivalent (CE) for the plate material, by heat analysis, do not exceed 0.14% and 0.40%, respectively, where

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

(3) for welded joints of all thicknesses if required by UW-2, except postweld heat treatment is not mandatory under the conditions specified below:

(a) for groove welds not over $\frac{1}{2}$ in. (13 mm) size and fillet welds with a throat not over $\frac{1}{2}$ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness, and preheat to a minimum temperature of 200°F (95°C) is applied;

(b) for groove welds not over $\frac{1}{2}$ in. (13 mm) in size or fillet welds with a throat thickness of $\frac{1}{2}$ in. (13 mm) or less that attach tubes to a tubesheet when the tube diameter does not exceed 2 in. (50 mm). A preheat of 200°F (95°C) minimum must be applied when the carbon content of the tubesheet exceeds 0.22%.

(c) for groove welds not over $\frac{1}{2}$ in. (13 mm) in size or fillet welds with a throat thickness of $\frac{1}{2}$ in. (13 mm) or less used for attaching nonpressure parts to pressure parts. When the thickness of the pressure part exceeds $1\frac{1}{4}$ in. (32 mm), preheat to a minimum temperature of 200°F (95°C) shall be applied prior to welding each pass;

(d) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of the pressure part exceeds $1\frac{1}{4}$ in. (32 mm);

(e) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see UCL-34). When the thickness of the pressure part exceeds $1\frac{1}{4}$ in. (32 mm), preheat to a minimum temperature of 200°F (95°C) shall be maintained during application of the first weld layer.

(c) NA = not applicable

Table UCS-56-2
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 3

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]		
		Up to 2 in. (50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
P-No. 3 Gr. Nos. 1, 2, 3	1,100 (595)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56.1.

(b) Postweld heat treatment is mandatory on P-No. 3 Gr. No. 3 material in all thicknesses.

(c) Except for the exemptions in General Note (d), postweld heat treatment is mandatory under the following conditions:

(1) on P-No. 3 Gr. No. 1 and P-No. 3 Gr. No. 2 over $^5/_8$ in. (16 mm) nominal thickness. For these materials, postweld heat treatment is mandatory on material up to and including $^5/_8$ in. (16 mm) nominal thickness unless a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld.

(2) on material in all thicknesses if required by UW-2.

(d) For welding connections and attachments to pressure parts, postweld heat treatment is not mandatory under the conditions specified below:

(1) for attaching to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits) or nonpressure parts with groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds that have a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(2) for circumferential butt welds in pipe or tube where the pipe or tube have both a nominal wall thickness of $^1/_2$ in. (13 mm) or less and a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);

(3) for studs welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is applied;

(4) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see UCL-34) when welded to pressure parts which have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is maintained during application of the first layer;

(5) for tubes or pressure-retaining handhole and inspection plugs or fittings that are secured by mechanical means (tube expansion, shoulder construction, machine threads, etc.) and seal welded, provided the seal weld has a throat thickness of $^3/_8$ in. (10 mm) or less, and preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of either part exceeds $^5/_8$ in. (16 mm).

Table UCS-56-3
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 4

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)] Up to 2 in. (50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
P-No. 4 Gr. Nos. 1, 2	1,200 (650)	1 hr/in. (25 mm), 15 min minimum	1 hr/in. (25 mm)	5 hr plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)

GENERAL NOTES:
(a) Except for exemptions in General Note (b), postweld heat treatment is mandatory under the following conditions:
(1) on material of all thicknesses if required by UW-2;
(2) on all other P-No. 4 Gr. Nos. 1 and 2 materials.
(b) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for circumferential butt welds in pipe or tube of P-No. 4 materials where the pipe or tubes comply with all of the following conditions:
(a) a maximum nominal thickness of $^5/_8$ in. (16 mm);
(b) a maximum specified carbon content of not more than 0.15% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);
(c) a minimum preheat of 250°F (120°C).
(2) for P-No. 4 pipe or tube materials meeting the requirements of (1)(a) and (1)(b) above, having nonpressure attachments fillet welded to them, provided:
(a) the fillet welds have a maximum throat thickness of $^1/_2$ in. (13 mm);
(b) a minimum preheat temperature of 250°F (120°C) is applied.
(3) for P-No. 4 pipe or tube materials meeting the requirements of (1)(a) and (1)(b) above, having studs welded to them, a minimum preheat temperature of 250°F (120°C) is applied.
(4) for P-No. 4 pipe or tube materials meeting the requirements of (1)(a) and (1)(b) above, having extended heat absorbing fins electrically resistance welded to them, provided:
(a) the fins have a maximum thickness of $^1/_8$ in. (3 mm);
(b) prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum pipe or tube wall thickness.
(5) for tubes or pressure-retaining handhole and inspection plugs or fittings that are secured by mechanical means (tube expansion, shoulder construction, machine threads, etc.) and seal welded, provided the seal weld has a throat thickness of $^3/_8$ in. (10 mm) or less, and preheat to a minimum temperature of 250°F (120°C) is applied when the thickness of either part exceeds $^5/_8$ in. (16 mm).

Table UCS-56-4
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-Nos. 5A, 5B, and 5C

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]		
		Up to 2 in. (50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
P-Nos. 5A, 5B Gr. No. 1, and 5C Gr. No. 1	1,250 (675)	1 hr/in. (25 mm), 15 min minimum	1 hr/in. (25 mm)	5 hr plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)

GENERAL NOTES:

(a) Except for exemptions in General Notes (b) and (d), postweld heat treatment is mandatory under all conditions.

(b) Postweld heat treatment is not mandatory under the following conditions:

(1) for circumferential butt welds in pipe or tube where the pipe or tubes comply with all of the following conditions:

(a) a maximum specified chromium content of 3.00%;

(b) a maximum nominal thickness of $^5/_8$ in. (16 mm);

(c) a maximum specified carbon content of not more than 0.15% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);

(d) a minimum preheat of 300°F (150°C) is applied.

(2) for pipe or tube materials meeting the requirements of (1)(a), (1)(b), and (1)(c) having nonpressure attachments fillet welded to them, provided:

(a) the fillet welds have a maximum throat thickness of $^1/_2$ in. (13 mm);

(b) a minimum preheat temperature of 300°F (150°C) is applied.

(3) for pipe or tube materials meeting the requirements of (1)(a), (1)(b), and (1)(c) having studs welded to them, provided a minimum preheat temperature of 300°F (150°C) is applied.

(4) for pipe or tube materials meeting the requirements of (1)(a) and (1)(b) above, having extended heat absorbing fins electrically resistance welded to them, provided:

(a) the fins have a maximum thickness of $^1/_8$ in. (3 mm);

(b) prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum pipe or tube wall thickness.

(5) for tubes or pressure-retaining handhole and inspection plugs or fittings in P-No. 5A materials with a specified maximum chromium content of 6% that are secured by mechanical means (tube expansion, shoulder construction, machine threads, etc.) and seal welded, provided the seal weld has a throat thickness of $^3/_8$ in. (10 mm) or less, and preheat to a minimum temperature of 300°F (150°C) is applied when the thickness of either part exceeds $^5/_8$ in. (16 mm).

(c) When it is impractical to postweld heat P-Nos. 5A, 5B Gr. No. 1, and 5C Gr. No. 1 materials at the temperature specified in this Table, it is permissible to perform the postweld heat treatment at 1,200°F (650°C) minimum provided that, for material up to 2 in. (50 mm) nominal thickness, the holding time is increased to the greater of 4 hr minimum or 4 hr/in. (25 mm) of thickness; for thickness over 2 in. (50 mm), the specified holding times are multiplied by 4. The requirements of UCS-85 must be accommodated in this reduction in postweld heat treatment.

(d) Postweld heat treatment is not mandatory for attaching bare-wire thermocouples by capacitor discharge welding or electric resistance welding, provided

(1) the requirements of UCS-56(g) are met

(2) the maximum carbon content of the base material is restricted to 0.15%

(3) the minimum wall thickness is 0.20 in. (5 mm)

Table UCS-56-5
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 9A

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]
P-No. 9A Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min/in. (25 mm) for thickness over 1 in. (25 mm)

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures [1,000°F (540°C) minimum] for longer periods of time in accordance with Table UCS-56.1.

(b) Except for exemptions in General Note (c), postweld heat treatment is mandatory under the following conditions:

(1) on material over 5/8 in. (16 mm) nominal thickness. For material up to and including 5/8 in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld.

(2) on material of all thicknesses if required by UW-2.

(c) Postweld heat treatment is not mandatory under conditions specified below:

(1) for circumferential butt welds in pipe or tubes where the pipe or tubes comply with all the following conditions:

(a) a maximum nominal outside diameter of 4 in. (100 mm) (DN 100);

(b) a maximum thickness of 1/2 in. (13 mm);

(c) a maximum specified carbon content of not more than 0.15% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits);

(d) a minimum preheat of 250°F (120°C).

(2) for pipe or tube materials meeting the requirements of (1)(a), (1)(b), and (1)(c) above, having attachments fillet welded to them, provided:

(a) the fillet welds have a throat thickness of 1/2 in. (13 mm) or less;

(b) the material is preheated to 250°F (120°C) minimum. A lower preheating temperature may be used, provided specifically controlled procedures necessary to produce sound welded joints are used. Such procedures shall include but shall not be limited to the following:

(-1) The throat thickness of fillet welds shall be 1/2 in. (13 mm) or less.

(-2) The maximum continuous length of fillet welds shall be not over 4 in. (100 mm).

(-3) The thickness of the test plate used in making the welding procedure qualification of Section IX shall not be less than that of the material to be welded.

(3) for attaching nonpressure parts to pressure parts with groove welds not over 1/2 in. (13 mm) in size or fillet welds that have a throat thickness of 1/2 in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(4) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(5) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see UCL-34), provided preheat to a minimum temperature of 200°F (95°C) is maintained during application of the first layer.

(d) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-6
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 9B

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]
P-No. 9B Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min/in. (25 mm) for thickness over 1 in. (25 mm)

GENERAL NOTES:
(a) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures [1,000°F (540°C) minimum] for longer periods of time in accordance with Table UCS-56.1.
(b) The holding temperature for postweld heat treatment shall not exceed 1,175°F (635°C).
(c) Except for exemptions in General Note (d), postweld heat treatment is mandatory under the following conditions:
(1) on material over $^{5}/_{8}$ in. (16 mm) nominal thickness. For material up to and including $^{5}/_{8}$ in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld.
(2) on material of all thicknesses if required by UW-2.
(d) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for attaching nonpressure parts to pressure parts with groove welds not over $^{1}/_{2}$ in. (13 mm) in size or fillet welds that have a throat thickness of $^{1}/_{2}$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;
(2) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied;
(3) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see UCL-34), provided preheat to a minimum temperature of 200°F (95°C) is maintained during application of the first layer.
(e) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-7
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10A

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]
P-No. 10A Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min/in. (25 mm) for thickness over 1 in. (25 mm)

GENERAL NOTES:

(a) See below.

(1) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56.1.

(2) Consideration should be given for possible embrittlement of materials containing up to 0.15% vanadium when postweld heat treating at the minimum temperature and at lower temperature for longer holding times.

(b) Except for exemptions in General Note (c), postweld heat treatment is mandatory under the following conditions:

(1) on all thicknesses of SA-487 Class 1Q material;

(2) on all other P-No. 10A materials over $^5/_8$ in. (16 mm) nominal thickness. For these materials up to and including $^5/_8$ in. (16 mm) nominal thickness, postweld heat treatment is mandatory unless a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld.

(3) on material of all thicknesses if required by UW-2.

(c) Postweld heat treatment is not mandatory under the conditions specified below:

(1) for attaching to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits) or nonpressure parts with groove weld not over $^1/_2$ in. (13 mm) in size or fillet welds having a throat thickness of $^1/_2$ in. (13 mm) or less, provided preheat to a minimum temperature of 200°F (95°C) is applied;

(2) for circumferential butt welds in pipes or tube where the pipe or tube has both a nominal wall thickness of $^1/_2$ in. (13 mm) or less and a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is applied;

(3) for studs welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is applied;

(4) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see UCL-34) when welded to pressure parts that have a specified maximum carbon content of not more than 0.25% (SA material specification carbon content, except when further limited by the purchaser to a value within the specification limits), provided preheat to a minimum temperature of 200°F (95°C) is maintained during application of the first layer.

(d) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-8
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10B

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]
P-No. 10B Gr. No. 1	1,100 (595)	1 hr minimum, plus 15 min/in. (25 mm) for thickness over 1 in. (25 mm)

GENERAL NOTES:

(a) Postweld heat treatment is mandatory for P-No. 10B materials for all thicknesses.

(b) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

Table UCS-56-9
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 10C

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]
P-No. 10C Gr. No. 1	1,000 (540)	1 hr minimum, plus 15 min/in. (25 mm) for thickness over 1 in. (25 mm)

GENERAL NOTES:
(a) When it is impractical to postweld heat treat at the temperatures specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56.1.
(b) Except for exemptions in General Note (c), postweld heat treatment is mandatory under the following conditions:
(1) for material over $1^1/_2$ in. (38 mm) nominal thickness. Postweld heat treatment is mandatory on materials over $1^1/_4$ in. (32 mm) nominal thickness through $1^1/_2$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (95°C) during welding.
(2) on material of all thicknesses if required by UW-2.
(c) Postweld heat treatment is not mandatory under the conditions specified below:
(1) for groove welds not over $^1/_2$ in. (13 mm) in size and fillet welds with throat not over $^1/_2$ in. (13 mm) that attach nozzle connections that have a finished inside diameter not greater than 2 in. (50 mm), provided the connections do not form ligaments that require an increase in shell or head thickness and preheat to a minimum temperature of 200°F (95°C) is applied;
(2) for groove welds not over $^1/_2$ in. (13 mm) in size or fillet welds having throat thickness of $^1/_2$ in. (13 mm) or less used for attaching nonpressure parts to pressure parts and preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of the pressure part exceeds $1^1/_4$ in. (32 mm);
(3) for studs welded to pressure parts, provided preheat to a minimum temperature of 200°F (95°C) is applied when the thickness of the pressure part exceeds $1^1/_4$ in. (32 mm);
(4) for corrosion resistant weld metal overlay cladding or for welds attaching corrosion resistant applied lining (see UCL-34), provided preheat to a minimum temperature of 200°F (95°C) is maintained during application of the first layer when the thickness of the pressure part exceeds $1^1/_4$ in. (32 mm).
(d) When the heating rate is less than 50°F/hr (28°C/h) between 800°F (425°C) and the holding temperature, the additional 15 min/in. (25 mm) holding time is not required. Additionally, where the Manufacturer can provide evidence that the minimum temperature has been achieved throughout the thickness, the additional 15 min/in. (25 mm) holding time is not required.

(19)

Table UCS-56-11
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 15E

Material	Minimum Holding Temperature, °F (°C) [Note (1)] and [Note (2)]	Maximum Holding Temperature, °F (°C)	Minimum Holding Time at Normal Temperature for Weld Thickness (Nominal)	
			Up to 5 in. (125 mm)	Over 5 in. (125 mm)
P-No. 15E Group No. 1	1,300 (705)	[Note (3)] and [Note (4)]	1 hr/in. (2 min/mm), 30 min minimum	5 hr plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)

GENERAL NOTES:

(a) Postweld heat treatment is not mandatory for electric resistance welds used to attach extended heat-absorbing fins to pipe and tube materials, provided the following requirements are met:

(1) a maximum pipe or tube size of NPS 4 (DN 100)

(2) a maximum specified carbon content (SA material specification carbon content, except when further limited by the Purchaser to a value within the specification limits) of not more than 0.15%

(3) a maximum fin thickness of $\frac{1}{8}$ in. (3 mm)

(4) prior to using the welding procedure, the Manufacturer shall demonstrate that the heat-affected zone does not encroach upon the minimum wall thickness

(b) Postweld heat treatment is not mandatory for attaching bare-wire thermocouples by capacitor discharge welding or electric resistance welding, provided

(1) the requirements of UCS-56(g) are met

(2) the maximum carbon content of the base material is restricted to 0.15%

(3) the minimum wall thickness is 0.20 in. (5 mm)

NOTES:

(1) If the nominal weld thickness is ≤ 0.5 in. (13 mm), the minimum holding temperature is 1,250°F (675°C).

(2) For dissimilar metal welds (i.e., welds made between a P-No. 15E Group No. 1 and another lower chromium ferritic, austenitic, or nickel-based steel), if filler metal chromium content is less than 3.0% or if the filler metal is nickel-based or austenitic, the minimum holding temperature shall be 1,300°F (705°C).

(3) For welds made with matching Grade 91 filler metal (e.g., AWS A.5.5 E90xx-B91, ISO EN CrMo91), the maximum holding temperature shall be determined as follows:

(a) If the Ni + Mn content of the filler metal is less than or equal to 1.0%, the maximum PWHT temperature shall be 1,455°F (790°C).

(b) If the Ni + Mn content of the filler metal is greater than 1.0% but less than or equal to 1.2%, the maximum PWHT temperature shall be 1,435°F (780°C).

(c) If the Ni + Mn content of the filler metal is greater than 1.2%, the maximum PWHT temperature shall be at least 20°F (10°C) below the lower critical transformation temperature (Ac1) as determined by measurement of that temperature for the specific heat (or heats) of filler metal to be used in accordance with ASTM A1033; in such case the following additional restrictions will apply:

(1) The Ac1 temperature of the filler metal as measured in accordance with ASTM A1033 shall be included in the Manufacturer's Construction Records.

(2) The maximum operating temperature for any vessel constructed using filler metal with a Ni + Mn content in excess of 1.2% shall be 975°F (525°C).

The lower transformation temperature for matching filler material is affected by alloy content, primarily the total of Ni + Mn. The maximum holding temperature has been set to avoid heat treatment in the intercritical zone.

(d) If multiple welds made with matching Grade 91 filler metal in a pressure part or pressure vessel are to be postweld heat treated at the same time, the maximum PWHT temperature shall be determined based on the weld with the highest Ni + Mn content.

(4) If a portion of the component is heated above the heat treatment temperature allowed above, one of the following actions shall be performed:

(a) The component in its entirety must be renormalized and tempered.

(b) If the maximum holding temperature in Note (3)(b) above is exceeded, but does not exceed 1,470°F (800°C), the weld metal shall be removed and replaced.

(c) The portion of the component heated above 1,470°F (800°C) and at least 3 in. (75 mm) on either side of the overheated zone must be removed and be renormalized and tempered or replaced.

(d) The allowable stress shall be that for Grade 9 material (i.e., SA-213-T9, SA-335-P9, or equivalent product specification) at the design temperature, provided that the portion of the component heated to a temperature greater than that allowed above is reheat treated within the temperature range specified above. To apply the provisions of this paragraph, the Manufacturer shall have qualified a WPS with representative test specimens that accurately simulate the thermal history of the production part. Specifically, the qualification specimens shall first be heat treated at a similar temperature for a similar time that violates the maximum holding temperature limit and then shall receive a final heat treatment for the required time within the temperature range specified by this Table. The use of this provision shall be noted in the Manufacturer's Data Report.

Table UCS-56.1
Alternative Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels

Decrease in Temperature Below Minimum Specified Temperature, °F (°C)	Minimum Holding Time [Note (1)] at Decreased Temperature, hr	Notes
50 (28)	2	...
100 (56)	4	...
150 (83)	10	(2)
200 (111)	20	(2)

GENERAL NOTE: Applicable only when permitted in Tables UCS-56-1 through UCS-56-11.

NOTES:
(1) Minimum holding time for 1 in. (25 mm) thickness or less. Add 15 min per inch (25 mm) of thickness for thicknesses greater than 1 in. (25 mm).
(2) These lower postweld heat treatment temperatures permitted only for P-No. 1 Gr. Nos. 1 and 2 materials.

UCS-57 RADIOGRAPHIC EXAMINATION

In addition to the requirements of UW-11, complete radiographic examination is required for each butt-welded joint at which the thinner of the plate or vessel wall thicknesses at the welded joint exceeds the thickness limit above which full radiography is required in Table UCS-57.

Table UCS-57
Thickness Above Which Full Radiographic Examination of Butt-Welded Joints Is Mandatory

P-No. and Group No. Classification of Material	Nominal Thickness Above Which Butt-Welded Joints Shall Be Fully Radiographed, in. (mm)
1 Gr. 1, 2, 3	$1^1/_4$ (32)
3 Gr. 1, 2, 3	$^3/_4$ (19)
4 Gr. 1, 2	$^5/_8$ (16)
5A Gr. 1, 2	0 (0)
5B Gr. 1	0 (0)
5C Gr. 1	0 (0)
15E, Gr. 1	0 (0)
9A Gr. 1	$^5/_8$ (16)
9B Gr. 1	$^5/_8$ (16)
10A Gr. 1	$^3/_4$ (19)
10B Gr. 1	$^5/_8$ (16)
10C Gr. 1	$^5/_8$ (16)

LOW TEMPERATURE OPERATION

UCS-65 SCOPE

The following paragraphs contain requirements for vessels and vessel parts constructed of carbon and low alloy steels with respect to minimum design metal temperatures.

UCS-66 MATERIALS (19)

(a) Unless exempted by the rules of UG-20(f) or other rules of this Division, Figure UCS-66 shall be used to establish impact testing exemptions for steels listed in Part UCS. When Figure UCS-66 is used, impact testing is required for a combination of minimum design metal temperature (see UG-20) and governing thickness (as defined below) that is below the curve assigned to the subject material. If a minimum design metal temperature and governing thickness combination is on or above the curve, impact testing is not required by the rules of this Division, except as required by (j) below and UCS-67(a)(3) for weld metal. Components, such as shells, heads, nozzles, manways, reinforcing pads, flanges, tubesheets, flat cover plates, backing strips which remain in place, and attachments which are essential to the structural integrity of the vessel when welded to pressure-retaining components, shall be treated as separate components. Each component shall be evaluated for impact test requirements based on its individual material classification, governing thickness as defined in (1) and (2) below, and the minimum design metal temperature.

(1) The following governing thickness definitions apply when using Figure UCS-66:

(-a) Excluding castings, the governing thickness t_g of a welded part is as follows:

(-1) for butt joints except those in flat heads and tubesheets, the nominal thickness of the thickest welded joint [see Figure UCS-66.3, sketch (a)].

(-2) for corner, fillet, or lap-welded joints, including attachments as defined above, the thinner of the two parts joined.

(-3) for flat heads or tubesheets, the larger of (-2) above or the flat component thickness divided by 4.

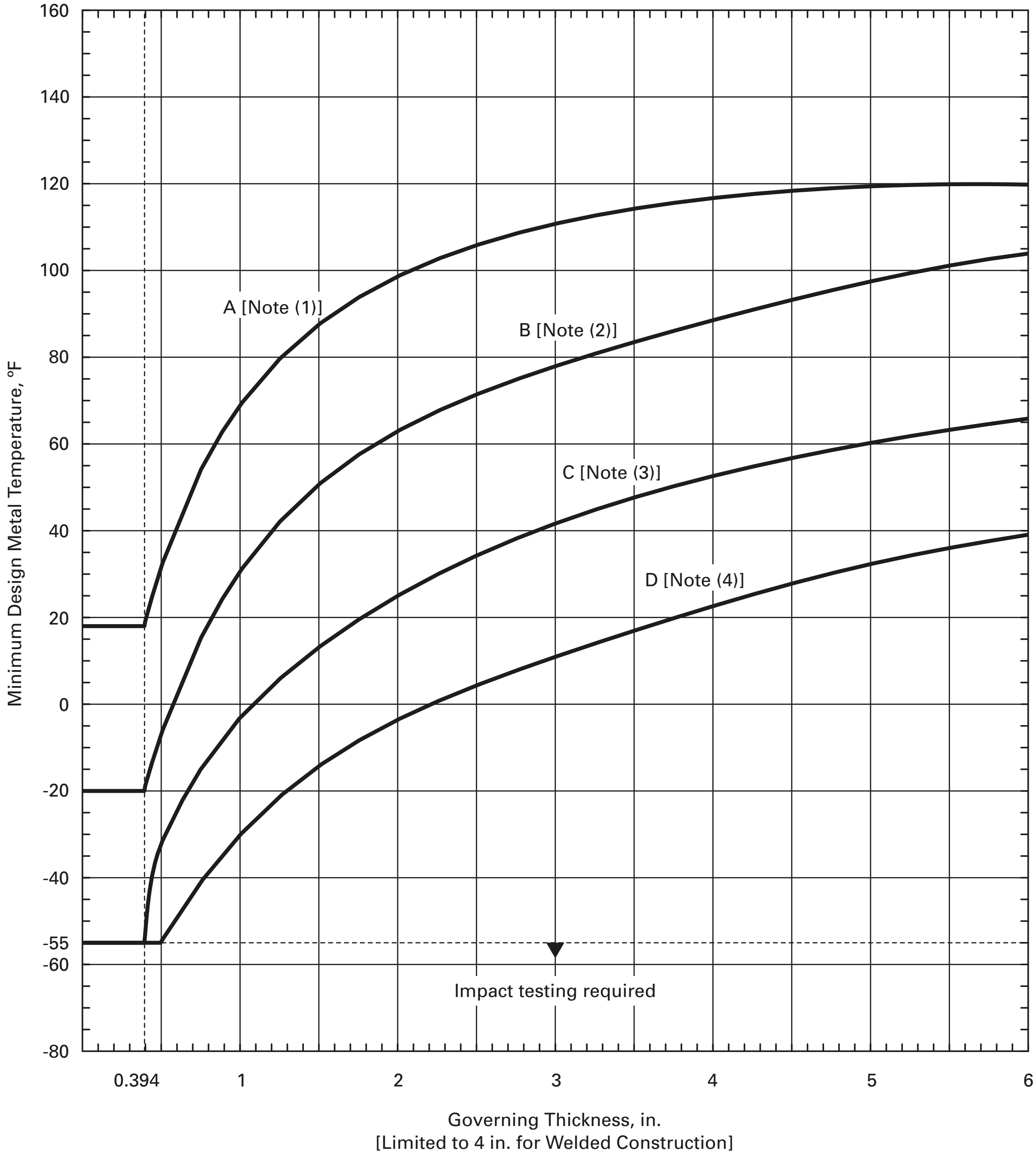
(-4) for welded assemblies comprised of more than two components (e.g., nozzle-to-shell joint with reinforcing pad), the governing thickness and permissible minimum design metal temperature of each of the individual welded joints of the assembly shall be determined, and the warmest of the minimum design metal temperatures shall be used as the permissible minimum design metal temperature of the welded assembly. [See Figure UCS-66.3, sketch (b).]

(-5) if the governing thickness at any welded joint exceeds 4 in. (100 mm) and the minimum design metal temperature is colder than 120°F (50°C), impact tested material shall be used.

(-b) The governing thickness of a casting shall be its largest nominal thickness.

(19)

Figure UCS-66
Impact Test Exemption Curves



GENERAL NOTES:
(a) Tabular values for this figure are provided in Table UCS-66.
(b) See UCS-66(a).
(c) For bolting and nuts, the following impact test exemption temperatures shall apply:

Bolting

Spec. No.	Grade	Diameter, in. (mm)	Impact Test Exemption Temperature, °F (°C)
SA-193	B5	Up to 4 (100), incl.	−20 (−30)
SA-193	B7	Up to $2^1/_2$ in. (64), incl.	−55 (−48)
SA-193	...	Over $2^1/_2$ (64) to 7 (175), incl.	−40 (−40)
SA-193	B7M	Up to $2^1/_2$ (64), incl.	−55 (−48)

Figure UCS-66 Impact Test Exemption Curves (Cont'd)

GENERAL NOTES (CONT'D):

Table continued

Bolting			
Spec. No.	**Grade**	**Diameter, in. (mm)**	**Impact Test Exemption Temperature, °F (°C)**
SA-193	B16	Up to 7 (175), incl.	−20 (−30)
SA-307	B	All	−20 (−30)
SA-320	L7, L7A, L7M	Up to $2^1/_2$ (64), incl.	See General Note (c) of Figure UG-84.1
SA-320	L43	Up to 1 (25), incl.	See General Note (c) of Figure UG-84.1
SA-325	1	$^1/_2$ (13) to $1^1/_2$ (38)	−20 (−30)
SA-354	BC	Up to 4 (100), incl.	0 (−18)
SA-354	BD	Up to 4 (100), incl.	+20 (−7)
SA-437	B4B, B4C	All diameters	See General Note (c) of Figure UG-84.1
SA-449	...	Up to 3 (75), incl.	−20 (−30)
SA-540	B21 Cl. All	All	Impact test required
SA-540	B22 Cl. 3	Up to 4 (100), incl.	Impact test required
SA-540	B23 Cl. 1, 2	All	Impact test required
SA-540	B23 Cl. 3, 4	Up to 6 (150), incl.	See General Note (c) of Figure UG-84.1
SA-540	B23 Cl. 3, 4	Over 6 (150) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B23 Cl. 5	Up to 8 (200), incl.	See General Note (c) of Figure UG-84.1
SA-540	B23 Cl. 5	Over 8 (200) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B24 Cl. 1	Up to 6 (150), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24 Cl. 1	Over 6 (150) to 8 (200), incl.	Impact test required
SA-540	B24 Cl. 2	Up to 7 (175), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24 Cl. 2	Over 7 (175) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B24 Cl. 3, 4	Up to 8 (200), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24 Cl. 3, 4	Over 8 (200) to $9^1/_2$ (240), incl.	Impact test required
SA-540	B24 Cl. 5	Up to $9^1/_2$ (240), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24V Cl. 3	All	See General Note (c) of Figure UG-84.1

Nuts		
Spec. No.	**Grade**	**Impact Test Exemption Temperature, °F (°C)**
SA-194	2, 2H, 2HM, 3, 4, 7, 7M, and 16	−55 (−48)
SA-540	B21/B22/B23/B24/B24V	−55 (−48)

(d) When no class or grade is shown, all classes or grades are included.

(e) The following shall apply to all material assignment notes:

(1) Cooling rates faster than those obtained by cooling in air, followed by tempering, as permitted by the material specification, are considered to be equivalent to normalizing or normalizing and tempering heat treatments.

(2) Fine grain practice is defined as the procedure necessary to obtain a fine austenitic grain size as described in SA-20.

(3) Normalized rolling condition is not considered as being equivalent to normalizing.

(f) Castings not listed in Notes (1) and (2) below shall be impact tested.

NOTES:

(1) Curve A applies to the following:

(a) all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below

(b) SA-216 Grades WCB and WCC if normalized and tempered or water-quenched and tempered; SA-217 Grade WC6 if normalized and tempered or water-quenched and tempered

(c) A/SA-105 forged flanges supplied in the as-forged condition

(2) Curve B applies to the following:

(a) see below:

A/SA-105 forged flanges produced to fine grain practice and normalized, normalized and tempered, or quenched and tempered after forging

SA-216 Grade WCA if normalized and tempered or water-quenched and tempered

SA-216 Grades WCB and WCC for thicknesses not exceeding 2 in. (50 mm) , if produced to fine grain practice and water-quenched and tempered

SA-217 Grade WC9 if normalized and tempered

SA-285 Grades A and B

SA-299

Figure UCS-66
Impact Test Exemption Curves (Cont'd)

NOTES (CONT'D):

SA-414 Grade A
SA-515 Grade 60
SA-516 Grades 65 and 70 if not normalized
SA-612 if not normalized
SA-662 Grade B if not normalized
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH as rolled
SA/AS 1548 Grades PT430NR and PT460NR
SA/GB 713 Grade Q345R if not normalized

(b) except for cast steels, all materials of Curve A, if produced to fine grain practice and normalized, that are not listed in Curves C and D below

(c) all pipe, fittings, forgings and tubing not listed for Curves C and D below

(d) parts permitted under UG-11 even when fabricated from plate that otherwise would be assigned to a different curve

(3) Curve C applies to the following:

(a) see below:

SA-182 Grades F21 and F22 if normalized and tempered
SA-302 Grades C and D
SA-336 F21 and F22 if normalized and tempered, or liquid quenched and tempered
SA-387 Grades 21 and 22 if normalized and tempered, or liquid quenched and tempered
SA-516 Grades 55 and 60 if not normalized
SA-533 Types B and C Class 1
SA-662 Grade A
SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered

(b) all materials listed in 2(a) and 2(c) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below

(4) Curve D applies to the following:

SA-203
SA-299 if normalized
SA-508 Grade 1
SA-516 if normalized or quenched and tempered
SA-524 Classes 1 and 2
SA-537 Classes 1, 2, and 3
SA-612 if normalized
SA-662 if normalized
SA-738 Grade A
SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C)
SA-738 Grade B not colder than −20°F (−29°C)
SA/AS 1548 Grades PT430N and PT460N
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH if normalized
SA/EN 10028-3 Grade P275NH
SA/GB 713 Grade Q345R if normalized

(-c) The governing thickness of flat nonwelded parts, such as bolted flanges, tubesheets, and flat heads, is the flat component thickness divided by 4.

(-d) The governing thickness of a nonwelded dished head [see Figure 1-6, sketch (c)] is the greater of the flat flange thickness divided by 4 or the minimum thickness of the dished portion.

(-e) If the governing thickness of the nonwelded part exceeds 6 in. (150 mm) and the minimum design metal temperature is colder than 120°F (50°C), impact tested material shall be used.

(2) Examples of the governing thickness for some typical vessel details are shown in Figure UCS-66.3.

NOTE: The use of provisions in UCS-66 which waive the requirements for impact testing does not provide assurance that all test results for these materials would satisfy the impact energy requirements of UG-84 if tested.

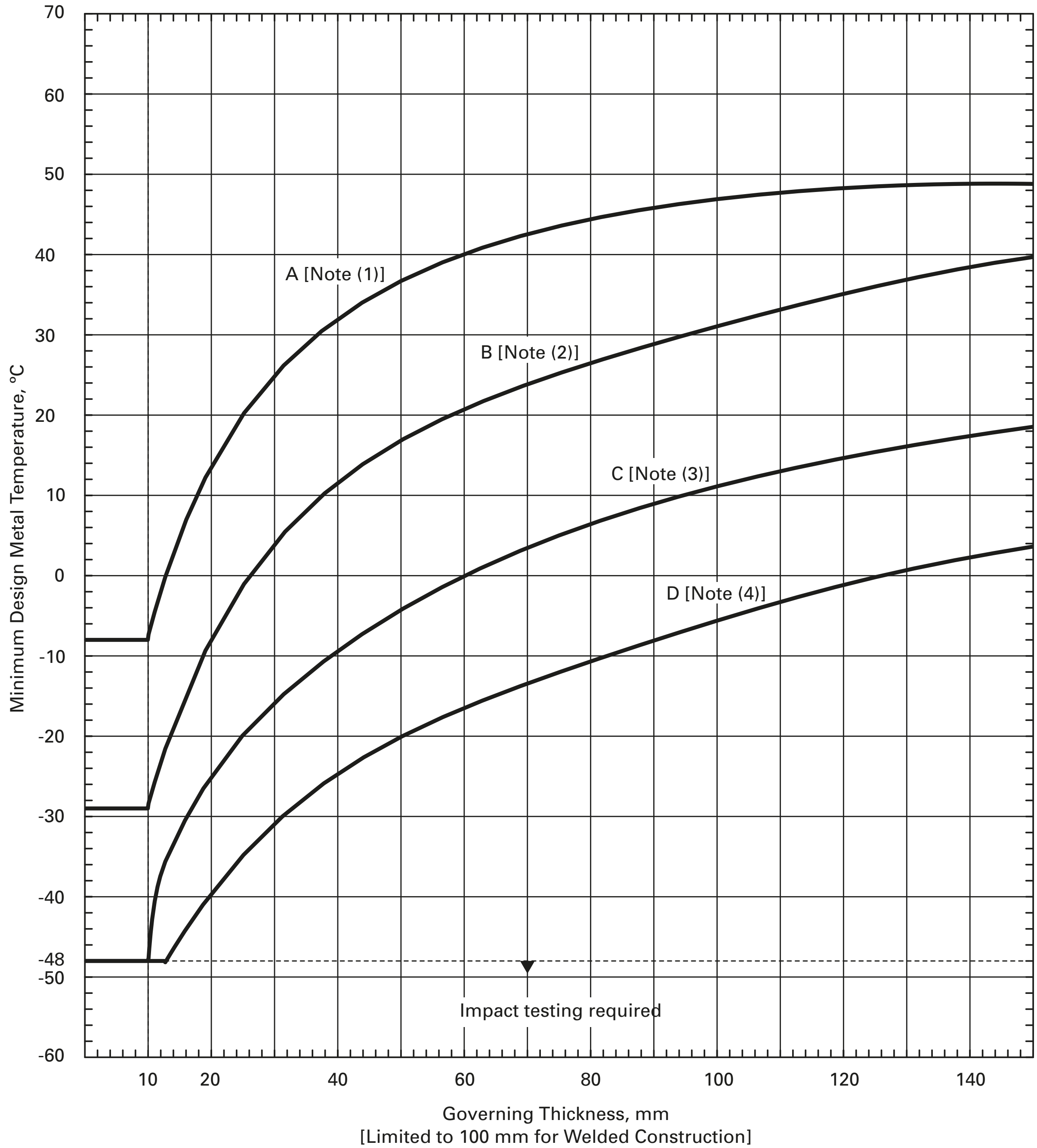
(b) When the coincident ratio defined in Figure UCS-66.1 is less than one, Figure UCS-66.1 provides a basis for the use of components made of Part UCS materials to have a colder MDMT than that derived from (a) above without impact testing. Use of Figure UCS-66.1 is not permitted for bolts and nuts.

(1) See below.

(-a) For such components, and for a MDMT of −55°F (−48°C) and warmer, the MDMT without impact testing determined in (a) above for the given material

(19)

Figure UCS-66M
Impact Test Exemption Curves



GENERAL NOTES:

(a) Tabular values for this figure are provided in Table UCS-66.

(b) See UCS-66(a).

(c) For bolting and nuts, the following impact test exemption temperatures shall apply:

Bolting

Spec. No.	Grade	Diameter, in. (mm)	Impact Test Exemption Temperature, °F (°C)
SA-193	B5	Up to 4 (100), incl.	−20 (−30)
SA-193	B7	Up to $2^1/_2$ in. (64), incl.	−55 (−48)
SA-193	...	Over $2^1/_2$ (64) to 7 (175), incl.	−40 (−40)
SA-193	B7M	Up to $2^1/_2$ (64), incl.	−55 (−48)

Figure UCS-66M
Impact Test Exemption Curves (Cont'd)

GENERAL NOTES (CONT'D):

Table continued

Bolting

Spec. No.	Grade	Diameter, in. (mm)	Impact Test Exemption Temperature, °F (°C)
SA-193	B16	Up to 7 (175), incl.	−20 (−30)
SA-307	B	All	−20 (−30)
SA-320	L7, L7A, L7M	Up to 2 1/2 (64), incl.	See General Note (c) of Figure UG-84.1
SA-320	L43	Up to 1 (25), incl.	See General Note (c) of Figure UG-84.1
SA-325	1	1/2 (13) to 1 1/2 (38)	−20 (−30)
SA-354	BC	Up to 4 (100), incl.	0 (−18)
SA-354	BD	Up to 4 (100), incl.	+20 (−7)
SA-437	B4B, B4C	All diameters	See General Note (c) of Figure UG-84.1
SA-449	...	Up to 3 (75), incl.	−20 (−30)
SA-540	B21 Cl. All	All	Impact test required
SA-540	B22 Cl. 3	Up to 4 (100), incl.	Impact test required
SA-540	B23 Cl. 1, 2	All	Impact test required
SA-540	B23 Cl. 3, 4	Up to 6 (150), incl.	See General Note (c) of Figure UG-84.1
SA-540	B23 Cl. 3, 4	Over 6 (150) to 9 1/2 (240), incl.	Impact test required
SA-540	B23 Cl. 5	Up to 8 (200), incl.	See General Note (c) of Figure UG-84.1
SA-540	B23 Cl. 5	Over 8 (200) to 9 1/2 (240), incl.	Impact test required
SA-540	B24 Cl. 1	Up to 6 (150), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24 Cl. 1	Over 6 (150) to 8 (200), incl.	Impact test required
SA-540	B24 Cl. 2	Up to 7 (175), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24 Cl. 2	Over 7 (175) to 9 1/2 (240), incl.	Impact test required
SA-540	B24 Cl. 3, 4	Up to 8 (200), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24 Cl. 3, 4	Over 8 (200) to 9 1/2 (240), incl.	Impact test required
SA-540	B24 Cl. 5	Up to 9 1/2 (240), incl.	See General Note (c) of Figure UG-84.1
SA-540	B24V Cl. 3	All	See General Note (c) of Figure UG-84.1

Nuts

Spec. No.	Grade	Impact Test Exemption Temperature, °F (°C)
SA-194	2, 2H, 2HM, 3, 4, 7, 7M, and 16	−55 (−48)
SA-540	B21/B22/B23/B24/B24V	−55 (−48)

(d) When no class or grade is shown, all classes or grades are included.

(e) The following shall apply to all material assignment notes:

(1) Cooling rates faster than those obtained by cooling in air, followed by tempering, as permitted by the material specification, are considered to be equivalent to normalizing or normalizing and tempering heat treatments.

(2) Fine grain practice is defined as the procedure necessary to obtain a fine austenitic grain size as described in SA-20.

(3) Normalized rolling condition is not considered as being equivalent to normalizing.

(f) Castings not listed in Notes (1) and (2) below shall be impact tested.

NOTES:

(1) Curve A applies to the following:

(a) all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below

(b) SA-216 Grades WCB and WCC if normalized and tempered or water-quenched and tempered; SA-217 Grade WC6 if normalized and tempered or water-quenched and tempered

(c) A/SA-105 forged flanges supplied in the as-forged condition

(2) Curve B applies to the following:

(a) see below:

A/SA-105 forged flanges produced to fine grain practice and normalized, normalized and tempered, or quenched and tempered after forging

SA-216 Grade WCA if normalized and tempered or water-quenched and tempered

SA-216 Grades WCB and WCC for thicknesses not exceeding 2 in. (50 mm) , if produced to fine grain practice and water-quenched and tempered

SA-217 Grade WC9 if normalized and tempered

SA-285 Grades A and B

SA-299

Figure UCS-66M
Impact Test Exemption Curves (Cont'd)

NOTES (CONT'D):

SA-414 Grade A
SA-515 Grade 60
SA-516 Grades 65 and 70 if not normalized
SA-612 if not normalized
SA-662 Grade B if not normalized
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH as rolled
SA/AS 1548 Grades PT430NR and PT460NR
SA/GB 713 Grade Q345R if not normalized

(b) except for cast steels, all materials of Curve A, if produced to fine grain practice and normalized, that are not listed in Curves C and D below

(c) all pipe, fittings, forgings and tubing not listed for Curves C and D below

(d) parts permitted under UG-11 even when fabricated from plate that otherwise would be assigned to a different curve

(3) Curve C applies to the following:

(a) see below:

SA-182 Grades F21 and F22 if normalized and tempered
SA-302 Grades C and D
SA-336 F21 and F22 if normalized and tempered, or liquid quenched and tempered
SA-387 Grades 21 and 22 if normalized and tempered, or liquid quenched and tempered
SA-516 Grades 55 and 60 if not normalized
SA-533 Types B and C Class 1
SA-662 Grade A
SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered

(b) all materials listed in 2(a) and 2(c) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below

(4) Curve D applies to the following:

SA-203
SA-299 if normalized
SA-508 Grade 1
SA-516 if normalized or quenched and tempered
SA-524 Classes 1 and 2
SA-537 Classes 1, 2, and 3
SA-612 if normalized
SA-662 if normalized
SA-738 Grade A
SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C)
SA-738 Grade B not colder than −20°F (−29°C)
SA/AS 1548 Grades PT430N and PT460N
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH if normalized
SA/EN 10028-3 Grade P275NH
SA/GB 713 Grade Q345R if normalized

and thickness may be reduced as determined from Figure UCS-66.2. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required.

(-b) Figure UCS-66.1 may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges. The MDMT of these components without impact testing as determined in (a) or (c) may be reduced as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT. If the resulting temperature is colder than the required MDMT, impact testing of the material is not required, provided the MDMT is not colder than −55°F (−48°C).

(-c) In lieu of using (-b) above, the MDMT determined in (a) may be reduced for a flange attached by welding, by the same reduction as determined in (-a) above for the neck or shell which the flange is attached.

NOTE: The bolt-up condition need not be considered when determining the temperature reduction for flanges.

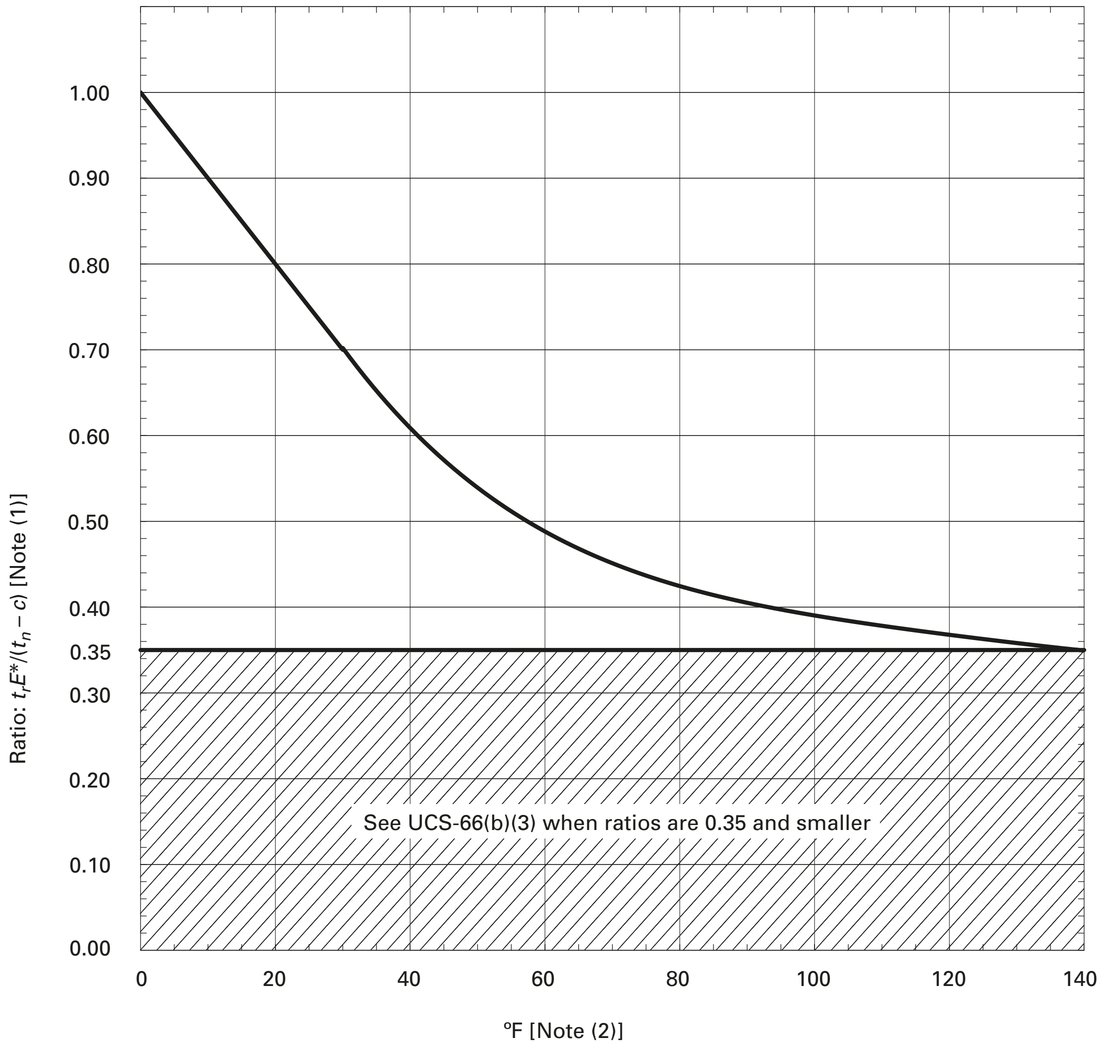
Table UCS-66
Tabular Values for Figure UCS-66 and Figure UCS-66M

Customary Units					SI Units				
Thick-ness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F	Thick-ness, mm	Curve A, °C	Curve B, °C	Curve C, °C	Curve D, °C
0.25	18	−20	−55	−55	6.4	−8	−29	−48	−48
0.3125	18	−20	−55	−55	7.9	−8	−29	−48	−48
0.375	18	−20	−55	−55	9.5	−8	−29	−48	−48
0.4375	25	−13	−40	−55	11.1	−4	−25	−40	−48
0.5	32	−7	−34	−55	12.7	0	−22	−37	−48
0.5625	37	−1	−26	−51	14.3	3	−18	−32	−46
0.625	43	5	−22	−48	15.9	6	−15	−30	−44
0.6875	48	10	−18	−45	17.5	9	−12	−28	−43
0.75	53	15	−15	−42	19.1	12	−9	−26	−41
0.8125	57	19	−12	−38	20.6	14	−7	−24	−39
0.875	61	23	−9	−36	22.2	16	−5	−23	−38
0.9375	65	27	−6	−33	23.8	18	−3	−21	−36
1.0	68	31	−3	−30	25.4	20	−1	−19	−35
1.0625	72	34	−1	−28	27.0	22	1	−18	−33
1.125	75	37	2	−26	28.6	24	3	−17	−32
1.1875	77	40	2	−23	30.2	25	4	−17	−31
1.25	80	43	6	−21	31.8	27	6	−14	−30
1.3125	82	45	8	−19	33.3	28	7	−13	−28
1.375	84	47	10	−18	34.9	29	8	−12	−28
1.4375	86	49	12	−16	36.5	30	9	−11	−27
1.5	88	51	14	−14	38.1	31	11	−10	−26
1.5625	90	53	16	−13	39.7	32	12	−9	−25
1.625	92	55	17	−11	41.3	33	13	−8	−24
1.6875	93	57	19	−10	42.9	34	14	−7	−23
1.75	94	58	20	−8	44.5	34	14	−7	−22
1.8125	96	59	22	−7	46.0	36	15	−6	−22
1.875	97	61	23	−6	47.6	36	16	−5	−21
1.9375	98	62	24	−5	49.2	37	17	−4	−21
2.0	99	63	26	−4	50.8	37	17	−3	−20
2.0625	100	64	27	−3	52.4	38	18	−3	−19
2.125	101	65	28	−2	54.0	38	18	−2	−19
2.1875	102	66	29	−1	55.6	39	19	−2	−18
2.25	102	67	30	0	57.2	39	19	−1	−18
2.3125	103	68	31	1	58.7	39	20	−1	−17
2.375	104	69	32	2	60.3	40	21	0	−17
2.4375	105	70	33	3	61.9	41	21	1	−16
2.5	105	71	34	4	63.5	41	22	1	−16
2.5625	106	71	35	5	65.1	41	22	2	−15
2.625	107	73	36	6	66.7	42	23	2	−14
2.6875	107	73	37	7	68.3	42	23	3	−14
2.75	108	74	38	8	69.9	42	23	3	−13
2.8125	108	75	39	8	71.4	42	24	4	−13
2.875	109	76	40	9	73.0	43	24	4	−13
2.9375	109	77	40	10	74.6	43	25	5	−12
3.0	110	77	41	11	76.2	43	26	5	−12
3.0625	111	78	42	12	77.8	44	26	6	−11
3.125	111	79	43	12	79.4	44	26	6	−11
3.1875	112	80	44	13	81.0	44	27	7	−11
3.25	112	80	44	14	82.6	44	27	7	−10
3.3125	113	81	45	15	84.1	45	27	7	−9
3.375	113	82	46	15	85.7	45	28	8	−9
3.4375	114	83	46	16	87.3	46	28	8	−9

Table UCS-66
Tabular Values for Figure UCS-66 and Figure UCS-66M (Cont'd)

Customary Units					SI Units				
Thickness, in.	Curve A, °F	Curve B, °F	Curve C, °F	Curve D, °F	Thickness, mm	Curve A, °C	Curve B, °C	Curve C, °C	Curve D, °C
3.5	114	83	47	17	88.9	46	28	8	−8
3.5625	114	84	48	17	90.5	46	29	9	−8
3.625	115	85	49	18	92.1	46	29	9	−7
3.6875	115	85	49	19	93.7	46	29	9	−7
3.75	116	86	50	20	95.3	47	30	10	−7
3.8125	116	87	51	21	96.8	47	31	11	−6
3.875	116	88	51	21	98.4	47	31	11	−6
3.9375	117	88	52	22	100.0	47	32	11	−6
4.0	117	89	52	23	101.6	47	32	11	−5
4.0625	117	90	53	23	103.0	47	32	12	−5
4.125	118	90	54	24	105.0	48	32	12	−4
4.1875	118	91	54	25	106.0	48	33	12	−4
4.25	118	91	55	25	108.0	48	33	12	−4
4.3125	118	92	55	26	110.0	48	33	12	−3
4.375	119	93	56	27	111.0	49	34	13	−3
4.4375	119	93	56	27	113.0	49	34	13	−3
4.5	119	94	57	28	114.0	49	34	13	−2
4.5625	119	94	57	29	115.0	49	34	13	−2
4.625	119	95	58	29	117.0	49	35	14	−2
4.6875	119	95	58	30	118.0	49	35	14	−1
4.75	119	96	59	30	119.0	49	35	14	−1
4.8125	119	96	59	31	120.0	49	35	14	−1
4.875	119	97	60	31	121.0	49	36	15	−1
4.9375	119	97	60	32	122.0	49	36	15	0
5	119	97	60	32	123.0	49	36	15	0
5.0625	119	98	61	33	124.0	49	36	15	0
5.125	119	98	61	33	125.0	49	36	15	0
5.1875	119	98	62	34	126.0	49	36	16	1
5.25	119	99	62	34	127.0	49	37	16	1
5.3125	119	99	62	35	128.0	49	37	16	1
5.375	119	100	63	35	129.0	49	37	16	1
5.4375	119	100	63	36	130.0	49	37	16	2
5.5	119	100	63	36	131.0	49	37	16	2
5.5625	119	101	64	36	132.0	49	38	17	2
5.625	119	101	64	37	133.0	49	38	17	2
5.6875	119	102	64	37	134.0	49	38	17	2
5.75	120	102	65	38	135.0	50	38	17	3
5.8125	120	103	65	38	136.0	50	39	17	3
5.875	120	103	66	38	137.0	50	39	18	3
5.9375	120	104	66	39	138.0	50	39	18	3
6.0	120	104	66	39	139.0	50	39	18	3

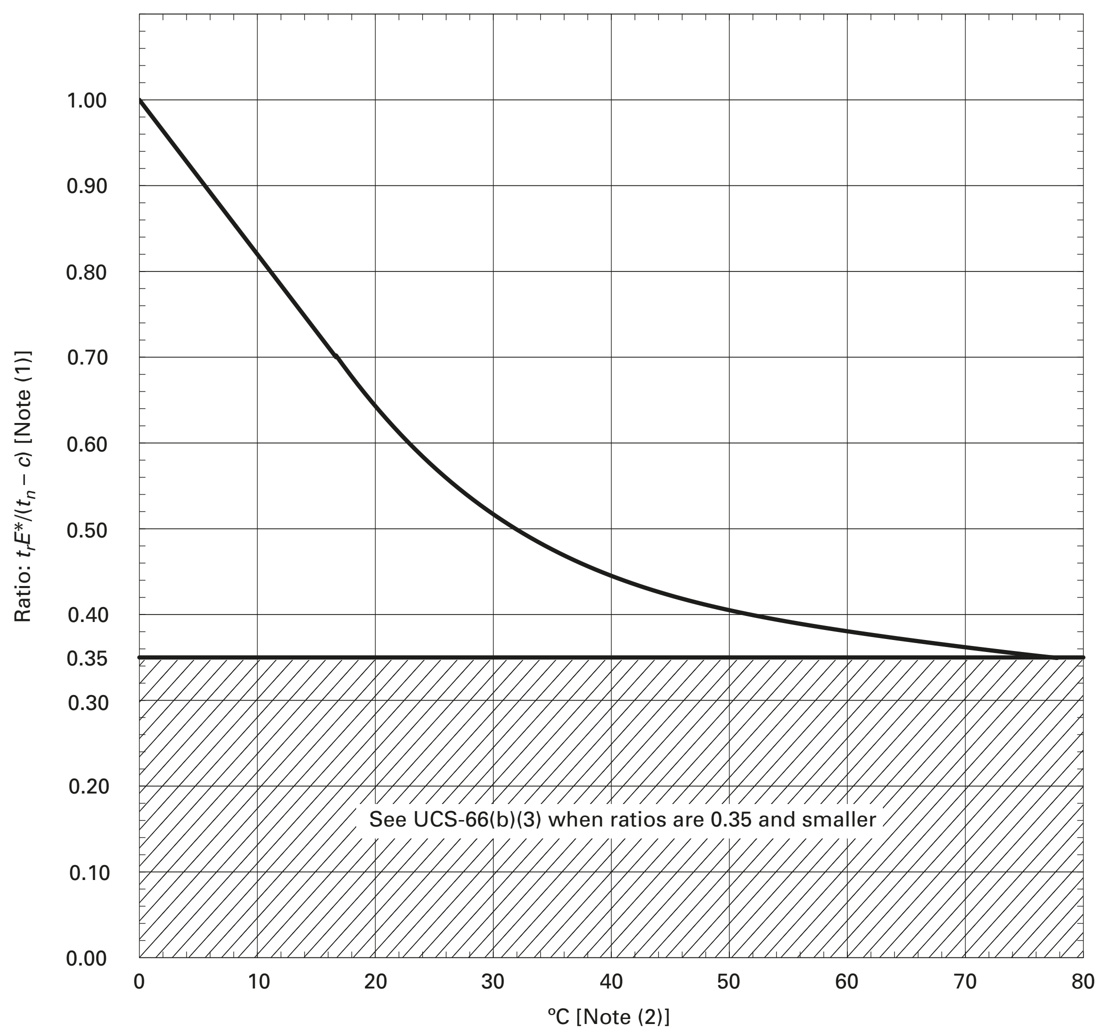
Figure UCS-66.1
Reduction in Minimum Design Metal Temperature Without Impact Testing



c = corrosion allowance, in.
E^* = as defined in Figure UCS-66.2, Note (3)
t_n = nominal thickness of the component under consideration before corrosion allowance is deducted, in.
t_r = required thickness of the component under consideration in the corroded condition for all applicable loadings [Figure UCS-66.2, Note (2)], based on the applicable joint efficiency E [Figure UCS-66.2, Note (3)], in.

NOTES:
(1) *Alternative Ratio* = $S^* E^*$ divided by the product of the maximum allowable stress value from Table UCS-23 times E, where S^* is the applied general primary membrane tensile stress and E and E^* are as defined in Figure UCS-66.2, Note (3)
(2) See UCS-66(b).

Figure UCS-66.1M
Reduction in Minimum Design Metal Temperature Without Impact Testing



c = corrosion allowance, mm
E^* = as defined in Figure UCS-66.2, Note (3)
t_n = nominal thickness of the component under consideration before corrosion allowance is deducted, mm
t_r = required thickness of the component under consideration in the corroded condition for all applicable loadings [Figure UCS-66.2, Note (2)], based on the applicable joint efficiency E [Figure UCS-66.2, Note (3)], mm

NOTES:
(1) *Alternative Ratio* = $S^* E^*$ divided by the product of the maximum allowable stress value from Table UCS-23 times E, where S^* is the applied general primary membrane tensile stress and E and E^* are as defined in Figure UCS-66.2, Note (3)
(2) See UCS-66(b).

Figure UCS-66.2
Diagram of UCS-66 Rules for Determining Lowest Minimum Design Metal Temperature (MDMT) Without Impact Testing

Step 1

Establish nominal thickness [Note (1)] of welded parts, nonwelded parts, and attachments under consideration both before and after corrosion allowance is deducted (t_n and $t_n - c$, respectively), and other pertinent data applicable to the nominal thickness, such as:

All applicable loadings [Note (2)] and coincident minimum design metal temperature (MDMT)
Materials of construction
E = joint efficiency [Note (3)]
t_n = nominal noncorroded thickness [Note (1)], in. (mm)
t_r = required thickness in corroded condition for all applicable loadings [Note (2)], based on the applicable joint efficiency [Note (3)], in. (mm)
Applicable curve(s) of Fig. UCS-66
c = corrosion allowance, in. (mm)

↓

Step 2

Select MDMT from Fig. UCS-66 [Note (4)] for each nominal noncorroded governing thickness [Note (5)].

↓

Step 3

Determine Ratio: $\dfrac{t_r E^*}{t_n - c}$

[Notes (3), (6), (7), and (8)]

↓

Step 4

Using Ratio from Step 3 to enter ordinate of Fig. UCS-66.1, determine reduction in Step 2 MDMT [Note (9)].

↓

Step 5

Determine adjusted MDMT for governing thickness under consideration.

↓

Step 6

Repeat for all governing thicknesses [Note (5)] and take *warmest* value as the lowest allowable MDMT to be marked on nameplate for the zone under consideration [Note (10)]. See UG-116.
See UG-99(h) for coldest recommended metal temperature during hydrostatic test [Note (6)].
See UG-100(c) for coldest metal temperature permitted during pneumatic test [Note (6)].

Legend
Requirement (solid box)   Optional (dashed box)

NOTES:
(1) For pipe where a mill undertolerance is allowed by the material specification, the thickness after mill undertolerance has been deducted shall be taken as the noncorroded nominal thickness t_n for determination of the MDMT to be stamped on the nameplate. Likewise, for formed heads, the minimum specified thickness after forming shall be used as t_n.
(2) Loadings, including those listed in UG-22, which result in general primary membrane tensile stress at the coincident MDMT.

Figure UCS-66.2
Diagram of UCS-66 Rules for Determining Lowest Minimum Design Metal Temperature (MDMT) Without Impact Testing (Cont'd)

NOTES (CONT'D):
(3) E is the joint efficiency (Table UW-12) used in the calculation of t_r; E^* has a value equal to E except that E^* shall not be less than 0.80. For castings, use quality factor or joint efficiency, E, whichever governs design.
(4) The construction of Figure UCS-66 is such that the MDMT so selected is considered to occur coincidentally with an applied general primary membrane tensile stress at the maximum allowable stress value in tension from Section II, Part D, Subpart 1, Table 1A. Tabular values for Figure UCS-66 are shown in Table UCS-66.
(5) See UCS-66(a)(1)(-a), (a)(1)(-b), and (a)(1)(-c) for definitions of governing thickness.
(6) If the basis for calculated test pressure is greater than the design pressure [UG-99(c) test], a Ratio based on the t_r determined from the basis for calculated test pressure and associated appropriate value of $t_n - c$ shall be used to determine the recommended coldest metal temperature during hydrostatic test and the coldest metal temperature permitted during the pneumatic test. See UG-99(h) and UG-100(c).
(7) Alternatively, a Ratio of S^* E^* divided by the product of the maximum allowable stress value in tension from Section II, Part D, Subpart 1, Table 1A times E may be used, where S^* is the applied general primary membrane tensile stress and E and E^* are as defined in Note (3).
(8) For UCS-66(b)(1)(-b) and UCS-66(i)(2), a ratio of the maximum design pressure at the MDMT to the maximum allowable pressure (MAP) at the MDMT shall be used. The MAP is defined as the highest permissible pressure as determined by the design equations for a component using the nominal thickness less corrosion allowance and the maximum allowable stress value from the Section II, Part D, Subpart 1, Table 1A at the MDMT. For ferritic steel flanges defined in UCS-66(c), the flange rating at the warmer of the MDMT or 100°F (38°C) may be used as the MAP.
(9) For reductions in MDMT up to and including 40°F (22°C), the reduction can be determined by: reduction in MDMT = (1 − Ratio) 100°F (56°C).
(10) A colder MDMT may be obtained by selective use of impact tested materials as appropriate to the need (see UG-84). See also UCS-68(c).

(2) For minimum design metal temperatures colder than −55°F (−48°C), impact testing is required for all materials, except as allowed in (3) below and in UCS-68(c).

(3) When the minimum design metal temperature is colder than −55°F (−48°C) and no colder than −155°F (−105°C), and the coincident ratio defined in Figure UCS-66.1 is less than or equal to 0.35, impact testing is not required.

(c) Impact testing is not required for the ferritic steel flanges shown below when they are produced to fine-grain practice and supplied in the heat-treated condition (normalized, normalized and tempered, or quenched and tempered after forging) when used at design temperatures no colder than −20°F (−29°C) and no colder than 0°F (−18°C) when supplied in the as-forged condition.

(1) ASME B16.5 flanges.

(2) ASME B16.47 flanges.

(3) long weld neck flanges, defined as forged nozzles that meet the dimensional requirements of a flanged fitting given in ASME B16.5 but have a straight hub/neck. The inside diameter of the neck shall not be less than the nominal size of the flange, and the outside diameter of the neck and any nozzle reinforcement shall not exceed the diameter of the hub as specified in ASME B16.5.

(d) No impact testing is required for Part UCS materials 0.10 in. (2.5 mm) in thickness and thinner, but such exempted Part UCS materials shall not be used at design metal temperatures colder than −55°F (−48°C). For vessels or components made from NPS 4 (DN 100) or smaller tubes or pipe of P-No. 1 materials, the following exemptions from impact testing are also permitted as a function of the material specified minimum yield strength (SMYS) for metal temperatures of −155°F (−105°C) and warmer:

SMYS, ksi (MPa)	Thickness, in. (mm)
20 to 35 (140 to 240)	0.237 (6.0)
36 to 45 (250 to 310)	0.125 (3.2)
46 (320) and higher	0.10 (2.5)

(e) The material manufacturer's identification marking required by the material specification shall not be stamped on plate material less than $^1/_4$ in. (6 mm) in thickness unless the following requirements are met.

(1) The materials shall be limited to P-No. 1 Gr. Nos. 1 and 2.

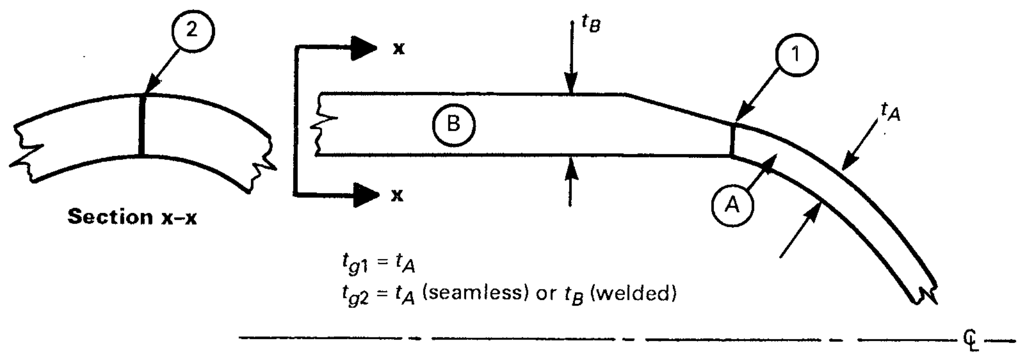
(2) The minimum nominal plate thickness shall be $^3/_{16}$ in. (5 mm), or the minimum nominal pipe wall thickness shall be 0.154 in. (3.91 mm).

(3) The minimum design metal temperature shall be no colder than −20°F (−29°C).

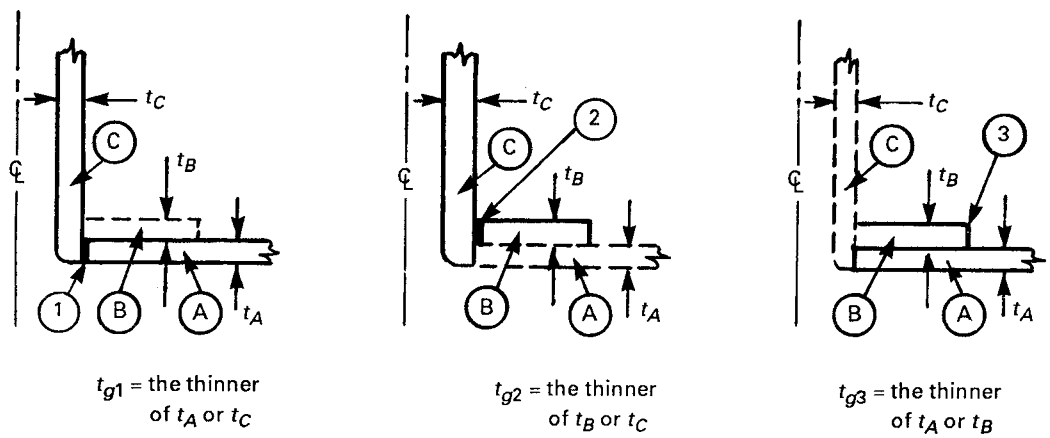
(f) Materials, other than bolting materials, having a specified minimum yield strength greater than 65 ksi (450 MPa) shall be impact tested. However, they may be used at temperatures colder than the minimum design metal temperature as limited in (1) and (2) below.

(1) When the coincident ratio defined in Figure UCS-66.1 is 0.35 or less, the corresponding minimum design metal temperature shall not be colder than −155°F (−104°C).

Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66

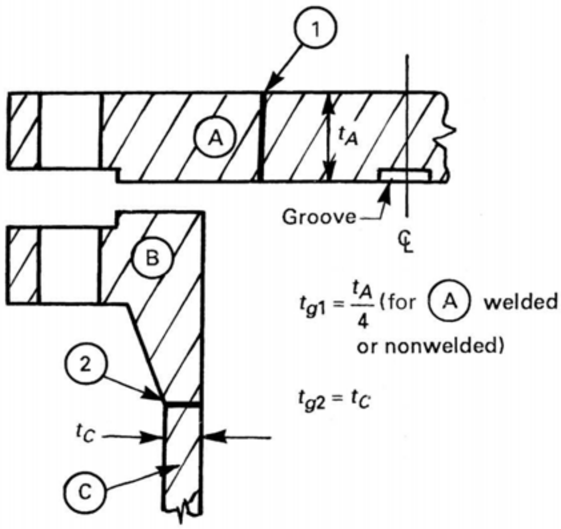


(a) Butt Welded Components

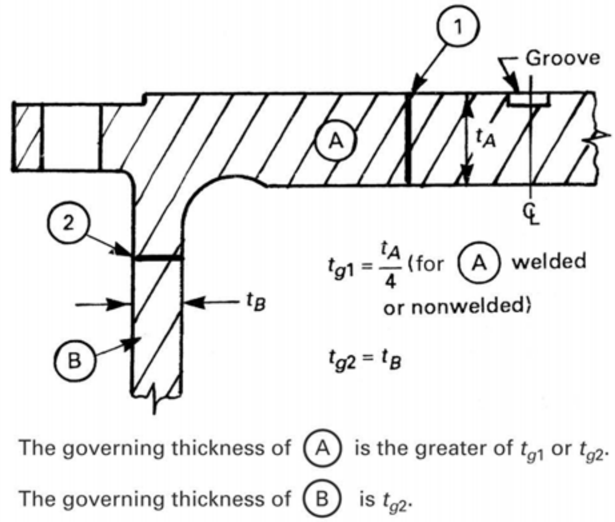


(b) Welded Connection With Reinforcement Plate Added

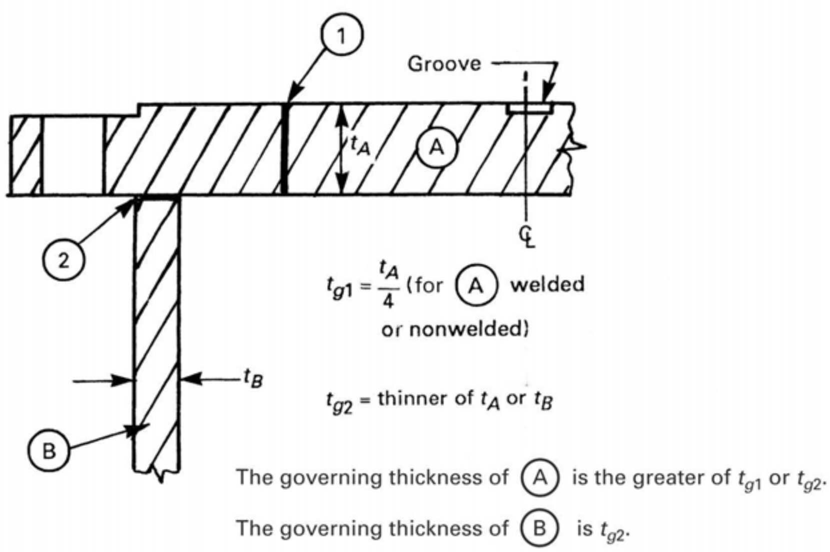
Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66 (Cont'd)



(c) Bolted Flat Head or Tubesheet and Flange

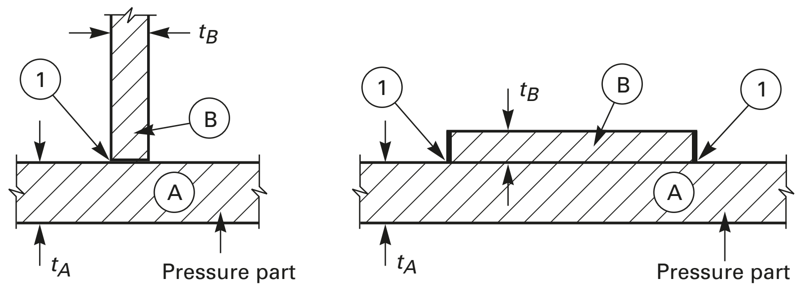


(d) Integral Flat Head or Tubesheet



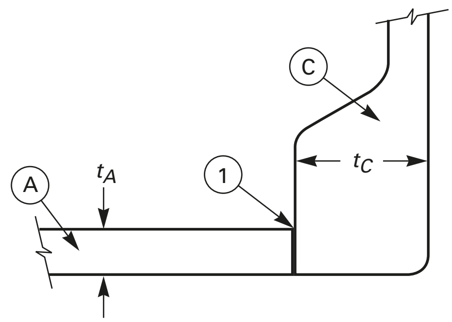
(e) Flat Head or Tubesheet With a Corner Joint

Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66 (Cont'd)



t_{g1} = thinner of t_A or t_B

(f) Welded Attachments as Defined in UCS-66(a)



t_{g1} = thinner of t_A or t_C

(g) Integrally Reinforced Welded Connection

GENERAL NOTES:
(a) Using t_{g1}, t_{g2}, and t_{g3}, determine the warmest MDMT and use that as the permissible MDMT for the welded assembly.
(b) t_g = governing thickness of the welded joint as defined in UCS-66.

(2) When the coincident ratio defined in Figure UCS-66.1 is greater than 0.35, the corresponding minimum design metal temperature shall not be colder than the impact test temperature less the allowable temperature reduction permitted in Figure UCS-66.1 and shall in no case be colder than −155°F (−104°C).

(g) Materials produced and impact tested in accordance with the requirements of the specifications listed in Figure UG-84.1, General Note (c), are exempt from impact testing by the rules of this Division at minimum design metal temperatures not more than 5°F (3°C) colder than the test temperature required by the specification.

(h) No impact testing is required for metal backing strips which remain in place made of materials assigned to Curve A of Figure UCS-66 in thicknesses not exceeding $^1/_4$ in. (6 mm) when the minimum design metal temperature is −20°F (−29°C) or warmer.

(i) For components made of Part UCS materials that are impact tested, Figure UCS-66.1 provides a basis for the use of these components at an MDMT colder than the impact test temperature.

(1) For such components, the MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Figure UCS-66.2.

(2) Figure UCS-66.1 may also be used for components not stressed in general primary membrane tensile stress, such as flat heads, covers, tubesheets, and flanges. The MDMT shall not be colder than the impact test temperature less the allowable temperature reduction as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum design pressure at the MDMT to the maximum allowable pressure (MAP) of the component at the MDMT.

(3) In lieu of using (2) above, the MDMT for a flange attached by welding shall not be colder than the impact test temperature less the allowable temperature reduction as determined in (1) above for the neck or shell to which the flange is attached.

(4) The MDMT adjustment as determined in (1) above may be used for impact tested welding procedures or production welds.

(5) The MDMT for the component shall not be colder than −155°F (−105°C).

(j) When the base metal is exempt from impact testing by (g) above or by Figure UCS-66, Curve C or Curve D, −20°F (−29°C) is the coldest MDMT to be assigned for welded components that do not meet the requirements of UCS-67(a)(3).

UCS-67 IMPACT TESTS OF WELDING PROCEDURES

Except as exempted in UG-20(f), UCS-66, and UCS-68, the welding procedure qualification shall include impact tests of the weld metal and heat-affected zones (HAZ) in accordance with UG-84 when required by the following provisions. The minimum design metal temperature (MDMT) used below shall be either the MDMT stamped on the nameplate or the exemption temperature of the welded component before applying the temperature reduction permitted by UCS-66(b) or UCS-68(c).

(a) Welds made with filler metal shall be deposited using welding procedures qualified with impact testing in accordance with UG-84 when any of the following apply:

(1) when either base metal is required to be impact tested by the rules of this Division; or

(2) when the thickness of any individual weld pass exceeds $^1/_2$ in. (13 mm) and the MDMT is colder than 70°F (21°C); or

(3) when joining base metals exempt from impact testing by UCS-66(g) or Figure UCS-66, Curve C or D and the MDMT is colder than −20°F (−29°C) but not colder than −55°F (−48°C). Qualification of the welding procedure with impact testing is not required when no individual weld pass in the production weld exceeds $^1/_4$ in. (6 mm) in thickness; and each heat and/or lot of filler metal or combination of heat and/or lot of filler metal and batch of flux has been classified by their manufacturer through impact testing per the applicable SFA specification at a temperature not warmer than the MDMT. Additional testing beyond the scope of the SFA specification may be performed by the filler metal and/or flux manufacturer to expand their classification for a broader range of temperatures; or

(4) when joining base metals exempt from impact testing by UCS-66(g) and the MDMT is colder than −55°F (−48°C).

(b) Except for welds made as part of the material specification, welds in Part UCS materials made without filler metal shall be completed using welding procedures qualified with impact testing any of the following conditions apply:

(1) when either base metal is required to be impact tested by the rules of this Division; or

(2) the thickness at the weld exceeds $^1/_2$ in. (13 mm) regardless of the MDMT; or

(3) when the thickness at the weld exceeds $^5/_{16}$ in. (8 mm) and the MDMT is colder than 50°F (10°C); or

(4) when joining base metals exempt from impact testing by UCS-66(g) and the MDMT is colder than −55°F (−48°C).

UCS-68 DESIGN[77]

(a) Welded joints shall comply with UW-2(b) when the minimum design metal temperature is colder than −55°F (−48°C), unless the coincident ratio defined in Figure UCS-66.1 is less than 0.35.

(b) Welded joints shall be postweld heat treated in accordance with the requirements of UW-40 when required by other rules of this Division. When the minimum design metal temperature is colder than −55°F (−48°C), and the coincident ratio defined in Figure UCS-66.1 is 0.35 or greater, postweld heat treatment is required, except that this requirement does not apply to the following welded joints, in vessels or vessel parts fabricated of P-No. 1 materials that are impact tested at the MDMT or colder in accordance with UG-84. The minimum average energy requirement for base metals and weldments shall be 25 ft-lb (34 J) instead of the values shown in Figure UG-84.1:

(1) Type 1 Category A and B joints, not including cone-to-cylinder junctions, which have been 100% radiographed. Category A and B joints attaching sections of unequal thickness shall have a transition with a slope not exceeding 3:1.

(2) the following welds:

(-a) fillet welds having leg dimensions not exceeding $^3/_8$ in. (10 mm) attaching lightly loaded attachments, provided the attachment material and the attachment weld meet requirements of UCS-66 and UCS-67. "Lightly loaded attachment," for this application, is defined as an attachment for which the stress in the attachment weld does not exceed 25% of the allowable stress.

(-b) seal welds defined in UW-20.2(c).

All such welds as described in (-a) and (-b) shall be examined by magnetic particle or liquid penetrant examination in accordance with Mandatory Appendix 6 or Mandatory Appendix 8.

(c) If postweld heat treating of a pressure-retaining weld is performed when it is not otherwise a requirement of this Division, a 30°F (17°C) reduction in impact testing exemption temperature may be given to the minimum permissible temperature from Figure UCS-66 for P-No. 1

materials. The resulting exemption temperature may be colder than −55°F (−48°C) when the PWHT exemption in (b) is applicable.

(d) The allowable stress values to be used in design at the minimum design metal temperature shall not exceed those given in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other materials for temperatures of 100°F (38°C).

FABRICATION

UCS-75 GENERAL

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of carbon and low alloy steel and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection B that pertain to the method of fabrication used.

UCS-79 FORMING PRESSURE PARTS

(a) The following provisions shall apply in addition to the general rules for forming given in UG-79.

(b) Carbon and low alloy steel plates shall not be formed cold by blows.

(c) Carbon and low alloy steel plates may be formed by blows at a forging temperature provided the blows do not objectionably deform the plate and it is subsequently postweld heat treated.

(**19**) *(d)* Except as addressed in (e) and for materials exempted below, the cold-formed areas of vessel shell sections, heads, and other pressure parts shall be heat treated if the resulting extreme fiber elongation determined in accordance with Table UG-79-1 exceeds 5% from the supplied condition. Heat treatment shall be applied in accordance with UCS-56, except that alternative heating and cooling rates and hold times may be applied to formed pipe and tube having a nominal thickness of $^1/_4$ in. (6 mm) or less when the heat treatment method is demonstrated to achieve a thorough heating of the pipe or tube.

(1) Cold-formed and bent P-No. 1 pipe and tube material having a nominal thickness not greater than $^3/_4$ in. (19 mm) does not require post-forming heat treatment.

(2) For P-No. 1, Group Nos. 1 and 2 materials other than those addressed by (1), post-forming heat treatment is required when the extreme fiber elongation exceeds 40% or if the extreme fiber elongation exceeds 5% and any of the following conditions exist:

(-a) The vessel will contain lethal liquid or gaseous substances (see UW-2).

(-b) The material is not exempt from impact testing by the rules of this Division, or impact testing is required by the material specification.

(-c) The nominal thickness of the part before cold forming exceeds $^5/_8$ in. (16 mm).

(-d) The reduction by cold forming from the nominal thickness is more than 10% at any location where the extreme fiber elongation exceeds 5%.

(-e) The temperature of the material during forming is in the range of 250°F to 900°F (120°C to 480°C).

(3) Cold-formed or bent P-Nos. 3 through 5C pipe and tube materials having an outside diameter not greater than $4^1/_2$ in. (114 mm) and a nominal thickness not greater than $^1/_2$ in. (13 mm) do not require a post-forming heat treatment.

The extreme fiber elongation shall be determined by the equations in Table UG-79-1.

(e) Forming of Creep-Strength-Enhanced Ferritic Steels (P-No. 15E Materials). The cold-formed areas of vessel shell sections, heads, and other pressure boundary parts of the creep-strength-enhanced ferritic steels shall be heat treated as listed in Table UCS-79-1. Cold forming is defined as any forming that is performed at a temperature below 1,300°F (705°C) and produces permanent strain in the material. Hot forming is defined as any forming that is performed at or above a temperature of 1,300°F (705°C) and produces permanent strain in the material. Forming strains (extreme fiber elongations) shall be calculated using the equations of Table UG-79-1.

(1) When the forming strains cannot be calculated as shown in Table UG-79-1, the Manufacturer shall have the responsibility to determine the maximum forming strain.

(2) For cold-formed flares, swages, or upsets in tubing and pipe, normalizing and tempering in accordance with Note (1) of Table UCS-79-1 shall apply, regardless of the amount of strain.

(3) For any hot-formed product form, normalizing and tempering in accordance with Note (1) of Table UCS-79-1 shall apply, regardless of the amount of strain.

(f) When vessel shell sections, heads, and other pressure boundary parts of carbon and low alloy steel are cold formed by other than the Manufacturer of the vessel, the required certification for the part shall indicate if the part has been heat treated per the requirements of UCS-79.

UCS-85 HEAT TREATMENT OF TEST SPECIMENS (**19**)

(a) The following provisions shall apply in addition to, or as exceptions to the general rules for heat treatment given in UG-85.

(b) Heat treatment as used in this section shall include all thermal treatments of the material during fabrication exceeding 900°F (480°C), except as exempted below.

(c) The material used in the vessel shall be represented by test specimens which have been subjected to the same heat treatments above the lower transformation temperature and postweld heat treatment except as provided in (e), (f), (g), (h), and (i) below. The kind and number of tests and test results shall be as required by the material specification. The vessel Manufacturer shall specify the temperature, time, and cooling rates to which the material will be subjected during fabrication, except as permitted in (h) below. Material from which the specimens

(19)

Table UCS-79-1
Post-Cold-Forming Strain Limits and Heat Treatment Requirements for P-No. 15E Materials

Grade	UNS Number	Limitations in Lower Temperature Range					Limitations in Higher Temperature Range			Required Heat Treatment When Design Temperature and Forming Strain Limits Are Exceeded
		For Design Temperature				And Forming Strains	For Design Temperature Exceeding		And Forming Strains	
		Exceeding		But Less Than or Equal to						
		°F	°C	°F	°C		°F	°C		
91	K90901	1,000	540	1,115	600	>25%	1,115	600	>20%	Normalize and temper [Note (1)]
		1,000	540	1,115	600	>5 to ≤25%	1,115	600	>5 to ≤20%	Post-forming heat treatment [Note (2)], [Note (3)], and [Note (4)]

GENERAL NOTE: The limits shown are for cylinders formed from plates, spherical or dished heads formed from plate, and tube and pipe bends. The forming strain limits tabulated above shall be divided by 2 if the equation, from Table UG-79-1, for double-curvature products such as heads, is applied.

NOTES:
(1) Normalization and tempering shall be performed in accordance with the requirements of the base material specification and shall not be performed locally. Either the material shall be heat treated in its entirety, or the cold-strained area (including the transition to the unstrained portion) shall be cut away from the balance of the component and heat treated separately, or replaced.
(2) Post-forming heat treatments shall be performed at 1,350°F to 1,435°F (730°C to 780°C) for 1 hr/in. (1 h/25 mm) or 30 min, minimum. Alternatively, a normalization and temper in accordance with the requirements in the base metal specification may be performed.
(3) For materials with greater than 5% strain but less than or equal to 25% strain with design temperatures less than or equal to 1,115°F (600°C), if a portion of the component is heated above the heat treatment temperature allowed in [Note (2)], one of the following actions shall be performed:
(a) The component in its entirety shall be renormalized and tempered.
(b) The allowable stress shall be that for Grade 9 material (i.e., SA-213 T9, SA-335 P9, or equivalent product specification) at the design temperature, provided that portion of the component that was heated to a temperature exceeding the maximum holding temperature is subjected to a final heat treatment within the temperature range and for the time required in [Note (2)]. The use of this provision shall be noted on the Manufacturer's Data Report.
(4) If a longitudinal weld is made to a portion of the material that is cold strained, that portion shall be normalized and tempered, prior to or following welding. This normalizing and tempering shall not be performed locally.

are prepared shall be heated at the specified temperature within reasonable tolerances such as are normal in actual fabrication. The total time at temperature shall be at least 80% of the total time at temperature during actual heat treatment of the product and may be performed in a single cycle.

(d) Thermal treatment of material is not intended to include such local heating as thermal cutting, preheating, welding, torch brazing, or heating below the lower transformation temperature of tubing and pipe for bending or sizing.

(e) An exception to the requirements of (c) above and UG-85 shall apply to standard nonwelded items such as described in UG-11(c) and UG-11(d). These may be subject to postweld heat treatment with the vessel or vessel part without the same treatment being required of the test specimens. This exception shall not apply to specially designed cast or wrought fittings.

(f) Materials conforming to one of the specifications listed in P-No. 1 Group Nos. 1 and 2 of Section IX, Table QW/QB-422 and all carbon and low alloy steels used in the annealed condition as permitted by the material specification are exempt from the requirements of (c) above when the heat treatment during fabrication is limited to postweld heat treatment at temperatures below the lower transformation temperature of the steel. This exemption does not apply to SA-841.

(g) Materials listed in Section IX, Table QW/QB-422 as P-No. 1 Group No. 3 and P-No. 3 Group Nos. 1 and 2 that are certified in accordance with (c) above from test specimens subjected to the PWHT requirements of Tables UCS-56-1 through UCS-56-11 need not be recertified if subjected to the alternate PWHT conditions permitted by Table UCS-56.1.

(h) The simulation of cooling rates for test specimens from nonimpact tested materials 3 in. and under in thickness is not required for heat treatments below the lower transformation temperature.

(i) All thermal treatments which precede a thermal treatment that fully austenitizes the material need not be accounted for by the specimen heat treatments, provided the austenitizing temperature is at least as high as any of the preceding thermal treatments.

INSPECTION AND TESTS

UCS-90 GENERAL

The provisions for inspection and testing in Subsections A and B shall apply without supplement to vessels constructed of carbon and low alloy steels.

MARKING AND REPORTS

UCS-115 GENERAL

The provisions for marking and reports in UG-115 through UG-120 shall apply without supplement to pressure vessels constructed of carbon and low alloy steels.

NONMANDATORY APPENDIX UCS-A

UCS-A-1 GENERAL

See Section II, Part D, Nonmandatory Appendix A, A-100.

UCS-A-2 CREEP–RUPTURE PROPERTIES OF CARBON STEELS

See Section II, Part D, Nonmandatory Appendix A, A-200.

UCS-A-3 VESSELS OPERATING AT TEMPERATURES COLDER THAN THE MDMT STAMPED ON THE NAMEPLATE

(a) Vessels or components may be operated at temperatures colder than the MDMT stamped on the nameplate, provided the provisions of UCS-66, UCS-67, and UCS-68 are met when using the reduced (colder) operating temperature as the MDMT, but in no case shall the operating temperature be colder than −155°F (−105°C).

(b) As an alternative to (a) above, for vessels or components whose thicknesses are based on pressure loading only, the coincident operating temperature may be as cold as the MDMT stamped on the nameplate less the allowable temperature reduction as determined from Figure UCS-66.2. The ratio used in Step 3 of Figure UCS-66.2 shall be the ratio of maximum pressure at the coincident operating temperature to the MAWP of the vessel at the stamped MDMT, but in no case shall the operating temperature be colder than −155°F (−105°C).

NOTE: One common usage of the exemptions in (a) and (b) is for vessels in which the internal pressure is dependent on the vapor pressure of the contents (e.g., vessels in refrigeration or hydrocarbon processing plants with operating systems that do not permit immediate repressurization). For such services, the primary thickness calculations (shell and head) are normally made for the maximum design pressure coincident with the design temperature (MDMT). The ratio of required thickness to nominal thickness as defined in Figure UCS-66.2, Step 3, for the design condition is then calculated. Thickness calculations are also made for other expected pressures at coincident temperature, along with the ΔT difference from the MDMT at design pressure, and the thickness ratio defined in Step 3 of Figure UCS-66.2. The ratio/ΔT points are then plotted on Figure UCS-66.1. Ratio/ΔT points that are on or below the Figure UCS-66.1 curve are acceptable, but in no case may the operating temperature be colder than −155°F (−104°C). See also ASME PTB-4–2012, example 3.3. Comparison of pressure–temperature or stress–temperature coincident ratios may also be used as noted in Figure UCS-66.1.

ENDNOTES

1 The water may contain additives, provided the flash point of the aqueous solution at atmospheric pressure is 185°F or higher. The flash point shall be determined by the methods specified in ASTM D93 or in ASTM D56, whichever is appropriate.

2 Requirements for pressure vessels for human occupancy are covered by ASME PVHO-1.

3 These requirements for design, fabrication, testing, and material for non-pressure-part attachments do not establish the length, size, or shape of the attachment material. Pads and standoffs are permitted and the scope can terminate at the next welded or mechanical joint.

4 See UG-90(b) and UG-90(c)(1) for summaries of the responsibilities of the Manufacturer and the duties of the Inspector.

5 Guidance for conversion of units from U.S. Customary to SI is found in Nonmandatory Appendix GG.

6 In some instances the limitations of the scope clause in the material specifications are based on a very realistic maximum. It is recommended that the designer and/or fabricator confer with the material manufacturer or supplier before proceeding, thus assuring himself that except for size or thickness, all requirements of the material specification will be met and so certified.

7 The term "plate" for the purpose of this usage includes sheet and strip also.

8 Pipe and tubing fabricated by fusion welding, with filler metal added, may not be used in Code construction unless it is fabricated in accordance with Code rules as a pressure part.

9 The pressure differential method is described in "Materials Research Standards," Vol. 1, No. 7, July 1961, published by ASTM.

10 When a pressure vessel is expected to operate at more than one pressure and temperature condition, other values of maximum allowable working pressure with the coincident permissible temperature may be added as required. See UG-20(b).

11 It is recommended that a suitable margin be provided above the pressure at which the vessel will be normally operated to allow for probable pressure surges in the vessel up to the setting of the pressure-relieving devices (see UG-134).

12 For the basis on which the tabulated stress values have been established, see Section II, Part D, Mandatory Appendix 1.

13 See 3-2, Definition of Terms.

14 The user of the Code is cautioned that for elevated metal temperatures when high membrane stress and/or high bending stress exist in the section, some inelastic straining due to creep in excess of the limits allowed by the criteria of Section II, Part D, Mandatory Appendix 1 may occur.

15 UG-23(d) permits an increase in allowable stress when earthquake or wind loading is considered in combination with other loads and pressure defined in UG-22. The 1.2 increase permitted is equivalent to a load reduction factor of 0.833. Some standards which define applicable load combinations do not permit an increase in allowable stress, however a load reduction factor (typically 0.75) is applied to multiple transient loads (e.g., wind plus live load, seismic plus live load, etc.).

16 *Pilot casting* — Any one casting, usually one of the first from a new pattern, poured of the same material and using the identical foundry procedure (risering, gating, pouring, and melting) as the castings it is intended to represent. Any pilot casting or castings taken to represent a lot and the castings of that lot shall be poured from a heat of metal from which the castings on the current order are poured.

17 Critical sections: For static castings, the sections where imperfections are usually encountered are abrupt changes in section and at the junctions of risers, gates, or feeders to the casting. For centrifugal castings, *critical sections* shall be interpreted to be any abrupt changes of section, the circumference for a distance of at least 3 in. (75 mm) from each end, and one additional circumferential band at least 3 in. (75 mm) wide and including the area of the most severe indication detected by other examination methods.

18 Formulas in terms of the outside radius and for thicknesses and pressures beyond the limits fixed in this paragraph are given in 1-1 to 1-3.

19 For pipe, the inside radius R is determined by the nominal outside radius minus the nominal wall thickness.

20 These formulas will govern only when the circumferential joint efficiency is less than one-half the longitudinal joint efficiency, or when the effect of supplementary loadings (UG-22) causing longitudinal bending or tension in conjunction with internal pressure is being investigated.

21 It is recommended that a suitable margin be provided when establishing the maximum allowable external working pressure to allow for pressure variations in service.

22 In order to ensure that a finished head is not less than the minimum thickness required, it is customary to use a thicker plate to take care of possible thinning during the process of forming. The neck of an opening in a head with an integrally flanged opening will thin out due to the fluing operation. This is permissible, provided the neck thickness is not less than the thickness required for a cylindrical shell subject to internal and/or external pressure, as applicable, and having an inside diameter equal to the maximum diameter of the opening [see UG-38(a) and UG-46(j)].

23 Formulas in terms of outside dimensions and for heads of other proportions are given in 1-4.

24 Special consideration shall be given to the design of shells, nozzle necks or flanges to which noncircular heads or covers are attached [see U-2(g)].

25 The formulas provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

26 The rules governing openings as given in this Division are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.

27 The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

28 An obround opening is one which is formed by two parallel sides and semicircular ends.

29 In the corroded condition, see UG-16(e).

30 All dimensions given, for size of vessel on which inspection openings are required, are nominal.

31 Dimensions referred to are nominal.

32 The minimum cross section is usually at the root of the thread.

33 The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups which extend a distance greater than the inside diameter of the shell as covered in (e) above. When this occurs, the efficiencies computed by the rules under (b) above shall govern.

34 Where applicable for Part UCS materials, the impact test temperature may be adjusted in accordance with UG-84(b)(2) and Table UG-84.4.

35 The maximum allowable working pressure may be assumed to be the same as the design pressure when calculations are not made to determine the maximum allowable working pressure.

36 In some cases it is desirable to test vessels when partly filled with liquids. For such vessels a combined hydrostatic and pneumatic test may be used as an alternative to the pneumatic test of this paragraph, provided the liquid level is set so that the maximum stress including the stress produced by pneumatic pressure at any point in the vessel

(usually near the bottom) or in the support attachments, does not exceed 1.3 times the allowable stress value of the material multiplied by the applicable joint efficiency. After setting the liquid level to meet this condition, the test is conducted as prescribed in (b) and (c) above.
Air or gas is hazardous when used as a testing medium. It is therefore recommended that special precautions be taken when air or gas is used for test purposes.

37 Examples of the use of modeling techniques are found in UG-127(a)(2)(-a)(-1)(+b) and UG-131(d)(2)(-b), or refer to textbooks on the subject.

38 The maximum allowable working pressure (external) is required only when specified as a design condition.

39 See UG-90(c)(2) for additional requirements applicable to mass produced pressure vessel fabrication.

40 In this usage, organization may be the same company at a single site, a multiplant company with separate Certificates of Authorization, regardless of type, or a multiplant corporation with extended corporate Certificates of Authorization.

41 For the purpose of these rules, gases are considered to be substances having a vapor pressure greater than 40 psia (300 kPa absolute) at 100°F (40°C).

42 Normally this temperature should not be less than 115°F (45°C).

43 A *pressure relief valve* is a pressure relief device which is designed to reclose and prevent the further flow of fluid after normal conditions have been restored. A *nonreclosing pressure relief device* is a pressure relief device designed to remain open after operation.

44 A *safety valve* is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action. A *relief valve* is a pressure relief valve actuated by inlet static pressure which opens in proportion to the increase in pressure over the opening pressure. A *safety relief valve* is a pressure relief valve characterized by rapid opening or pop action, or by opening in proportion to the increase in pressure over the opening pressure, depending on application. A *pilot-operated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and is controlled by a self-actuated auxiliary pressure relief valve.

45 A *rupture disk device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure-containing disk. A *rupture disk* is the pressure-containing and pressure-sensitive activation component of a rupture disk device. Rupture disks may be designed in several configurations, such as plain flat, prebulged, or reverse buckling. A *rupture disk holder* is the structure that encloses and clamps the rupture disk in position.

46 The *manufacturing design range* is a range of pressure within which the marked burst pressure must fall to be acceptable for a particular requirement as agreed upon between the rupture disk Manufacturer and the user or his designated agent. The manufacturing design range must be evaluated in conjunction with the specified burst pressure to ensure that the marked burst pressure of the rupture disk will always be within applicable limits of UG-134. Users are cautioned that certain types of rupture disks have manufacturing ranges that can result in a marked burst pressure greater than the specified burst pressure.

47 The specified disk temperature supplied to the rupture disk Manufacturer shall be the temperature of the disk when the disk is expected to burst.

48 A *lot of rupture disks* is those disks manufactured of a material at the same time, of the same size, thickness, type, heat, and manufacturing process including heat treatment.

49 The *minimum net flow area* is the calculated net area after a complete activation of the rupture disk or pin device with appropriate allowance for any structural members which may reduce the net flow area through the device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

50 The *certified flow resistance* K_R is a dimensionless factor used to calculate the velocity head loss that results from the presence of a nonreclosing pressure relief device in a pressure relief system.

51 Use of a rupture disk device in combination with a pressure relief valve shall be carefully evaluated to ensure that the media being handled and the valve operational characteristics will result in opening of the valve coincident with the bursting of the rupture disk.

52 Users are warned that a rupture disk will not burst at its design pressure if back pressure builds up in the space between the disk and the pressure relief valve which will occur should leakage develop in the rupture disk due to corrosion or other cause.

53 This use of a rupture disk device in series with the pressure relief valve is permitted to minimize the loss by leakage through the valve of valuable or of noxious or otherwise hazardous materials, and where a rupture disk alone or disk located on the inlet side of the valve is impracticable, or to prevent corrosive gases from a common discharge line from reaching the valve internals.

54 Users are warned that many types of pressure relief valves will not open at the set pressure if pressure builds up in the space between the pressure relief valve disk and the rupture disk device. A specially designed pressure relief valve such as a diaphragm valve, pilot-operated valve, or a valve equipped with a balancing bellows above the disk may be required.

55 Some adverse effects resulting from leakage may include obstructing the flow path, corrosion of pressure relief valve components, and undesirable bursts of the outlet side rupture disk.

56 A *pin device* is a nonreclosing pressure relief device actuated by inlet static or differential pressure and designed to function by the activation of a load bearing section of a pin that supports a pressure-containing member. A *pin* is the load bearing activation component of a pin device its crosssectional area is not limited to a circular shape. A *pin device body* is the structure that encloses the pressure-containing members.

57 The specified temperature supplied to the pin manufacturer shall be the temperature of the pin when an emergency condition exists and the pin is expected to activate.

58 Vacuum relief devices are not covered by Certification Mark requirements.

59 Pressure relief device capacities flow resistances are published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229.

60 The *set pressure* is the value of increasing inlet static pressure at which a pressure relief device displays one of the operational characteristics as defined by opening pressure, popping pressure, start-to-leak pressure, burst pressure, breaking pressure or buckling pressure. (The applicable operating characteristic for a specific device design is specified by the device Manufacturer.)

61 Users are warned that the proper operation of nonreclosing pressure relief devices depends upon following the Manufacturer's installation instructions closely with regard to the flow direction marked on the device. Some device designs will burst at pressures much greater than their marked burst pressure when installed with the process pressure on the vent side of the device.

62 The User may specify a higher test pressure commensurate with the back pressure anticipated in service.

63 The *pin temperature* may be different from the operating temperature for devices where the pin is isolated from operating conditions.

64 By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid mixed or unmixed with air is dangerous to life when inhaled. For purposes of this Division, this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel.

65 *Communicating chambers* are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure-containing enclosure, e.g., sumps.

66 *Side plates of a flat-sided vessel* are defined as any of the flat plates forming an integral part of the pressure-containing enclosure.

67 One test specimen may represent a group of forgings, provided they are of the same design, are from the same heat of material and are forged in the same manner.

68 *Welder* includes brazer, welding operator, and brazing operator.

69 Examination shall be by magnetic particle or liquid penetrant methods when the material is ferromagnetic, or by the liquid penetrant method when the material is nonferromagnetic.

70 It is not the intent of this paragraph to require measurement of reductions in thickness due to the welding process. If a disagreement between the Manufacturer and the Inspector exists as to the acceptability of any reduction in thickness, the depth shall be verified by actual measurement.

71 Concavity due to the welding process on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld is at least equal to the thickness of the thinner member of the two sections being joined and the contour of the concavity is smooth.

72 Furnace gas temperature measurement alone is not considered sufficiently accurate.

73 Flux residues can be extremely corrosive as well as interfering with visual inspection.

74 Low alloy steels — those alloy steels listed in Table UCS-23.

75 See Section II, Part D, Mandatory Appendix 1 for the basis on which the allowable stress values have been established.

76 The rates of heating and cooling need not be less than 100°F/hr (56°C/h). However, in all cases consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

77 No provisions of this paragraph waive other requirements of this Division, such as UW-2(a), UW-2(d), UW-10, and UCS-56.

78 This is defined in Section V, Article 2, T-277, and A-1(a).

79 Thermal treatments of materials are not intended to include warming to temperatures not exceeding 600°F (315°C), thermal cutting, or welding.

80 Either base metal or weld metal.

81 Calculated stress from pressure and nonpressure loadings, including those listed in UG-22 which result in general primary membrane tensile stress.

82 See Section II, Part D, Nonmandatory Appendix A, A-206.

83 By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid mixed or unmixed with air is dangerous to life, when inhaled. For purposes of this Division, this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel.

84 It is the intent that cast ductile irons with an elongation of less than 15% in 2 in. (50 mm) be treated as cast iron and that vessels or pressure parts of such material be designed and fabricated in accordance with the rules in Part UCI.

85 Buttered means buildup overlay welding.

86 Temper bead welding technique is done when the final beads of welding are made over-flush, deposited only on previous beads of welding for tempering purposes without making contact with the base metal, and then removing these final beads.

87 Layer wash is defined as the indications resulting from slight weld penetration at the layer interfaces.

88 Ellipsoidal heads designed under $K > 1.0$ and all torispherical heads made of materials having a specified minimum tensile strength exceeding 70,000 psi (485 MPa) shall be designed using a value of S equal to 20,000 psi (138 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in the appropriate table (see UG-23).

89 When the flange material is cast iron, particular care should be taken when tightening the bolts to avoid excessive stress that may break the flange. The longitudinal hub stress has been limited to S_f in order to minimize any cracking of flanges. An attempt should be made to apply no greater torque than is needed to assure tightness during the hydrostatic test.

90 Loose flanges of the type shown in Figure 2-4, sketch (1) are of the split design when it is necessary to install them after heat treatment of a stainless steel vessel, or when for any reason it is desired to have them completely removable from the nozzle neck or vessel.

91 When internal pressure occurs only during the required pressure test, the design may be based on external pressure, and auxiliary devices such as clamps may be used during the application of the required test pressure.

92 The Code as currently written provides minimum requirements for construction and it is recognized to be the responsibility of the designing engineer to determine when the intended service is of a nature that requires supplementary requirements to ensure safety; consequently, the designer should determine when the service warrants that this class of inspection be specified for steel castings of less than 4 in. (100 mm) nominal body thickness.

93 The coefficients of these formulas include a factor that effectively increases the allowable stress for such construction to 1.5S.

94 The complexity of the work includes factors such as design simplicity versus complexity, the types of materials and welding procedures used, the thickness of materials, the types of nondestructive examinations applied, and whether heat treatments are applied.

95 The size and complexity of the organization includes factors such as the number of employees, the experience level of employees, the number of Code items produced, and whether the factors defining the complexity of the work cover a wide or narrow range.

96 Knowing the official rating capacity of a safety valve which is stamped on the valve, it is possible to determine the overall value of KA in either of the following formulas in cases where the value of these individual terms is not known:

Official Rating in Steam	Official Rating in Air
$KA = \frac{W_s}{51.5P}$	$KA = \frac{W_a}{CP}\sqrt{\frac{T}{M}}$

This value for KA is then substituted in the above formulas to determine the capacity of the safety valve in terms of the new gas or vapor.

97 Use E = 1.0 for Category C and D joints that are not butt welded since stresses in these joints are controlled by the applicable rules for sizing such joints. See Figures UG-34 and UW-13.2

98 $I = bt^3/12$ where b = 1.0 for vessels without reinforcements and for vessels with stay plates or stay rods. $I = pt^3/12$ for vessels with reinforcements that do not extend around the corners of the vessel [see Figure 13-2(a), sketches (5) and (6)].

99 For unreinforced vessels of rectangular cross section (13-7 and parts of 13-18), the given moments are defined on a per-unit-width basis. That is, moments have dimensions [Length × Force/Length] = [Force].

100 See Manual of Steel Construction, AISC, American Institute of Steel Construction, Inc., One East Wacker Drive, Chicago, IL 60601-1802.

101 Air or gas is hazardous when used as a testing medium. It is therefore recommended the vessel be tested in such a manner as to ensure personnel safety from a release of the total internal energy of the vessel. See also ASME PCC-2, Article 501, Mandatory Appendix 501-II, "tored Energy Calculations for Pneumatic Pressure Test," and Mandatory Appendix 501-III, "Safe Distance Calculations for Pneumatic Pressure Test."

102 When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

103 See "Stresses in Large Cylindrical Pressure Vessels on Two Saddle Supports," p. 959, *Pressure Vessels and Piping: Design and Analysis, A Decade of Progress*, Volume Two, published by ASME.

104 See Transactions ASCE, Volume 98 — 1931 "Design of Large Pipe Lines."

105 This construction has the further advantage of not transmitting discharge-pipe strains to the valve. In these types of installation, the back pressure effect will be negligible, and no undue influence upon normal valve operation can result.

106 A Nonmandatory Appendix Y flange bolted to a rigid foundation may be analyzed as a Class 1 assembly by substituting 2l for l in eq. Y-6.1(12) of Y-6.1.

107 Where the flanges are identical dimensionally and have the same elastic modulus E, but have different allowable stresses S_f, the assembly may be analyzed as a Class 1 assembly, provided the calculated stresses are evaluated against the lower allowable stress.

108 The symbols for the various stresses in the case of a Class 3 assembly also carry the subscript I or II. For example, $S_{H\mathrm{I}}$ represents the longitudinal hub stress in Flange I of the Class 3 assembly.

109 Manufacturers are cautioned to calculate the minimum ratio based upon mill test values of the tube and tubesheet.

110 The Manufacturer may correlate rolling torque, hydraulic expanding pressure, or explosive charge with shear load tests. For explosive expanding, the Manufacturer may correlate interference of fit.

MANDATORY APPENDIX 4
ROUNDED INDICATIONS CHARTS ACCEPTANCE STANDARD FOR RADIOGRAPHICALLY DETERMINED ROUNDED INDICATIONS IN WELDS

4-1 APPLICABILITY OF THESE STANDARDS

These standards are applicable to ferritic, austenitic, and nonferrous materials.

Table 4-1

Customary Units			
	Maximum Size of Acceptable Rounded Indication, in.		Maximum Size of Nonrelevant Indication, in.
Thickness, t, in.	**Random**	**Isolated**	
Less than $^1/_8$	$^1/_4\ t$	$^1/_3\ t$	$^1/_{10}\ t$
$^1/_8$	0.031	0.042	0.015
$^3/_{16}$	0.047	0.063	0.015
$^1/_4$	0.063	0.083	0.015
$^5/_{16}$	0.078	0.104	0.031
$^3/_8$	0.091	0.125	0.031
$^7/_{16}$	0.109	0.146	0.031
$^1/_2$	0.125	0.168	0.031
$^9/_{16}$	0.142	0.188	0.031
$^5/_8$	0.156	0.210	0.031
$^{11}/_{16}$	0.156	0.230	0.031
$^3/_4$ to 2, incl.	0.156	0.250	0.031
Over 2	0.156	0.375	0.063

SI Units			
	Maximum Size of Acceptable Rounded Indication, mm		Maximum Size of Nonrelevant Indication, mm
Thickness, t, mm	**Random**	**Isolated**	
Less than 3	$^1/_4\ t$	$^1/_3\ t$	$^1/_{10}\ t$
3	0.79	1.07	0.38
5	1.19	1.60	0.38
6	1.60	2.11	0.38
8	1.98	2.64	0.79
10	2.31	3.18	0.79
11	2.77	3.71	0.79
13	3.18	4.27	0.79
14	3.61	4.78	0.79
16	3.96	5.33	0.79
17	3.96	5.84	0.79
19.0 to 50, incl.	3.96	6.35	0.79
Over 50	3.96	9.53	1.60

GENERAL NOTE: This Table contains examples only.

4-2 TERMINOLOGY

(a) Rounded Indications. Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any imperfection in the weld, such as porosity, slag, or tungsten.

(b) Aligned Indications. A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

(c) Thickness t. t is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

4-3 ACCEPTANCE CRITERIA

(a) Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

(b) Relevant Indications. (See Table 4-1 for examples.) Only those rounded indications which exceed the following dimensions shall be considered relevant.

(1) $^1/_{10}t$ for t less than $^1/_8$ in. (3 mm)

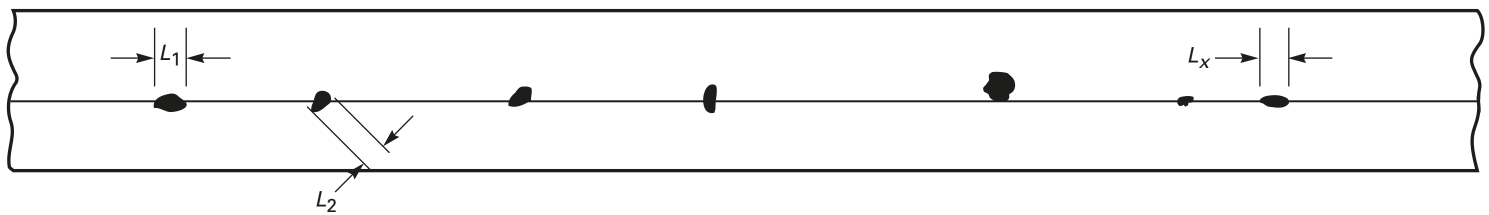
(2) $^1/_{64}$ in. for t from $^1/_8$ in. to $^1/_4$ in. (3 mm to 6 mm), incl.

(3) $^1/_{32}$ in. for t greater than $^1/_4$ in. to 2 in. (6 mm to 50 mm), incl.

(4) $^1/_{16}$ in. for t greater than 2 in. (50 mm)

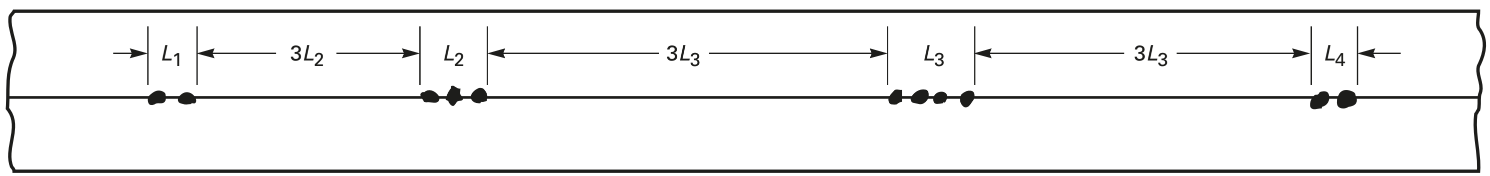
(c) Maximum Size of Rounded Indication. (See Table 4-1 for examples.) The maximum permissible size of any indication shall be $^1/_4t$, or $^5/_{32}$ in. (4 mm), whichever is smaller; except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be $^1/_3t$, or $^1/_4$ in. (6 mm), whichever is less. For t greater than 2 in. (50 mm) the maximum permissible size of an isolated indication shall be increased to $^3/_8$ in. (10 mm).

Figure 4-1
Aligned Rounded Indications



GENERAL NOTE: Sum of L_1 to L_x shall be less than t in a length of $12t$.

Figure 4-2
Groups of Aligned Rounded Indications



Maximum Group Length

L = $^1/_4$ in. (6 mm) for t less than $^3/_4$ in. (19 mm)
L = $^1/_3t$ for t $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm)
L = $^3/_4$ in. (19 mm) for t greater than $2^1/_4$ in. (57 mm)

Minimum Group Spacing

$3L$ where L is the length of the longest adjacent group being evaluated

GENERAL NOTE: Sum of the group lengths shall be less than t in a length of $12t$.

(d) Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$. See Figure 4-1. The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure 4-2.

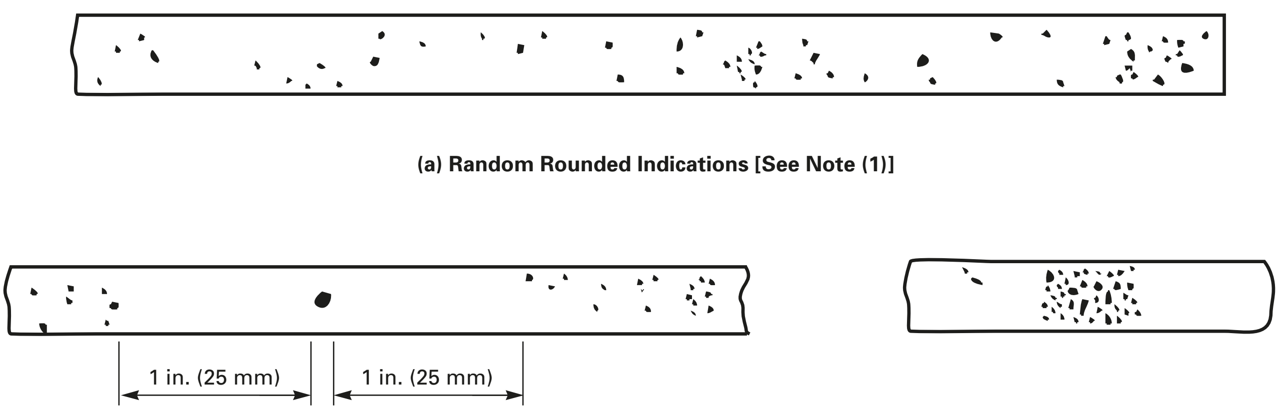
(e) Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

(f) Rounded Indication Charts. The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures 4-3 through 4-8 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than $^1\!/_8$ in. (3 mm). These charts represent the maximum acceptable concentration limits for rounded indications. The charts for each thickness range represent full-scale 6 in. (150 mm) radiographs, and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

(g) Weld Thickness t Less Than $^1\!/_8$ in. (3 mm). For t less than $^1\!/_8$ in. (3 mm) the maximum number of rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (150 mm) in length.

(h) Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (150 mm) length weld.

Figure 4-3
Charts for t Equal to $^1\!/_8$ in. to $^1\!/_4$ in. (3 mm to 6 mm), Inclusive



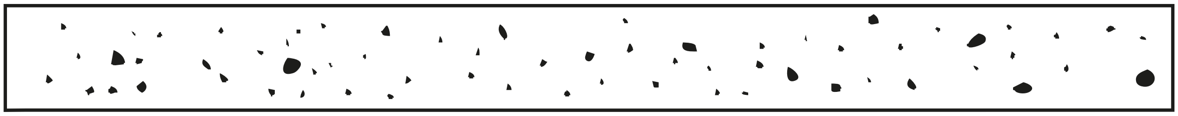
(a) Random Rounded Indications [See Note (1)]

(b) Isolated Indication [See Note (2)]

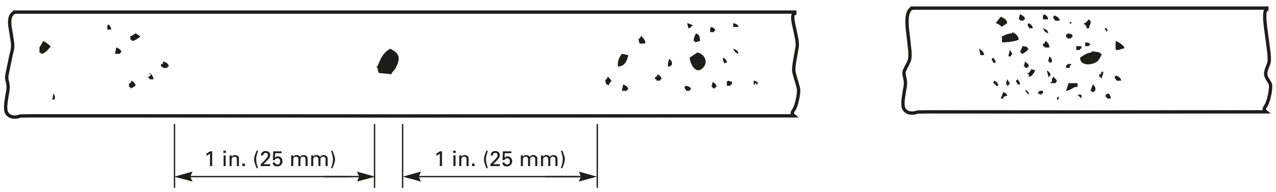
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-4
Charts for t Over $\frac{1}{4}$ in. to $\frac{3}{8}$ in. (6 mm to 10 mm), Inclusive



(a) Random Rounded Indications [See Note (1)]

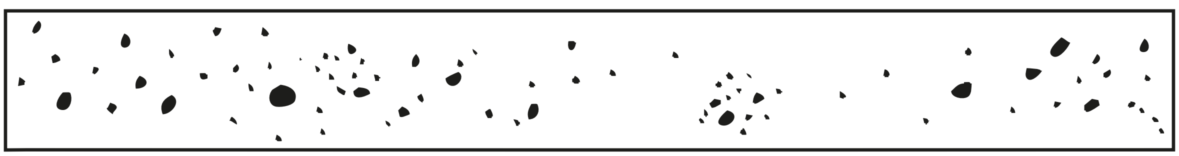


(b) Isolated Indication [See Note (2)]

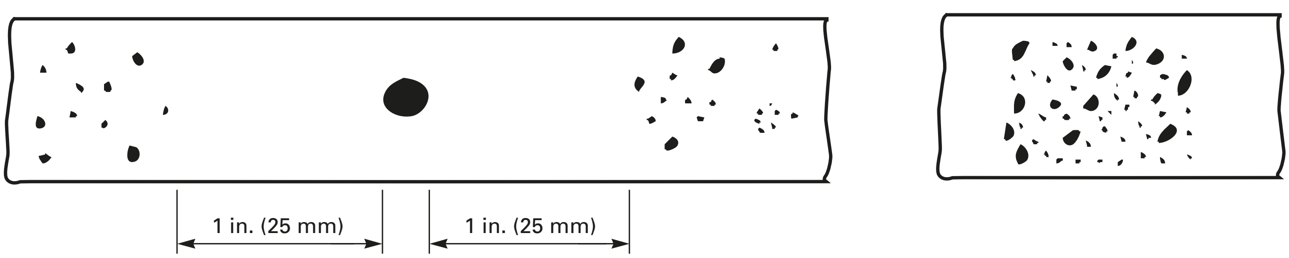
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-5
Charts for t Over $\frac{3}{8}$ in. to $\frac{3}{4}$ in. (10 mm to 19 mm), Inclusive



(a) Random Rounded Indications [See Note (1)]

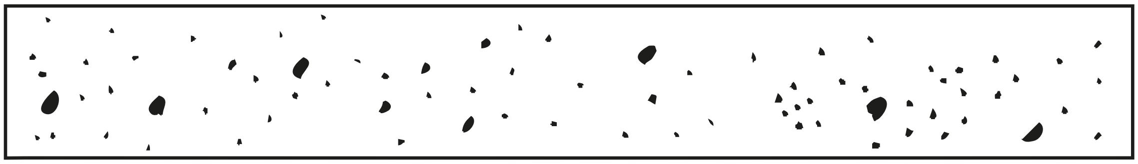


(b) Isolated Indication [See Note (2)]

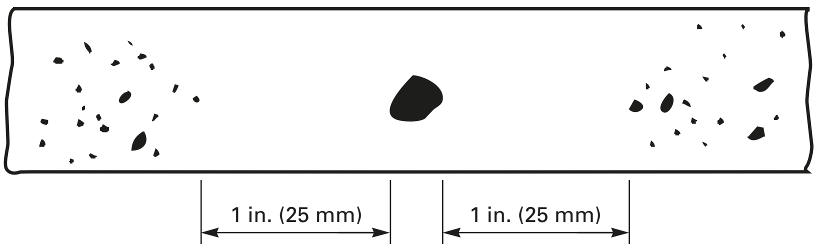
(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

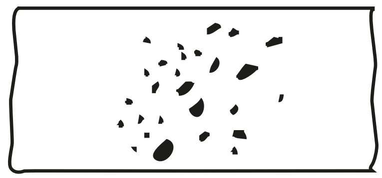
Figure 4-6
Charts for t Over $\frac{3}{4}$ in. to 2 in. (19 mm to 50 mm), Inclusive



(a) Random Rounded Indications [See Note (1)]



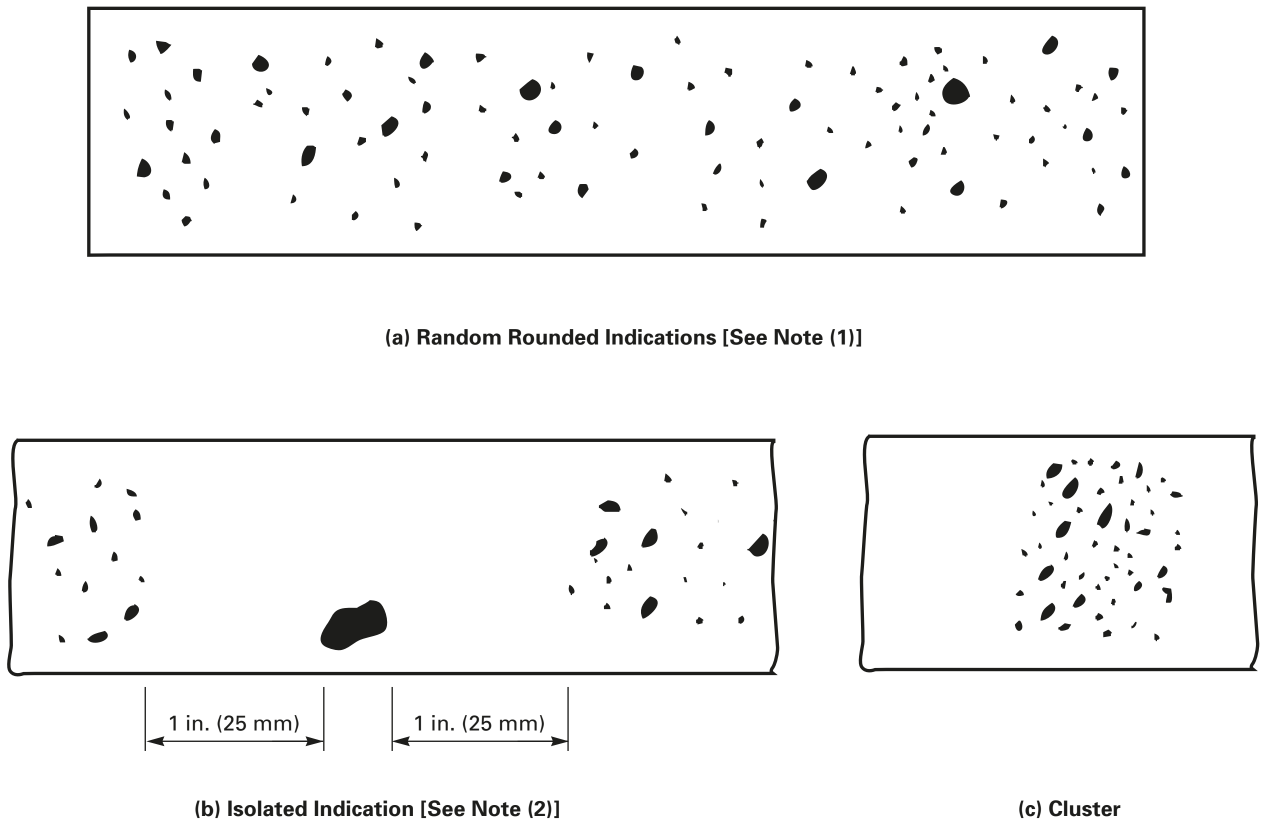
(b) Isolated Indication [See Note (2)]



(c) Cluster

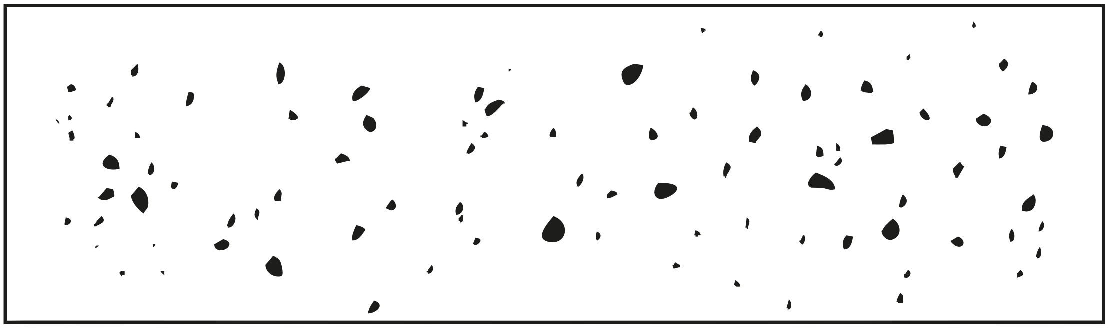
NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

Figure 4-7
Charts for t Over 2 in. to 4 in. (50 mm to 100 mm), Inclusive

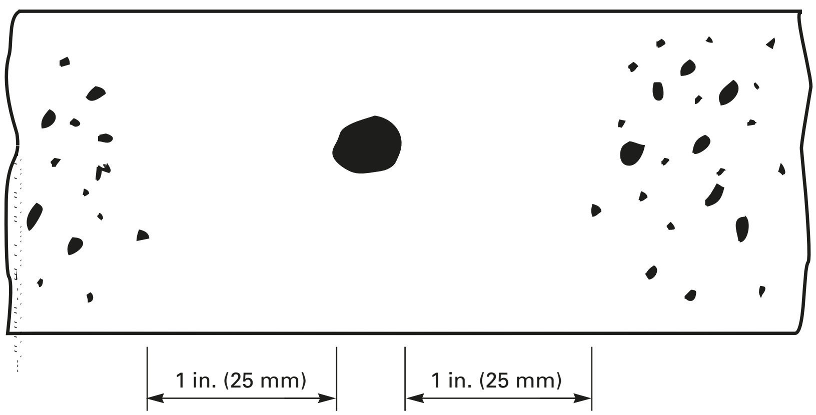


NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

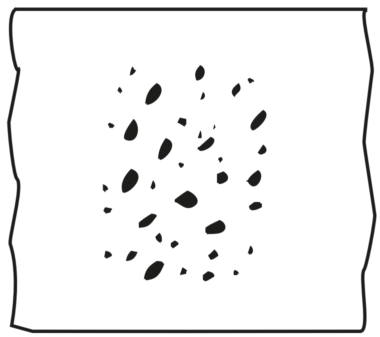
Figure 4-8
Charts for *t* Over 4 in. (100 mm)



(a) Random Rounded Indications [See Note (1)]



(b) Isolated Indication [See Note (2)]



(c) Cluster

NOTES:
(1) Typical concentration and size permitted in any 6 in. (150 mm) length of weld.
(2) Maximum size per Table 4-1.

MANDATORY APPENDIX 6
METHODS FOR MAGNETIC PARTICLE EXAMINATION (MT)

6-1 SCOPE

(a) This Appendix provides for procedures which shall be followed whenever magnetic particle examination is specified in this Division.

(b) Section V, Article 7 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.

(c) Magnetic particle examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150

(d) Documentation showing that the required examinations have been performed and that the results are acceptable shall be made available to the Inspector.

6-2 CERTIFICATION OF COMPETENCY FOR NONDESTRUCTIVE EXAMINATION PERSONNEL

The manufacturer shall certify that each magnetic particle examiner meets the following requirements:

(a) He/she has vision, with correction if necessary, to enable him/her to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in., and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) He/she is competent in the techniques of the magnetic particle examination method for which he/she is certified, including making the examination and interpreting and evaluating the results, except that where the examination method consists of more than one operation, he/she may be certified as being qualified only for one or more of these operations.

6-3 EVALUATION OF INDICATIONS

Indications will be revealed by retention of magnetic particles. All such indications are not necessarily imperfections, however, since excessive surface roughness, magnetic permeability variations (such as at the edge of heat-affected zones), etc., may produce similar indications.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications which have any dimension greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(a) A linear indication is one having a length greater than three times the width.

(b) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(c) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

6-4 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division.

All surfaces to be examined shall be free of:

(a) relevant linear indications;

(b) relevant rounded indications greater than $^3/_{16}$ in. (5 mm);

(c) four or more relevant rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less, edge to edge.

6-5 REPAIR REQUIREMENTS

The defect shall be removed or reduced to an imperfection of acceptable size. Whenever an imperfection is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

(a) Treatment of Indications Believed Nonrelevant. Any indication which is believed to be nonrelevant shall be regarded as an imperfection unless it is shown by reexamination by the same method or by the use of other nondestructive methods and/or by surface conditioning that no unacceptable imperfection is present.

(b) Examination of Areas From Which Imperfections Have Been Removed. After a defect is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to ensure it has been removed or reduced to an acceptably sized imperfection.

(c) Reexamination of Repair Areas. After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners and reexamined by the magnetic particle method and by all other methods of examination that were originally required for the affected area, except that, when the depth of repair is less than the radiographic sensitivity required, reradiography may be omitted.

MANDATORY APPENDIX 8
METHODS FOR LIQUID PENETRANT EXAMINATION (PT)

NOTE: Satisfactory application of this method of examination requires special skills in the techniques involved and in interpreting the results. The requirements specified herein presume application by suitably experienced personnel.

8-1 SCOPE

(a) This Appendix describes methods which shall be employed whenever liquid penetrant examination is specified in this Division.

(b) Section V, Article 6 shall be applied for detail requirements in methods and procedures, unless otherwise specified within this Appendix.

(c) Liquid penetrant examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

(d) Documentation showing that the required examinations have been performed and that the results are acceptable shall be made available to the Inspector.

8-2 CERTIFICATION OF COMPETENCY OF NONDESTRUCTIVE EXAMINATION PERSONNEL

The manufacturer shall certify that each liquid penetrant examiner meets the following requirements.

(a) He has vision, with correction if necessary, to enable him to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in. (300 mm), and is capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) He is competent in the techniques of the liquid penetrant examination method for which he is certified, including making the examination and interpreting and evaluating the results, except that, where the examination method consists of more than one operation, he may be certified as being qualified only for one or more of these operations.

8-3 EVALUATION OF INDICATIONS

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(a) A linear indication is one having a length greater than three times the width.

(b) A rounded indication is one of circular or elliptical shape with the length equal to or less than three times the width.

(c) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

8-4 ACCEPTANCE STANDARDS

These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division.

All surfaces to be examined shall be free of:

(a) relevant linear indications;

(b) relevant rounded indications greater than $^3/_{16}$ in. (5 mm);

(c) four or more relevant rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less (edge to edge).

8-5 REPAIR REQUIREMENTS

Unacceptable imperfections shall be repaired and reexamination made to assure removal or reduction to an acceptable size. Whenever an imperfection is repaired by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after repair of an imperfection, the area shall be cleaned and welding performed in accordance with a qualified welding procedure.

(a) Treatment of Indications Believed Nonrelevant. Any indication which is believed to be nonrelevant shall be regarded as an imperfection unless it is shown by reexamination by the same method or by the use of other nondestructive methods and/or by surface conditioning that no unacceptable imperfection is present.

(b) Examination of Areas From Which Defects Have Been Removed. After a defect is thought to have been removed and prior to making weld repairs, the area shall be examined by suitable methods to ensure it has been removed or reduced to an acceptably sized imperfection.

(c) Reexamination of Repair Areas. After repairs have been made, the repaired area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners and reexamined by the liquid penetrant method and by all other methods of examination that were originally required for the affected area, except that, when the depth of repair is less than the radiographic sensitivity required, reradiography may be omitted.

MANDATORY APPENDIX 12
ULTRASONIC EXAMINATION OF WELDS (UT)

12-1 SCOPE

(a) This Appendix describes methods which shall be employed when ultrasonic examination of welds is specified in this Division.

(b) Section V, Article 4 shall be applied for detail requirements in methods and procedures, unless otherwise specified in this Appendix.

(c) Ultrasonic examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

12-2 CERTIFICATION OF COMPETENCE OF NONDESTRUCTIVE EXAMINER

Personnel performing and evaluating ultrasonic examinations required by this Division shall meet the requirements of UW-54.

12-3 ACCEPTANCE–REJECTION STANDARDS

These Standards shall apply unless other standards are specified for specific applications within this Division.

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) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

(b) Other imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths which exceed:

(1) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm);

(2) $^1/_3t$ for t from $^3/_4$ in. to $2^1/_4$ in. (19 mm to 57 mm);

(3) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm).

where t is the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

12-4 REPORT OF EXAMINATION

The Manufacturer shall prepare a report of the ultrasonic examination and a copy of this report shall be retained by the Manufacturer as required by this Division (10-13). The report shall contain the information required by Section V. In addition, a record of repaired areas shall be noted as well as the results of the reexamination of the repaired areas. The Manufacturer shall also maintain a record of all reflections from uncorrected areas having responses that exceed 50% of the reference level. This record shall locate each area, the response level, the dimensions, the depth below the surface, and the classification.