# PART PG
# GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION

## GENERAL

(17) **PG-1 SCOPE**

The requirements of Part PG apply to power boilers and high pressure, high-temperature water boilers and liquid phase thermal fluid heaters and to parts and appurtenances thereto and shall be used in conjunction with the specific requirements in the applicable Parts of this Section that pertain to the methods of construction used.

### PG-2 SERVICE LIMITATIONS

**PG-2.1** The rules of this Section are applicable to the following services:

*(a)* boilers in which steam or other vapor is generated at a pressure of more than 15 psig (100 kPa) for use external to itself

*(b)* high-temperature water boilers intended for operation at pressures exceeding 160 psig (1.1 MPa) and/or temperatures exceeding 250°F (120°C)

**PG-2.2** For services below those specified in PG-2.1 it is intended that rules of Section IV apply; however, boilers for such services may be constructed and stamped in accordance with this Section provided all applicable requirements are met.

**PG-2.3** Coil-type hot water boilers where the water can flash into steam when released directly to the atmosphere through a manually operated nozzle may be exempted from the rules of this Section provided the following conditions are met:

*(a)* There is no drum, header, or other steam space.

*(b)* No steam is generated within the coil.

*(c)* Tubing outside diameter does not exceed 1 in. (25 mm).

*(d)* Pipe size does not exceed NPS $^3/_4$ (DN 20).

*(e)* Nominal water capacity does not exceed 6 gal (23 L).

*(f)* Water temperature does not exceed 350°F (175°C).

*(g)* Adequate pressure relief valves and controls are provided.

(17) **PG-2.4**

**DELETED**

### PG-3 REFERENCED STANDARDS

The Manufacturer shall establish the effective Code Edition, Addenda, and Code Cases for boilers and replacement parts in accordance with Mandatory Appendix VI. Specific editions of standards referenced in this Section are shown in Table A-360.

### PG-4 UNITS

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

In general, it is expected that a single system of units shall be used for all aspects of design except where unfeasible or impractical. 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. 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.

For any single equation, all variables shall be expressed in a single system of units. 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 may be converted to other units.

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:

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

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

Conversion of units, using the precision specified above shall be performed to ensure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in A-391 through A-393 of Nonmandatory Appendix A. 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.

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 or SI units may be used regardless of the units system used in design.

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. It is acceptable to show alternate units parenthetically. Users of this Code are cautioned that the receiving jurisdiction should be contacted to ensure the units are acceptable.

# MATERIALS

## PG-5 GENERAL

**PG-5.1** Except as otherwise permitted in PG-8.2, PG-8.3, PG-10, and PG-11, material subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those that are listed in the Tables of Section II, Part D. The Manufacturer shall ensure that the correct material has been received and is properly identified before proceeding with construction (see A-302.4). Materials shall not be used at temperatures above those for which stress values are limited, for Section I construction, in the Tables of Section II, Part D. Specific additional requirements described in PG-5 through PG-13 shall be met as applicable.

**PG-5.2** Material covered by specifications in Section II is not restricted as to the method of production unless so stated in the specification, and as long as the product complies with the requirements of the specification.

**PG-5.3** If, in the development of the art of boiler construction, it is desired to use materials other than those herein described, data should be submitted to the Boiler and Pressure Vessel Committee in accordance with the requirements of Section II, Part D, Mandatory Appendix 5. Material not completely identified with any approved Code specifications may be used in the construction of boilers under the conditions outlined in PG-10.

### PG-5.4 Size Limits and Tolerances.

**PG-5.4.1** Materials outside the limits of size or thickness given in the title or scope clause of any specification in Section II may be used if the material is in compliance with the other requirements of the specification, and no similar limitation is given in the rules for construction.

**PG-5.4.2** Pipe having a tolerance of ±1% on either the O.D. or the I.D., rather than the tolerance specified in the material specification, may be used, provided the material complies with all other requirements of the specifications. When used under external pressure, such pipe shall be limited to a maximum of 24 in. (600 mm) in diameter. The pipe shall include the designation 1% O.D. or 1% I.D., as appropriate, in any required documentation and marking of the material.

**PG-5.5** The use of austenitic alloy steel is permitted for boiler pressure parts that are steam touched in normal operation. Except as specifically provided in PG-9.1.1, PG-12, PEB-5.3, and PFE-4, the use of such austenitic alloys for boiler pressure parts that are water wetted in normal service is prohibited.[1]

### PG-5.6 P-No. 15E, Group 1 Materials.

**PG-5.6.1** If during any phase of manufacturing or erection any portion of the component that does not contain a weld is heated to a temperature greater than 1,470°F (800°C), one of the following actions shall be performed:

*(a)* The component shall be reaustenitized and retempered in its entirety in accordance with the specification requirements.

*(b)* That portion of the component heated above 1,470°F (800°C), including the heat-affected zone created by the local heating, must be replaced or must be removed, reaustenitized, and retempered in accordance with the specification requirements and then replaced in the component.

*(c)* If the allowable stress values to be used are less than or equal to those provided in Section II, Part D, Subpart 1, Table 1A for Grade 9 (e.g., SA-213 T9, SA-335 P9, or equivalent product specifications) at the design temperature, then the requirements stated above may be waived, provided that the portion of the component heated above 1,470°F (800°C) is retempered in accordance with the specification requirements. The use of this provision shall be noted on the Manufacturer's Data Report.

**PG-5.6.2** If during any phase of manufacturing or erection of the component, any portion that does contain a weld is heated above 1,445°F (785°C), then the requirements of Notes (3) and (4) of Table PW-39-5 for P-No. 15E, Group 1 Materials, shall apply for reheat treatment.

## PG-6 PLATE

**PG-6.1** Steel plates for any part of a boiler subject to pressure, whether or not exposed to the fire or products of combustion, shall be of pressure vessel quality in accordance with one of the following specifications:

SA-204, Pressure Vessel Plates, Alloy Steel, Molybdenum

SA-240, (Type 405 only) Pressure Vessel Plates, Alloy Steel (Ferritic Stainless), Chromium

SA-285, Pressure Vessel Plates, Carbon Steel, Low-and Intermediate-Tensile Strength

SA-299, Pressure Vessel Plates, Carbon Steel, Manganese-Silicon

SA-302, Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel

SA-387, Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum

SA-515, Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service

SA-516, Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service

SA/AS 1548, Fine Grained, Weldable Steel Plates for Pressure Equipment

SA/EN-10028-2, Flat Products Made of Steels for Pressure Purposes

SA/GB 713, Steel Plates for Boilers and Pressure Vessels

SA/JIS G3118, Carbon Steel Plates for Pressure Vessels for Intermediate and Moderate Temperature Service

## PG-7 FORGINGS

**PG-7.1** Seamless steel drum forgings made in accordance with SA-266 for Carbon-Steel and SA-336 for Alloy Steel may be used for any part of a boiler for which pressure vessel quality is specified or permitted.

**PG-7.2** Forged flanges, fittings, nozzles, valves, and other pressure parts of the boiler shall be of material that conforms to one of the forging specifications as listed in PG-9.

**PG-7.3** Drums, shells, or domes may be of seamless drawn construction, with or without integral heads, provided the material conforms to the requirements of the Code for shell material.

## PG-8 CASTINGS

**PG-8.1** Except for the limited usage permitted by PG-8.2 and PG-8.3, cast material used in the construction of vessels and vessel parts shall conform to one of the specifications listed in PG-9 for which maximum allowable stress values are given in Section II, Part D, Subpart 1, Tables 1A and 1B. The allowable stress values shall be multiplied by the applicable casting quality factor given in PG-25 for all cast materials except cast iron.

When cast iron is used as allowed in PG-11.1 for standard pressure parts, it shall conform to one of these standards

ASME B16.1, Gray Iron Pipe Flanges and Flanged Fittings

ASME B16.4, Cast Iron Threaded Fittings

Material conforming to ASTM A126 may be used subject to all requirements of the particular standard. Such usage is subject also to all the requirements for the use of cast iron given in PG-8.2 and other paragraphs of this Section.

**PG-8.2 Cast Iron.**

**PG-8.2.1** Cast iron shall not be used for nozzles or flanges attached directly to the boiler for any pressure or temperature.

**PG-8.2.2** Cast iron as designated in SA-278 may be used for boiler and superheater connections under pressure, such as pipe fittings, water columns, valves and their bonnets, for pressures up to 250 psi (1.7 MPa), provided the steam temperature does not exceed 450°F (230°C).

**PG-8.3 Cast Nodular Iron.** Cast nodular iron as designated in SA-395 may be used for boiler and superheater connections under pressure, such as pipe fittings, water columns, and valves and their bonnets, for pressures not to exceed 350 psi (2.5 MPa), provided the steam temperature does not exceed 450°F (230°C).

**PG-8.4 Nonferrous.** Bronze castings shall conform to SB-61, SB-62, and SB-148, and may be used only for the following:

**PG-8.4.1** For flanges and flanged or threaded fittings complying with the pressure and temperature requirements of ASME B16.15 or B16.24, except that such fittings shall not be used where steel or other material is specifically required. Threaded fittings shall not be used where flanged types are specified.

**PG-8.4.1.1** For valves at allowable stress values not to exceed those given in Section II, Part D, Subpart 1, Table 1B, with maximum allowable temperatures of 550°F (290°C) for SB-61 and SB-148, and 406°F (208°C) for SB-62.

**PG-8.4.1.2** For parts of pressure relief valves subject to limitations of PG-73.3.4.

## PG-9 PIPES, TUBES, AND PRESSURE-CONTAINING PARTS

Pipes, tubes, and pressure-containing parts used in boilers shall conform to one of the specifications listed in this paragraph for which maximum allowable stresses are given in Section II, Part D, Subpart 1, Tables 1A and 1B. The stress values given in these tables include the applicable joint efficiency factor for welded pipes and tubes.

Open-hearth, electric furnace, or basic oxygen steel shall be used for boiler pressure parts exposed to the fire or products of combustion. When used for internal pressure, the material stress and dimensions shall meet the appropriate requirements of PG-27 and Part PW and be in accordance with the following:

**PG-9.1** Boiler parts shall be of the following specifications only:

SA-53, Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless (excluding galvanized)

SA-105, Carbon Steel Forgings for Piping Applications

SA-106, Seamless Carbon Steel Pipe for High-Temperature Service

SA-178, Electric-Resistance-Welded Carbon Steel and Carbon-Manganese Steel Boiler and Superheater Tubes

SA-181, Carbon Steel Forgings, for General-Purpose Piping

SA-182, Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (ferritic only)

SA-192, Seamless Carbon Steel Boiler Tubes for High Pressure Service

SA-209, Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes

SA-210, Seamless Medium-Carbon Steel Boiler and Superheater Tubes

SA-213, Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat Exchanger Tubes (ferritic only)

SA-216, Steel Castings, Carbon, Suitable for Fusion Welding for High-Temperature Service

SA-217, Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service

SA-234, Pipe Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High-Temperature Service

SA-250, Electric-Resistance-Welded Ferritic Alloy-Steel Boiler and Superheater Tubes

SA-266, Carbon Steel Forgings for Pressure Vessel Components

SA-268, Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service

SA-333, Seamless and Welded Steel Pipe for Low-Temperature Service

SA-335, Seamless Ferritic Alloy Steel Pipe for High-Temperature Service

SA-336, Alloy Steel Forgings for Pressure and High-Temperature Parts

SA-350, Carbon and Low-Alloy Steel Forgings Requiring Notch Toughness Testing for Piping Components

SA-423, Seamless and Electric-Welded Low Alloy Steel Tubes

SA-660, Centrifugally Cast Carbon Steel Pipe for High-Temperature Service

SA-731, Seamless, Welded Ferritic, and Martensitic Stainless Steel Pipe

SA/EN 10216-2, Seamless Steel Tubes for Pressure Purposes — Part 2: Technical Delivery Conditions for Non-Alloy and Alloy Steel Tubes With Specified Elevated Temperature Properties

SA/EN 10222-2, Steel Forgings for Pressure Purposes — Part 2: Ferritic and Martensitic Steels With Specified Elevated Temperature Properties

**PG-9.1.1** Boiler parts on once-through boilers shall be any of the specifications listed in PG-9.1 or any of the following:[2]

SB-407, Nickel-Iron-Chromium Alloy Seamless Pipe and Tube

SB-408, Nickel-Iron-Chromium Alloy Rod and Bar

SB-409, Nickel-Iron-Chromium Alloy Plate, Sheet, and Strip

SB-423, Nickel-Iron-Chromium-Molybdenum-Copper Alloy Seamless Pipe and Tube

SB-424, Nickel-Iron-Chromium-Molybdenum-Copper Alloy Plate, Sheet, and Strip

SB-425, Nickel-Iron-Chromium-Molybdenum-Copper Alloy Rod and Bar

SB-515, Welded Nickel-Iron-Chromium Alloy Tubes

SB-564, Nickel Alloy Forgings

**PG-9.1.2** Materials for use in connector piping or tubing and the pressure chamber for remote water level-sensing devices, as referenced in PG-12.2, shall be one of the specifications listed in PG-9.1 or one of the following:

SA-213, Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes

SA-312, Seamless and Welded Austenitic Stainless Steel Pipes

SB-163, Seamless Nickel and Nickel Alloy Condenser and Heat-Exchanger Tubes

SB-167, Nickel-Chromium-Iron Alloys and Nickel–Chromium–Cobalt Molybdenum Alloy Seamless Pipe and Tube

SB-407, Nickel-Iron-Chromium Alloy Seamless Pipe and Tube

SB-423, Nickel-Iron-Chromium-Molybdenum-Copper Alloy Seamless Pipe and Tube

SB-515, Welded Nickel-Iron-Chromium Alloy Tubes

SB-516, Welded Nickel-Chromium-Iron Alloy Tubes

SB-517, Welded Nickel-Chromium-Iron Alloy Pipe

SB-619, Welded Nickel and Nickel-Cobalt Alloy Pipe

SB-622, Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube

SB-626, Welded Nickel and Nickel-Cobalt Alloy Tube

**PG-9.2** Superheater parts shall be of any one of the specifications listed in PG-9.1, PG-9.1.1, or one of the following:

SA-182, Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service

SA-213, Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes

SA-240, Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

SA-249, Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger, and Condenser Tubes

SA-312, Seamless and Welded Austenitic Stainless Steel Pipes

SA-351, Castings, Austenitic, Austenitic-Ferritic (Duplex) for Pressure-Containing Parts (Duplex excluded)

SA-369, Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service

SA-376, Seamless Austenitic Steel Pipe for High-Temperature Central-Station Service

SA-479, Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels

SA-965, Steel Forgings, Austenitic, for Pressure and High Temperature Parts

SA/JIS G 4303, Specification for Stainless Steel Bars

SB-163, Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes

SB-166, Nickel-Chromium Iron Alloys and Nickel-Chromium-Cobalt-Molybdenum Alloy Rod, Bar, and Wire

SB-167, Nickel-Chromium Iron Alloys and Nickel-Chromium-Cobalt-Molybdenum Alloy Seamless Pipe and Tube

SB-168, Nickel-Chromium Iron Alloys and Nickel-Chromium-Cobalt-Molybdenum Alloy Plate, Sheet, and Strip

SB-366, Factory-Made Wrought Nickel and Nickel Alloy Fittings

SB-435, N06230 Plate, Sheet, and Strip

SB-443, Nickel-Chromium-Molybdenum-Columbium Alloy Plate, Sheet, and Strip

SB-444, Nickel-Chromium-Molybdenum-Columbium Alloy Pipe and Tube

SB-446, Nickel-Chromium-Molybdenum-Columbium Alloy Rod and Bar

SB-462, Forged or Rolled Nickel Alloy Pipe Flanges, Forged Fittings, and Valves and Parts for Corrosive, High-Temperature Service

SB-511, Nickel-Iron-Chromium-Silicon Alloy Bars and Shapes

SB-516, Welded Nickel-Chromium-Iron Alloy Tubes

SB-517, Welded Nickel-Chromium-Iron Alloy Pipe

SB-535, Nickel-Iron-Chromium-Silicon Alloys Seamless Pipe and Tube

SB-536, Nickel-Iron-Chromium-Silicon Alloys Plate, Sheet, and Strip

SB-572, Nickel-Molybdenum-Chromium-Iron Alloy Rod

SB-574, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod

SB-575, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Plate, Sheet, and Strip

SB-619, Welded Nickel and Nickel-Cobalt Alloy Pipe

SB-622, Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube

SB-626, Welded Nickel and Nickel-Cobalt Alloy Tube

**PG-9.3** Copper or copper alloy pipe or tubes shall not be used in the boiler proper for any service where the temperature exceeds 406°F (208°C). Except as provided in PFT-12.1.1, copper and copper alloys shall be seamless, having a thickness not less than ASME Schedule 40 standard pipe, and shall comply to one of the following specifications: SB-42, Seamless Copper Pipe, Standard Sizes; SB-43, Seamless Red Brass Pipe, Standard Sizes; SB-75, Seamless Copper Tube; or SB-111, Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock.

**PG-9.4** Bimetallic tubes, having a core of an acceptable boiler and superheater material, and having an external cladding of another metal alloy, may be used provided the requirements of PG-27.2.1.5 are met. In applying the rules of PG-27.2.1, tubes that are diffusion coated shall not be permitted to include the strength of the clad. The permissible variation in wall thickness tolerance of SA-450 or SB-163, as applicable, shall apply to the total wall thickness. The thickness and over and undertolerances of the cladding shall be included in the ordering information. Marking of the bimetallic tubular product shall meet the specification requirements of the core material, but shall also suitably identify the cladding alloy.

**PG-9.5** ERW products shall be limited to a maximum thickness of $^1/_2$ in. (13 mm) for internal pressure applications. For external pressure applications, ERW products shall be limited to a maximum thickness of $^1/_2$ in. (13 mm) and a maximum size of NPS 24 (DN 600). The thickness and diameter limitations noted above shall be within tolerances stated by the product material specification.

**PG-9.6** In addition to other materials permitted by this Section, instrument wells may be fabricated from one of the following titanium alloys:

*(a)* SB-265, titanium and titanium alloy strip, sheet, and plate

*(b)* SB-338, seamless and welded titanium and titanium alloy tubes for condensers and heat exchangers

*(c)* SB-348, titanium and titanium alloy bars and billets

*(d)* SB-861, titanium and titanium alloy seamless pipe

*(e)* SB-862, titanium and titanium alloy welded pipe

**PG-9.7** In addition to other materials permitted by this Section, the following materials are permitted only for use in economizers or feedwater heaters and associated piping:

*(a)* SA-182, Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Pressure Service (S31803 only)

*(b)* SA-240, Pressure Vessel Plate, Alloy Steel (Ferritic Stainless), Chromium (S31803 only)

*(c)* SA-479, Stainless Steel Bars and Shapes (S31803 only)

*(d)* SA-789, Seamless and Welded Ferritic Austenitic Stainless Steel Tubing (S31803 only)

*(e)* SA-790, Seamless and Welded Ferritic Austenitic Stainless Steel Pipe (S31803 only)

*(f)* SA-815, Wrought Ferritic, Ferritic Austenitic, and Martensitic Stainless Steel Piping Fittings (S31803 only)

## PG-10 MATERIAL IDENTIFIED WITH OR PRODUCED TO A SPECIFICATION NOT PERMITTED BY THIS SECTION, AND MATERIAL NOT FULLY IDENTIFIED

**PG-10.1 Identified With Complete Certification From the Material Manufacturer.** Material identified with a specification not permitted by this Section, or material procured to chemical composition requirements 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 Section provided the conditions set forth in PG-10.1.1 or PG-10.1.2 are satisfied.

**PG-10.1.1** Recertification by an organization other than the boiler or part manufacturer:

**PG-10.1.1.1** All requirements, including but not limited to, melting method, melting practice, deoxidation, quality, and heat treatment, of the specification permitted by this Section, to which the material is to be recertified, have been demonstrated to have been met.

**PG-10.1.1.2** A copy of the certification by the material manufacturer of the chemical analysis required by the permitted specification, with documentation showing the requirements to which the material was produced and purchased, and which demonstrates that there is no conflict with the requirements of the permitted specification, has been furnished to the boiler or part manufacturer.

**PG-10.1.1.3** A certification that the material was manufactured and tested in accordance with the requirements of the specification to which the material is recertified, excluding the specific marking requirements, has been furnished to the boiler or part manufacturer, together with copies of all documents and test reports pertinent to the demonstration of conformance to the requirements of the permitted specification.

**PG-10.1.1.4** The material, and the Certificate of Compliance or the Material Test Report have been identified with the designation of the specification to which the material is recertified and with the notation "Certified per PG-10."

**PG-10.1.2** Recertification by the boiler or part manufacturer.

**PG-10.1.2.1** A copy of the certification by the material manufacturer of the chemical analysis required by the permitted specification, with documentation showing the requirements to which the material was produced and purchased, which demonstrates that there is no conflict with the requirements of the permitted specification, is available to the Inspector.

**PG-10.1.2.2** For applications in which the maximum allowable stresses are subject to a note of Section II, Part D, Subpart 1, Table 1A, requiring the use of killed steel, documentation is available to the Inspector that establishes that the material is a killed steel.

**PG-10.1.2.3** Documentation is available to the Inspector that demonstrates that the metallurgical structure, mechanical property, and hardness requirements of the permitted specification have been met.

**PG-10.1.2.4** For material recertified to a permitted specification that requires a fine austenitic grain size or that requires that a fine grain practice be used during melting, documentation is available to the Inspector that demonstrates that the heat treatment requirements of the permitted specification have been met, or will be met during fabrication.

**PG-10.1.2.5** The material has marking, acceptable to the Inspector, for identification to the documentation.

**PG-10.1.2.6** When the conformance of the material with the permitted specification has been established, the material has been marked as required by the permitted specification.

**PG-10.2 Material Identified to a Particular Production Lot as Required by a Specification Permitted by This Section but That Cannot Be Qualified Under PG-10.1.** Any material identified to a particular production lot as required by a specification permitted by this Section, but for which the documentation required in PG-10.1 is not available, may be accepted as satisfying the requirements of the specification permitted by this Section provided that the conditions set forth below are satisfied.

**PG-10.2.1** Recertification by an organization other than the boiler or part manufacturer — not permitted.

**PG-10.2.2** Recertification by the boiler or part manufacturer.

**PG-10.2.2.1** Chemical analyses are made on different pieces from the lot to establish a mean analysis which is to be accepted as representative of the lot. The pieces chosen for analyses 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 in the permitted specification and the mean for each element shall conform to the heat analysis limits of that specification. Analyses need to be made for only those elements required by the permitted specification. However, consideration should be given to making analyses for elements not specified in the specification but which would be deleterious if present in excessive amounts.

**PG-10.2.2.2** 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.

**PG-10.2.2.3** For applications in which the maximum allowable stresses are subject to a note of Section II, Part D, Subpart 1, Table 1A, requiring the use of killed steel, documentation is available to the Inspector which establishes that the material is a killed steel.

**PG-10.2.2.4** When the requirements of the permitted specification include metallurgical structure requirements (i.e., fine austenitic grain size), tests are made and the results are sufficient to establish that those requirements of the specification have been met.

**PG-10.2.2.5** When the requirements of the permitted specification include heat treatment, the material is heat treated in accordance with those requirements, either prior to or during fabrication.

**PG-10.2.2.6** When the conformance of the material with the permitted specification has been established, the material has been marked as required by the permitted specification.

**PG-10.3 Material Not Fully Identified.** Material which cannot be qualified under the provisions of either PG-10.1 or PG-10.2, such as material not fully identified as required by the permitted specification or as unidentified material, may be accepted as satisfying the requirements of a specification permitted by this Section provided that the conditions set forth below are satisfied.

**PG-10.3.1** Qualification by an organization other than the boiler or part manufacturer — not permitted.

**PG-10.3.2** Qualification by the boiler or part manufacturer.

**PG-10.3.2.1** Each piece is tested to show that it meets the chemical composition for product analysis and the mechanical properties requirements of the permitted specification. Chemical analyses need only be made for those elements required by the permitted specification. However, consideration shall be given to making analyses for elements not specified in the specification but which would be deleterious if present in excessive amounts. For plates, when the direction of final rolling is not known, both a transverse and a longitudinal tension test specimen shall be taken from each sampling location designated in the permitted specification. The results of both tests shall conform to the minimum requirements of the specification, but the tensile strength of only one of the two specimens need conform to the maximum requirement.

**PG-10.3.2.2** The provisions of PG-10.2.2.3, PG-10.2.2.4, and PG-10.2.2.5 are met.

**PG-10.3.2.3** When the identity of the material with the permitted specification has been established in accordance with PG-10.3.2.1 and PG-10.3.2.2, each piece (or bundle, etc., if permitted in the specification) is 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 boiler 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.

## PG-11 PREFABRICATED OR PREFORMED PRESSURE PARTS FURNISHED WITHOUT A CERTIFICATION MARK

**PG-11.1 General.** In general, all prefabricated or preformed pressure parts shall be certified as meeting the rules of this Section via ASME Data Reports and conformity marking requirements included elsewhere in this Section. Where stamping directly on the material is prohibited and a nameplate is used for those required markings, if the nameplate interferes with further fabrication, installation, or service, it may be removed by the Manufacturer of the completed boiler with the concurrence of the Authorized Inspector. Such removal of the nameplate shall be noted in the "Remarks" section of the boiler Manufacturer's Data Report, and the nameplate shall be destroyed. (17)

Prefabricated or preformed pressure parts supplied under the provisions of PG-11.2 through PG-11.4 are exempt from the requirements for ASME Data Reports and conformity markings included elsewhere in this Section. The rules of PG-11.2 through PG-11.4 shall not be applied to welded shells or heads. A part furnished under the requirements of PG-11.2, PG-11.3, and PG-11.4 need not be manufactured by a Certificate Holder. The Manufacturer of the completed boiler or of the part stamped with the Certification Mark into which the preformed or prefabricated part is incorporated shall first ensure the parts meet all applicable Code requirements. Prefabricated or preformed pressure parts may be supplied as indicated in PG-11.2 through PG-11.4.

**PG-11.2 Cast, Forged, Rolled, or Die-Formed Nonstandard Pressure Parts.** Pressure parts such as shells, heads, and removable and access-opening cover plates 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 Section, and the manufacturer of the part shall furnish identification in accordance with PG-5. 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 the part is suitable for the design conditions specified for the completed vessel in accordance with the rules of this Section.

**PG-11.3 Cast, Forged, Rolled, or Die-Formed Standard Pressure Parts, Either Welded or Nonwelded, That Comply With an ASME Product Standard.**

**PG-11.3.1** PG-11.3 applies to pressure parts such as pipe fittings, valves, flanges, nozzles, welding caps, manhole frames and covers, and pump casings that are a part of the boiler circulating system, that comply with an ASME product standard accepted by reference in PG-42 and are so marked. The ASME product standard establishes the basis for the pressure–temperature rating and marking unless modified in PG-42.

**PG-11.3.2** Materials for standard pressure parts shall be either as permitted by this Section or as specifically listed in the ASME product standard.

**PG-11.3.3** When welding is performed, in addition to meeting all requirements of the ASME product standard, the welding shall meet either the requirements of Part PW of this Code or the welding requirements of ASME specification SA-234 for parts conforming to ASME B16.9 and ASME B16.11 only.

**PG-11.3.4** If heat treatment [including postweld heat treatment (PWHT), postforming heat treatment, or any heat treatment needed to achieve material properties or mitigate material degradation mechanisms] is required, 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. If heat treatment is performed by other than the Manufacturer of the completed boiler, the heat treatment procedure, including mitigation heat treatment procedures for alloys that may be affected by the environment (e.g., those subject to stress corrosion cracking) between the time they are welded and the time PWHT is performed, shall be specified by the Manufacturer. These activities shall be documented and provided to the Manufacturer.

**PG-11.3.5** If radiography or other volumetric examination is required by the rules of this Section, it may be performed at the location of the Manufacturer of the completed boiler or the location of the pressure parts manufacturer.

**PG-11.3.6** Pressure parts meeting the requirements of PG-11.3 do not require inspection, mill test reports, or Manufacturer's Partial Data Reports.

**PG-11.3.7** The Manufacturer of the completed boiler shall have the following responsibilities when using standard pressure parts that comply with an ASME product standard:

*(a)* Ensure all standard pressure parts comply with applicable rules of this Section.

*(b)* Ensure all standard pressure parts are suitable for the design conditions of the completed boiler.

*(c)* When volumetric examination is required by the rules of this Section, obtain the completed radiographs or duplicate thereof, properly identified, with a radiographic examination report, or any other applicable volumetric examination report.

**PG-11.3.8** The Manufacturer shall fulfill the responsibilities of PG-11.3.7 by obtaining, when necessary, documentation as provided below, providing for retention of this documentation until the final boiler stamping has been completed, and having such documentation available for review by the Authorized 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

**PG-11.4 Cast, Forged, Rolled, or Die-Formed Standard Pressure Parts, Either Welded or Nonwelded, That Comply With a Standard Other Than an ASME Product Standard.**

**PG-11.4.1** Standard pressure parts, such as pipe fittings, valves, flanges, nozzles, welding caps, manhole frames and covers, and pump casings, that are a part of the boiler circulating system, that are either welded or nonwelded and comply with a manufacturer's proprietary standard, a standard other than an ASME product standard, or an ASME product standard not adopted by this Section may be supplied by a Certificate Holder or a pressure parts manufacturer.

**PG-11.4.2** Parts of small size falling within this category for which it is impossible to obtain identified material or which may be stocked and for which identification cannot be obtained and is not customarily furnished may be used as non-pressure-bearing attachments and need not conform to the specifications for the material to which they are attached or to a material specification permitted in this Section. If attached to the boiler by welding, such parts shall be of weldable quality.

**PG-11.4.3** Materials for these parts shall be as permitted by this Section only.

**PG-11.4.4** When welding is performed, it shall meet the requirements of Part PW of this Section.

**PG-11.4.5** Pressure parts such as welded standard pipe fittings, welding caps, and flanges that are fabricated by one of the welding processes recognized by this Section do not require Authorized Inspection or Partial Data Reports, provided the requirements of PG-11.4 are met.

**PG-11.4.6** If postweld heat treatment is required by the rules of this Section, it may be performed either in the location of the parts manufacturer or in the location of the Manufacturer of the completed boiler. If postweld heat treatment is performed by other than the Manufacturer of the completed boiler, the heat treatment procedure shall be documented and provided to the Manufacturer.

**PG-11.4.7** If volumetric examination is required, it may be performed at the location of the Manufacturer of the completed boiler, the location of the parts Manufacturer, or the location of the pressure parts manufacturer.

**PG-11.4.8** Marking for these parts shall be as follows:

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

**PG-11.4.9** The Manufacturer of the completed boiler shall have the following responsibilities when using standard pressure parts:

*(a)* Ensure all standard pressure parts comply with applicable rules of this Section.

*(b)* Ensure all standard pressure parts are suitable for the design conditions of the completed boiler.

*(c)* When volumetric examination is required by the rules of this Section, obtain the completed radiographs or duplicate thereof, properly identified, with a radiographic examination report, or any other applicable volumetric examination report for retention until the final boiler stamping has been completed.

**PG-11.4.10** The Manufacturer of the completed boiler shall fulfill the responsibilities of PG-11.4.9 by one of the following methods:

*(a)* Obtain, when necessary, documentation as provided in PG-11.4.11, provide for retention of this documentation until the final boiler stamping has been completed, and have such documentation available for review by the Authorized Inspector when requested.

*(b)* Perform an analysis of the pressure part in accordance with the rules of this Section subject to the acceptance of the Authorized Inspector, while being mindful this Section does not contain rules to cover all details of design and construction. It is intended the Manufacturer shall provide details of design and construction that will be as safe as those provided by the rules of this Section. This analysis shall be included in the documentation and shall be made available for inspection by the Authorized Inspector when requested.

**PG-11.4.11** 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)* written certification by the pressure parts manufacturer that all welding complies with Code requirements

**PG-11.5** A Manufacturer holding an ASME Certificate of Authorization may provide standard pressure parts in accordance with PG-11.4. In lieu of the requirements of PG-11.4.4, such organizations may subcontract for welding services to an individual or an organization that does not hold an ASME Certificate of Authorization, provided the conditions of PG-11.5.1 through PG-11.5.10 are met.

**PG-11.5.1** The activities to be performed by the subcontractor shall be included within the Certificate Holder's quality control system.

**PG-11.5.2** The Certificate Holder's quality control system shall provide 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 Section that are permitted to be subcontracted

*(b)* welding operations

*(c)* Authorized Inspection activities

*(d)* placement of the Certificate Holder's marking in accordance with PG-11.4.8

**PG-11.5.3** The Certificate Holder's quality control system shall provide for the Manufacturer of the boiler to arrange for the Authorized Inspector to have free access to such parts of all plants as are concerned with the supply or manufacture of materials for the boiler, when so requested. The Authorized Inspector shall be permitted free access, at all times while work on the boiler 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 Authorized Inspector informed of the progress of the work and shall notify him reasonably in advance for any required tests or inspections.

**PG-11.5.4** The Certificate Holder shall be responsible for reviewing and accepting the quality control programs of the subcontractor.

**PG-11.5.5** The Certificate Holder shall ensure that the subcontractor uses written procedures and welding operations that have been qualified as required by this Section.

**PG-11.5.6** The Certificate Holder shall ensure that the subcontractor uses personnel that have been qualified as required by this Section.

**PG-11.5.7** The Certificate Holder and the subcontractor shall describe in the quality control system the operational control of procedure and personnel qualifications of the subcontracted welding operations.

**PG-11.5.8** 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 Authorized Inspector for acceptance conform to all applicable requirements of this Section.

**PG-11.5.9** The Certificate Holder shall describe in the quality control system the operational control for maintaining traceability of materials received from the subcontractor.

**PG-11.5.10** The Certificate Holder shall receive approval for subcontracting from the Authorized Inspection Agency prior to commencing of activities.

## PG-12 WATER LEVEL INDICATORS AND CONNECTOR MATERIAL

**PG-12.1** Gage glass body and connector materials shall comply with a Manufacturer's standard that defines the pressure–temperature rating marked on the unit. The materials used may include austenitic stainless steels and nickel-based alloys.[1]

(17) **PG-12.2** Boilers having a maximum allowable working pressure not exceeding 900 psi (6 MPa) may use alternative methods for independent remote water level indicators or water level-sensing devices (see PG-60 for requirements for water level indicators and water columns). The sensing devices may include a magnetically coupled float inside a nonferromagnetic cylindrical pressure chamber to utilize through-the-wall sensing of float position. The pressure chamber stresses and dimensions shall meet the appropriate requirements of PG-27 and Part PW, shall comply with one of the specifications in PG-9.1.2, and shall be restricted to the material grades listed in PG-12.3.

**PG-12.3** Connector material and the pressure chamber material of the remote water level indicator or water level-sensing devices, except for water columns, may include austenitic stainless steels and nickel-based alloys. The material shall be in the solution-annealed heat treatment condition. If filler metals are used in welding of the austenitic stainless steels, they shall be limited to low-carbon content.

The material shall be one of the grades from the following list:

| Grade | UNS Number |
|---|---|
| 304L | S30403 |
| 316L | S31603 |
| 800 | N08800 |
| ... | N08020 |
| 825 | N08825 |
| C-276 | N10276 |
| ... | N06022 |
| 690 | N06690 |
| 59 | N06059 |
| 625 | N06625 |
| 600 | N06600 |

The allowable stresses shall be those listed in Section II, Part D, Subpart 1, Table 1A or Table 1B for Section I. If allowable stresses are not listed for Section I but are listed for Section VIII, Division 1, the allowable stresses for Section VIII, Division 1 may be utilized. When two lines of stresses are listed in Section II, Part D, the design shall be based on the lower allowable stresses.

## PG-13 STAYS

Threaded stays shall be of steel complying with SA-36, SA/CSA-G40.21, or SA-675.

Seamless steel tubes for threaded stays shall comply with SA-192 or SA-210.

Staybolts, stays, through-rods, or stays with ends for attachment by fusion welding shall comply with SA-36, SA/CSA-G40.21, or SA-675.

## PG-14 RIVETS

**PG-14.1** Rivets shall conform to SA-31, Specification for Steel Rivets and Bars for Rivets, Pressure Vessels.

**PG-14.1.1** In lieu of SA-31, it is permissible to substitute bar which is converted to rivets from SA-36, Specification for Carbon Structure Steel, under the conditions specified in PG-14.1.1.1 and PG-14.1.1.2.

**PG-14.1.1.1** In addition to compliance with SA-36, the bar shall comply with

*(a)* the "rivet bend tests" for SA-31 Grade B, para. 6.1.2

*(b)* the "rivet flattening tests" for SA-31 Grades A and B, para. 6.2

*(c)* the "bar bend tests" for SA-31 Grade B, para. 6.4.2

**PG-14.1.1.2** The following paragraphs of SA-31 shall be applicable to the additional mechanical properties tests:

*(a)* paragraph 9, Number of Tests and Retests

*(b)* paragraph 10, Specimen Preparation

*(c)* paragraph 11, Test Methods

*(d)* paragraph 12, Inspection

*(e)* paragraph 13, Rejection and Reheating

**PG-14.1.2** When rivets made from SA-36 bar are substituted for those made from SA-31, the design stresses for SA-31 Grade B shall apply.

**PG-14.2** In computing the ultimate strength of rivets in shear, the following shear stresses in ksi (MPa) of the cross-sectional area of the rivet shank shall be used:

*(a)* Steel rivets, SA-31 Grade A, in single shear, 44.0 (305)

*(b)* Steel rivets, SA-31 Grade A, in double shear, 88.0 (605)

*(c)* Steel rivets, SA-31 Grade B, in single shear, 52.0 (360)

*(d)* Steel rivets, SA-31 Grade B, in double shear, 104.0 (715)

The cross-sectional area used in the computations shall be that of the rivet after driving.

# DESIGN

## PG-16 GENERAL

**PG-16.1** The design of power boilers, high-temperature water boilers, and other pressure parts included within the scope of these rules 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 this Section that pertain to the methods of construction used. This Section does not contain rules to cover all possible details of design. When detailed rules are not given, it is intended that the Manufacturer, subject to the acceptance of the Inspector, shall provide details of design that will be as safe as those provided by the rules of this Section. This may be done by appropriate analytical methods, the appropriate use of rules from other design codes or, as permitted by PG-18, by proof test.

**PG-16.2** When the pressure parts of a forced-flow steam generator with no fixed steam and waterline are designed for different pressure levels as permitted in PG-21.3, the owner shall provide or cause to be provided a boiler pressure system design diagram, certified by a Professional Engineer experienced in the mechanical design of power plants, which supplies the following information.

**PG-16.2.1** The relative location of the various pressure parts within the scope of Section I, with respect to the path of water-steam flow.

**PG-16.2.2** A line showing the expected maximum sustained pressure as described in PG-21.3, indicating the expected variation in pressure along the path of water-steam flow.

**PG-16.2.3** The maximum allowable working pressure of the various pressure parts.

**PG-16.2.4** The location and set pressure of the overpressure protection devices.

Copy of this diagram shall be attached to the Master Data Report per PG-113.

**PG-16.3 Minimum Thicknesses.** The minimum thickness of any boiler plate under pressure shall be $^1/_4$ in. (6 mm) except for electric boilers constructed under the rules of Part PEB. The minimum thickness of plates to which stays may be applied in other than cylindrical outer shell plates shall be $^5/_{16}$ in. (8 mm). When pipe larger than NPS 5 (DN 125) is used in lieu of plate for the shell of cylindrical components under pressure, its minimum wall shall not be less than the smaller of $^1/_4$ in. (6 mm) or the minimum wall thickness of Standard wall pipe listed in ASME B36.10M, Table 1.

**PG-16.4 Undertolerance on Plates.** Plate material that is not more than 0.01 in. (0.3 mm) thinner than that calculated from the formula may be used in Code constructions provided the material specification permits such plate to be furnished not more than 0.01 in. (0.3 mm) thinner than ordered.

**PG-16.5 Undertolerance on Pipe and Tubes.** Pipe or tube material shall not be ordered thinner than that calculated from the applicable formula of this Section. The ordered material shall include provision for the allowed manufacturing undertolerance as given in Section II in the applicable pipe or tube specification.

**PG-16.6** The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters shall be considered nominal, and allowable tolerances or local variances should be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

**PG-16.7** The dimensional symbols used in the design (**17**)
formulas throughout this Code do not include any allowance for corrosion, erosion, and forming, except where noted. Additional thickness should be provided where these allowances are applicable.

## PG-17 FABRICATION BY A COMBINATION OF METHODS

A boiler and parts thereof may be designed and fabricated by a combination of the methods of fabrication given in this Section, provided the rules applying to the respective methods of fabrication are followed and the boiler is limited to the service permitted by the method of fabrication having the most restrictive requirements.

## PG-18 DESIGN VALIDATION BY PROOF TEST

Where no rules are given for calculating the strength of a boiler or any part thereof, the Manufacturer may establish MAWP by testing a full-size sample in accordance with A-22, Proof Tests to Establish Maximum Allowable Working Pressure.

## PG-19 COLD FORMING OF AUSTENITIC MATERIALS[3]

The cold-formed areas of pressure-retaining components manufactured of austenitic alloys shall be heat treated for 20 min per inch of thickness or for 10 min, whichever is greater, at the temperatures given in Table PG-19 under the following conditions:

*(a)* the finishing-forming temperature is below the minimum heat-treating temperature given in Table PG-19

*(b)* the design metal temperature and the forming strains exceed the limits shown in Table PG-19. Forming strains shall be calculated as follows:

Forming strains shall be calculated as follows:

*(1)* Cylinders formed from plate

$$\%Strain = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

*(2)* Spherical or dished heads formed from plate

$$\%Strain = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

*(3)* Tube and pipe bends

$$\%Strain = \frac{100r}{R}$$

where

$R$ = nominal bending radius to centerline of pipe or tube
$r$ = nominal outside radius of pipe or tube
$R_f$ = mean radius after forming
$R_o$ = original mean radius (equal to infinity for a flat plate)
$t$ = nominal thickness of the plate, pipe, or tube before forming

**PG-19.1** When the forming strains cannot be calculated as shown in PG-19, the manufacturer shall have the responsibility to determine the maximum forming strain.

**PG-19.2** For flares, swages, or upsets, heat treatment in accordance with Table PG-19 shall apply, regardless of the amount of strain.

## PG-20 COLD FORMING OF CREEP STRENGTH ENHANCED FERRITIC STEELS

The cold-formed areas of pressure-retaining components manufactured of creep strength enhanced ferritic alloys shall be heat treated as listed in Table PG-20. Cold forming is defined as any method that is performed at a temperature below 1,300°F (705°C) and produces strain in the material. The calculations of cold strains shall be made in accordance with PG-19.

## PG-21 MAXIMUM ALLOWABLE WORKING PRESSURE

The maximum allowable working pressure is the pressure determined by employing the allowable stress values, design rules, and dimensions designated in this Section.

Whenever the term maximum allowable working pressure is used in this Section of the Code, it refers to gage pressure, or the pressure above atmosphere.

**PG-21.1** No boiler, except a forced-flow steam generator with no fixed steam and water line that meets the special provisions of PG-67, shall be operated at a pressure higher than the maximum allowable working pressure except when the pressure relief valve or valves are discharging, at which time the maximum allowable working pressure shall not be exceeded by more than 6%.

**PG-21.2** Expected maximum sustained conditions of pressure and temperature are intended to be selected sufficiently in excess of any expected operating conditions (not necessarily continuous) to permit satisfactory boiler operation without operation of the overpressure protection devices.

**PG-21.3** In a forced-flow steam generator with no fixed steam and waterline it is permissible to design the pressure parts for different pressure levels along the path of water-steam flow. The maximum allowable working pressure of any part shall be not less than that required by the rules of Part PG for the expected maximum sustained conditions of pressure and temperature to which that part is subjected except when one or more of the overpressure protection devices covered by PG-67.4 is in operation.

**PG-21.4 Components With Multiple Design Conditions.**

**PG-21.4.1** Components with multiple design conditions may be designed considering the coincident pressures and temperatures if all of the conditions specified in PG-21.4.1.1 through PG-21.4.2 are met.

**PG-21.4.1.1** The component shall be designed for the most severe condition of coincident pressure and temperature expected to be sustained during operation that results in the greatest calculated thickness for the pressure part and that will not exceed the maximum temperature or the maximum allowable stress permitted in Section II, Part D for the material.

**PG-21.4.1.2** The design requirements of this Section shall be met for each design condition (coincident pressure and temperature).

**PG-21.4.1.3** The maximum allowable working pressure (MAWP) selected for the part shall be sufficiently in excess of the highest pressure of the multiple design conditions to permit satisfactory boiler operation without operation of the overpressure protection device(s).

## Table PG-19 (17)
## Post Cold-Forming Strain Limits and Heat-Treatment Requirements for Austenitic Materials and Nickel-Based Alloys

| | | Limitations in Lower Temperature Range | | | | | Limitations in Higher Temperature Range | | | Minimum Heat-Treatment Temperature When Design Temperature and Forming Strain Limits Are Exceeded [Note (1)] and [Note (2)] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | For Design Temperature | | | | | For Design Temperature Exceeding | | And Forming Strains Exceeding | | |
| | UNS | Exceeding | | But Less Than or Equal to | | And Forming Strains Exceeding | | | | | |
| Grade | Number | °F | °C | °F | °C | | °F | °C | | °F | °C |
| 304 | S30400 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 304H | S30409 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| ... | S30432 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 304N | S30451 | 1,075 | (580) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 309S | S30908 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 310H | S31009 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 310S | S31008 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 310HCbN | S31042 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 316 | S31600 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 316H | S31609 | 1,075 | (580) | 1,250 | (675) | 20% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 316N | S31651 | 1,075 | (580) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 321 | S32100 | 1,000 | (540) | 1,250 | (675) | 15% [Note (3)] | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 321H | S32109 | 1,000 | (540) | 1,250 | (675) | 15% [Note (3)] | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 347 | S34700 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 347H | S34709 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| 347HFG | S34710 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,150 | (1 175) |
| 348 | S34800 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 1,900 | (1 040) |
| 348H | S34809 | 1,000 | (540) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,000 | (1 095) |
| ... | N06230 | 1,100 | (595) | 1,400 | (760) | 15% | 1,400 | (760) | 10% | 2,200 | (1 205) |
| 600 | N06600 | 1,075 | (580) | 1,200 | (650) | 20% | 1,200 | (650) | 10% | 1,900 | (1 040) |
| 601 | N06601 | 1,075 | (580) | 1,200 | (650) | 20% | 1,200 | (650) | 10% | 1,900 | (1 040) |
| 617 | N06617 | 1,200 | (650) | 1,400 | (760) | 15% | 1,400 | (760) | 10% | 2,100 | (1 150) |
| 690 | N06690 | 1,075 | (580) | 1,200 | (650) | 20% | 1,200 | (650) | 10% | 1,900 | (1 040) |
| 800 | N08800 | 1,100 | (595) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 1,800 | (980) |
| 800H | N08810 | 1,100 | (595) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,050 | (1 120) |
| ... | N08811 | 1,100 | (595) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 2,100 | (1 150) |
| ... | S30815 | 1,075 | (580) | 1,250 | (675) | 15% | 1,250 | (675) | 10% | 1,920 | (1 050) |
| ... | N06022 | 1,075 | (580) | 1,250 | (675) | 15% | ... | ... | ... | 2,050 | (1 120) |

GENERAL NOTE: The limits shown are for cylinders formed from plates, spherical or dished heads formed from plate, and tube and pipe bends. When the forming strains cannot be calculated as shown in PG-19, the forming strain limits shall be half those tabulated in this Table (see PG-19.1).

NOTES:
(1) Rate of cooling from heat-treatment temperature not subject to specific control limits.
(2) While minimum heat-treatment temperatures are specified, it is recommended that the heat-treatment temperature range be limited to 150°F (85°C) above that minimum, and 250°F (140°C) for 310HCbN, 347, 347H, 348, and 348H.
(3) For simple bends of tubes or pipes whose outside diameter is less than 3.5 in. (89 mm), this limit is 20%.

**Table PG-20**
**Post Cold-Forming Strain Limits and Heat-Treatment Requirements**

| | | Limitations in Lower Temperature Range | | | | | Limitations in Higher Temperature Range | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | For Design Temperature | | | | | | | | |
| | | Exceeding | | But Less Than or Equal to | | | For Design Temperature Exceeding | | | |
| Grade | UNS Number | °F | °C | °F | °C | And Forming Strains | °F | °C | And Forming Strains | Required Heat Treatment When Design Temperature and Forming Strain Limits Are Exceeded |
| 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% | Postbend heat treatment [Note (2)], [Note (3)], [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 in the table shall be divided by two if PG-19.1 is applied. For any material formed at 1,300°F (705°C) or above, and for cold swages, flares, or upsets, normalizing and tempering is required regardless of the amount of strain.

NOTES:
(1) Normalization and tempering shall be performed in accordance with the requirements in the base material specification, and shall not be performed locally. The material shall either 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 tube or component and heat treated separately or replaced.
(2) Postbend heat treatments shall be performed at 1,350°F to 1,445°F (730°C to 785°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 material 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 above, one of the following actions shall be performed:
*(a)* The component in its entirety must 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)] above. 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.

Each design condition (coincident pressure and temperature) shall be reported on the Manufacturer's Data Report.

**PG-21.4.2 Definitions.**

*coincident pressure and temperature*: a specific combination of pressure and temperature that is coincident with a specific normal operating condition.

*normal operating condition*: a sustained (or steady-state) condition that is a stable mode of operation of the boiler (not a transient condition).

*start-up and shutdown*: transient condition of the boiler to bring it from a cold condition or low-load condition to a normal operating condition or to a shutdown condition.

*sustained condition*: a steady-state normal operating condition whose duration in time is significant and long running.

*transient condition*: a controlled transitional mode of operating the boiler to bring it from one steady-state condition of temperature and pressure to another steady-state condition of temperature and pressure.

## PG-22 LOADINGS

**PG-22.1** Stresses due to hydrostatic head shall be taken into account in determining the minimum thickness required unless noted otherwise. This Section does not fully address additional loadings other than those from working pressure or static head. Consideration shall be given to such additional loadings (see PG-16.1).

**PG-22.2** Loading on structural attachments — refer to PG-56.

## PG-23 STRESS VALUES FOR CALCULATION FORMULAS

**PG-23.1** The maximum allowable stress values in Section II, Part D, Subpart 1, Tables 1A and 1B, are the unit stresses to be used in the equations of this Section to calculate the minimum required thickness or the maximum allowable working pressure of the pressure part (see Section II, Part D, Mandatory Appendix 1).

**PG-23.2** The yield strength values for use in PG-28.3 may be found in Section II, Part D, Subpart 1, Table Y-1.

**PG-23.3** With the publication of the 2004 Edition, Section II, Part D is published as two separate publications. One publication contains values only in U.S. Customary units and the other contains values only in SI units. The selection of the version to use is dependent on the set of units selected for analysis.

## PG-25 QUALITY FACTORS FOR STEEL CASTINGS

A quality factor as specified below shall be applied to the allowable stresses for steel casting materials given in Section II, Part D, Subpart 1, Table 1A.

**PG-25.1** A factor not to exceed 80% shall be applied when a casting is inspected only in accordance with the minimum requirements of the specification for the material, except when the special methods of examination prescribed by the selected specification are followed, thus permitting the use of the applicable higher factor in this paragraph.

**PG-25.2** A factor not to exceed 100% shall be applied when the casting meets the requirements of PG-25.2.1 through PG-25.2.4.

**PG-25.2.1** All steel castings $4\frac{1}{2}$ in. (114 mm) nominal body thickness or less, other than steel flanges and fittings complying with ASME B16.5, and valves complying with ASME B16.34, shall be examined as specified in PG-25.2.1.1 through PG-25.2.1.5.

**PG-25.2.1.1** All critical areas, including the junctions of all gates, risers, and abrupt changes in section or direction and weld-end preparations, shall be radiographed in accordance with Section V, Article 2, and the radiographs shall conform to the requirements of ASTM E446 or ASTM E186, depending upon the section thickness. The maximum acceptable severity level for 100% quality factor shall be

For ASTM E446

| Imperfection Category | Severity Level: Up to and Including 1 in. (25 mm) Thick | Severity Level: Greater Than 1 in. (25 mm) Thick |
|---|---|---|
| A | 1 | 2 |
| B | 2 | 3 |
| C Types 1, 2, 3, and 4 | 1 | 3 |
| D, E, F, and G | None acceptable | None acceptable |

For ASTM E186

| Imperfection Category | Severity Level |
|---|---|
| A and B, Types 1 and 2 of C | 2 |
| Type 3 of C | 3 |
| D, E, and F | None acceptable |

**PG-25.2.1.2** All surfaces of each casting, including machined gasket seating surfaces, shall be examined after heat treatment by the magnetic particle method in accordance with PG-25.2.1.2.1 or by the liquid penetrant method in accordance with PG-25.2.1.2.2.

**PG-25.2.1.2.1** The technique for magnetic particle examination shall be in accordance with Section V, Article 7. Imperfections causing magnetic particle indications exceeding degree 1 of Type I, degree 2 of Type II, and degree 3 of Type III, and exceeding degree 1 of Types IV and V of ASTM E125 are unacceptable.

**PG-25.2.1.2.2** The technique for liquid penetrant examination shall be in accordance with Section V, Article 6. Surface indications determined by liquid penetrant examination are unacceptable if they exceed the following:

*(a)* all cracks and hot tears

*(b)* any group of more than six linear indications other than those in (a) in any rectangular area of $1\frac{1}{2}$ in. × 6 in. (38 mm × 150 mm) or less, or any circular area having a diameter of $3\frac{1}{2}$ in. (89 mm) or less, these areas being taken in the most unfavorable location relative to the indications being evaluated

*(c)* other linear indications more than $\frac{1}{4}$ in. (6 mm) long for thicknesses up to $\frac{3}{4}$ in. (19 mm) inclusive, more than one-third of the thickness in length for thicknesses from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in. (19 mm to 57 mm), and more than $\frac{3}{4}$ in. (19 mm) long for thicknesses over $2\frac{1}{4}$ in. (57 mm) (Aligned acceptable indications separated from one another by a distance equal to the length of the longer indication are acceptable.)

*(d)* all indications of nonlinear imperfections that have any dimension exceeding $\frac{3}{16}$ in. (5 mm)

**PG-25.2.1.3** Where more than one casting of a particular design is produced, each of the first five castings shall be examined as above. Where more than five castings are being produced, the examination shall be performed on the first five plus one additional casting to represent each five additional castings. If this additional casting proves to be unacceptable, each of the remaining castings in the group shall be examined.

**PG-25.2.1.4** Any indications in excess of the maximum permitted in PG-25.2.1.1 and PG-25.2.1.2 shall be cause for rejection unless the casting is repaired by welding after the base metal has been examined to ensure that the imperfection has been removed or reduced to an acceptable size. The completed repair shall be subject to reexamination by the same method as was used in the original examination and the repaired casting shall be postweld heat treated.

**PG-25.2.1.5** All welding shall be performed using welding procedures qualified in accordance with Section IX. The procedure qualification shall be performed on test specimens of cast material of the same specification and subjected to the same heat treatment before and after welding as will be applied to the work. All welders and operators performing this welding shall also be qualified in accordance with Section IX.

**PG-25.2.2** All steel castings having a body greater than $4^1/_2$ in. (114 mm) nominal thickness shall be examined as specified in PG-25.2.2.1 through PG-25.2.2.6.

**PG-25.2.2.1** All surfaces of each casting, including machined gasket seating surfaces, shall be examined after heat treatment by the magnetic particle method in accordance with PG-25.2.1.2.1 or liquid penetrant method in accordance with PG-25.2.1.2.2.

**PG-25.2.2.2** All parts of castings shall be subjected to complete radiographic examination in accordance with Section V, Article 2, and the radiographs shall conform to the requirements of ASTM E280.

The maximum acceptable severity level for a 100% quality factor shall be

| Imperfection Category | Severity Level |
|---|---|
| A, B, and Types 1, 2, and 3 of C | 2 |
| D, E, and F | None acceptable |

**PG-25.2.2.3** Any indications in excess of the maximum permitted in PG-25.2.2.1 and PG-25.2.2.2 are unacceptable. The casting may be repaired by welding after the base metal has been magnetic particle or liquid penetrant examined to ensure that the imperfection has been removed or reduced to an acceptable size.

**PG-25.2.2.4** All weld repairs of depth exceeding 1 in. (25 mm) or 20% of the section thickness, whichever is less, shall be examined by radiography in accordance with PG-25.2.2.2 and by magnetic particle or liquid penetrant examination of the finished weld surface. All weld repairs of depth less than 20% of the section thickness, or 1 in. (25 mm), whichever is less, and all weld repairs of sections which cannot be effectively radiographed shall be examined by magnetic particle or liquid penetrant examination of the first layer, of each $^1/_4$ in. (6 mm) thickness of deposited weld metal and of the finished weld surface. Magnetic particle or liquid penetrant examination of the finished weld surface shall be performed after postweld heat treatment.

**PG-25.2.2.5** When repair welding is done after heat treatment of the casting, the casting shall be postweld heat treated.

**PG-25.2.2.6** All welding shall be performed using welding procedures qualified in accordance with Section IX. The procedure qualification shall be performed on test specimens of cast material of the same specification and subjected to the same heat treatment before and after welding as will be applied to the work. All welders and operators performing this welding shall also be qualified in accordance with Section IX.

**PG-25.2.3 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 material designation.

**PG-25.2.4** Personnel performing radiographic, magnetic particle, or liquid penetrant examinations under this paragraph shall be qualified in accordance with their employer's written practice. SNT-TC-1A[4] or CP-189 shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. If the techniques of computed radiography (CR) or digital radiography (DR) are used, the training, experience, and examination requirements in Section V, Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable. (17)

When personnel have been certified according to their employer's written practice based upon an edition of SNT-TC-1A or CP-189 earlier than that referenced in A-360, their certification shall be valid for performing nondestructive examination required by this Section until their next scheduled recertification. Any recertifications, reexaminations, or new examinations shall be performed to the employer's written practice based on the edition of SNT-TC-1A or CP-189 referenced in A-360.

## PG-26 WELD JOINT STRENGTH REDUCTION FACTOR

At elevated temperatures, the long-term strength of weld joints can be lower than the long-term strength of the base material. Table PG-26 specifies a weld joint strength reduction factor, $w$, to be used to account for this lower long-term strength in determining the required thickness of components operating in the creep range. This factor shall be applied in the design of cylinders containing longitudinal butt welds and to hemispherical heads or any other spherical sections that comprise segments joined by welding. As defined in PW-11.2, longitudinal butt welds shall be interpreted to include spiral (helical) welds. Weld strength reduction factors apply to such seams made by any welding process, with or without filler metal added, regardless whether the welding is performed as part of material manufacture or by the Certificate Holder as part of Section I fabrication. The designer is responsible for determining the applicability of weld joint strength reduction factors to other (e.g., circumferential) welds. The weld joint strength reduction factor is not required when evaluating occasional loads, such as wind and earthquake.

## PG-27 CYLINDRICAL COMPONENTS UNDER INTERNAL PRESSURE

**PG-27.1 General.** Unless the requirements of A-317 of Nonmandatory Appendix A are selected, the equations under this paragraph shall be used to determine the minimum required thickness or the maximum allowable working pressure of piping, tubes, drums, Shells, and headers in accordance with the appropriate dimensional categories as given in PG-27.2.1, PG-27.2.2, and PG-27.2.3 for temperatures not exceeding those given for the various materials listed in Section II, Part D, Subpart 1, Tables 1A and 1B.

The calculated and ordered thickness of material must include the requirements of PG-16.3, PG-16.4, and PG-16.5. Stress calculations must include the loadings as defined in PG-22 unless the formula is noted otherwise.

When required by the provisions of this Code, allowance must be provided in material thickness for threading and minimum structural stability (see PG-27.4.3, PG-27.4.5, and PWT-9.2).

If local thin areas are present in cylindrical shells, the required thickness may be less than the thickness determined in PG-27 provided the requirements of Mandatory Appendix IV are met.

**PG-27.2 Equations for Calculation.**

**PG-27.2.1 Tubing — Up to and Including 5 in. (125 mm) Outside Diameter.** For bare tubes or bimetallic tubes when the strength of the clad is not included,[5] use the following equations:

$$t = \frac{PD}{2Sw + P} + 0.005D + e$$

$$P = Sw\left[\frac{2t - 0.01D - 2e}{D - (t - 0.005D - e)}\right]$$

See PG-27.4.2, PG-27.4.4, PG-27.4.8, and PG-27.4.9.

For bimetallic tubes when the strength of the clad is included,[5] use the following equations:

$$tb + tc' = \frac{PD}{2Sb + P} + 0.005D + e$$

$$tc' = tc\left[\frac{Sc}{Sb}\right]$$

$$t = tb + tc$$

$$P = Sb\left[\frac{2(tb + tc') - 0.01D - 2e}{D - [(tb + tc') - 0.005D - e]}\right]$$

See PG-27.4.4, PG-27.4.8, PG-27.4.9, and PG-27.4.10.

**PG-27.2.1.2** The wall thickness of the ends of tubes strength-welded to headers or drums need not be made greater than the run of the tube as determined by these equations.

**PG-27.2.1.3** The wall thickness of the ends of tubes permitted to be attached by threading under the limitations of PWT-9.2 shall be not less than $t$ as determined by this formula, plus $0.8/n$ $(20/n)$, where $n$ equals the number of threads per inch (per mm).

**PG-27.2.1.4** A tube in which a fusible plug is to be installed shall be not less than 0.22 in. (5.6 mm) in thickness at the plug in order to secure four full threads for the plug (see also A-20).

**PG-27.2.1.5** Bimetallic tubes for which the strength of the clad is not included and meeting the requirements of PG-9.4 shall use an outside diameter, $D$, in the appropriate equation in PG-27.2.1 no less than the calculated outside diameter of the core material. The outside diameter of the core material shall be determined by subtracting twice the minimum thickness of the cladding from the outside diameter of the bimetallic tube, including the maximum plus tolerance of the core tube. The minimum required thickness, $t$, shall apply only to the core material.

Tubes for which the strength of the clad is included and meeting the requirements of PG-9.4 shall use an outside diameter, $D$, in the appropriate equation in PG-27.2.1 equal to the outside diameter of the bimetallic tube, including the maximum plus tolerance for both the core tube diameter and clad thickness.

**PG-27.2.2 Piping, Drums, Shells, and Headers.** Based on strength of weakest course.

$$t = \frac{PD}{2SE + 2yP} + C \quad \text{or} \quad \frac{PR}{SE - (1 - y)P} + C$$

$$P = \frac{2SE(t - C)}{D - 2y(t - C)} \quad \text{or} \quad \frac{SE(t - C)}{R + (1 - y)(t - C)}$$

See PG-27.4.1, PG-27.4.3, and PG-27.4.5 through PG-27.4.8.

**PG-27.2.3 Thickness Greater Than One-Half the Inside Radius of the Component.** The maximum allowable working pressure for parts of boilers of cylindrical cross section, designed for temperatures up to that of saturated steam at critical pressure [705.4°F (374.1°C)], shall be determined by the equations in A-317.

**PG-27.3 Symbols.** Symbols used in the preceding equations are defined as follows: (17)

$C$ = minimum allowance for threading and structural stability (see PG-27.4.3)
$D$ = outside diameter of cylinder
$E$ = efficiency (see PG-27.4.1)

## Table PG-26
## Weld Strength Reduction Factors to Be Applied When Calculating Maximum Allowable Working Pressure or Minimum Required Thickness of Components Fabricated With a Longitudinal Seam Weld

| Temperature,°F | 700 | 750 | 800 | 850 | 900 | 950 | 1,000 | 1,050 | 1,100 | 1,150 | 1,200 | 1,250 | 1,300 | 1,350 | 1,400 | 1,450 | 1,500 | 1,550 | 1,600 | 1,650 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature,°C | 371 | 399 | 427 | 454 | 482 | 510 | 538 | 566 | 593 | 621 | 649 | 677 | 704 | 732 | 760 | 788 | 816 | 843 | 871 | 899 |
| Steel Group | Weld Strength Reduction Factor [Note (1)]–[Note (6)] | | | | | | | | | | | | | | | | | | | |
| C-Mo [Note (7)] | ... | ... | 1.00 | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| Cr-Mo [Note (8)], [Note (9)] | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| CSEF (N + T) [Note (9)], [Note (10)], [Note (11)] | ... | ... | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| CSEF (subcrit.) [Note (9)], [Note (11)], [Note (12)] | ... | ... | ... | ... | 1.00 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| Austenitic stainless steels and alloys 800H (N08810 and N08811) [Note (13)], [Note (14)] | ... | ... | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | 0.59 | 0.55 | 0.50 | NP | NP | NP |
| Autogenously welded austenitic stainless [Note (15)] | ... | ... | ... | ... | ... | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | NP | NP | NP |
| Nickel base alloys | | | | | | | | | | | | | | | | | | | | |
| N06045 | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | 0.59 | 0.55 | 0.50 | 0.50 | 0.50 | 0.50 | NP | NP | NP |
| N06600 | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| N06690 | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| N06601 | ... | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | 0.59 | 0.55 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| N06025 | ... | ... | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | 0.73 | 0.68 | 0.64 | 0.59 | 0.55 | 0.50 | 0.50 | 0.50 | 0.50 |
| N10276 | ... | ... | ... | ... | ... | 1.00 | 0.95 | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| N06022 | ... | ... | ... | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 | NP | NP | NP | NP | NP | NP | NP | NP |
| N06230 | ... | ... | ... | ... | ... | ... | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| N06625 | ... | ... | ... | ... | ... | ... | ... | ... | 1.00 | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP | NP |
| N06617 (except SAW) [Note (16)] | ... | ... | ... | ... | ... | ... | ... | ... | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| N06617 (SAW) [Note (17)] | ... | ... | ... | ... | ... | ... | ... | ... | 1.00 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| N07740 | ... | ... | ... | ... | ... | ... | ... | ... | 1.00 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | NP | NP | NP |
| Autogenously welded nickel base alloys [Note (15)] | ... | ... | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

GENERAL NOTE: Nothing in this table shall be construed to permit materials that are not permitted by PG-5 through PG-9 of this Section or to permit use of materials at temperatures beyond limitations established by this Section. Several materials covered by this table are currently permitted for Section I application only via code case.

NOTES:
(1) Cautionary Note: There are many factors that may affect the life of a welded joint at elevated temperature, and all of those factors cannot be addressed in a table of weld strength reduction factors. For example, fabrication issues such as the deviation from a true circular form in pipe (e.g., "peaking" at longitudinal weld seams) or offset at the weld joint can cause an increase in stress that may result in reduced service life, and control of these deviations is recommended.
(2) NP = not permitted.
(3) Components made from carbon steel are exempt from the requirements of PG-26 and Table PG-26.

## Table PG-26
## Weld Strength Reduction Factors to Be Applied When Calculating Maximum Allowable Working Pressure or Minimum Required Thickness of Components Fabricated With a Longitudinal Seam Weld (Cont'd)

NOTES (CONT'D):

(4) Longitudinal seam welds in components made from materials not covered in this table operating in the creep regime are not permitted. For the purposes of this table, the creep regime temperature range is defined to begin at a temperature 50°F (25°C) below the T-note temperature listed in Section II, Part D design property tables for the base material involved.

(5) All weld filler metal shall have a minimum carbon content of 0.05% for the Cr-Mo and CSEF materials and a minimum carbon content of 0.04% for the austenitic stainless steels.

(6) At temperatures below those where WSRFs are tabulated, a value of 1.0 shall be used for the factor *w* where required by the rules of this Section; however, the additional rules of this table and notes do not apply.

(7) Longitudinal seam fusion welded construction is not permitted for C-$^1/_2$ Mo steel above 850°F (454°C).

(8) The Cr-Mo steels include $^1/_2$Cr–$^1/_2$Mo, 1Cr–$^1/_2$Mo, 1$^1/_4$Cr–$^1/_2$Mo–Si, 2$^1/_4$Cr–1Mo, 3Cr–1Mo, and 5Cr–$^1/_2$Mo. Longitudinal welds shall either be normalized, normalized and tempered, or subjected to proper subcritical PWHT for the alloy.

(9) Basicity index of SAW flux ≥ 1.0.

(10) N + T = normalizing + tempering PWHT.

(11) The CSEF (creep strength enhanced ferritic) steels include Grades 91, 92, 911, 122, and 23.

(12) subcrit. = subcritical PWHT is required. No exemptions from PWHT are permitted. The PWHT time and temperature shall meet the requirements of Tables PW-39-1 through PW-39-14; the alternative PWHT requirements of Table PW-39.1 are not permitted.

(13) Certain heats of the austenitic stainless steels, particularly for those grades whose creep strength is enhanced by the precipitation of temper-resistant carbides and carbo-nitrides, can suffer from an embrittlement condition in the weld heat-affected zone that can lead to premature failure of welded components operating at elevated temperatures. A solution annealing heat treatment of the weld area mitigates this susceptibility.

(14) Alternatively, the following factors may be used as the weld joint strength reduction factor for the materials and welding consumables specified, provided the weldment is solution annealed after welding.

| **Temperature,°F** | **950** | **1,000** | **1,050** | **1,100** | **1,150** | **1,200** |
|---|---|---|---|---|---|---|
| **Temperature,°C** | **510** | **538** | **566** | **593** | **621** | **649** |
| **Materials** | **Weld Strength Reduction Factor** | | | | | |
| Type 304 stainless steel welded with SFA-5.22 EXXXT-G (16-8-2 chemistry), SFA 5.4E 16-8-2, and SFA-5.9 ER 16-8-2 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Type 316 stainless steel welded with SFA-5.22 EXXXT-G (16-8-2 chemistry), SFA 5.4 E 16-8-2, and SFA-5.9 ER 16-8-2 | 1.00 | 0.85 | 0.90 | 0.97 | 0.99 | 1.00 |

(15) Autogenous welds (made without weld filler metal) have been assigned a WSRF of 1.0 for austenitic SS materials up to 1,500°F (816°C) and for nickel base alloys up to 1,650°F (899°C), provided that the product is solution annealed after welding and receives nondestructive electric examination, in accordance with the material specification.

(16) Includes autogenous and SMAW, GTAW, and GMAW filler metal welds.

(17) SAW filler metal welds.

$e$ = thickness factor for expanded tube ends (see PG-27.4.4)
$P$ = maximum allowable working pressure (see PG-21)
$R$ = inside radius of cylinder; for pipe, the inside radius is determined by the outside radius minus the nominal wall thickness
$S$ = maximum allowable stress value at the design temperature of the metal, as listed in the tables specified in PG-23 (see PG-27.4.2)
$Sb$ = maximum allowable stress value at the design temperature of the base metal, as listed in the tables specified in PG-23, for a bimetallic tube in which the clad strength is to be included (see PG-27.4.10)
$Sc$ = maximum allowable stress value at the design temperature of the clad metal, as listed in Section II, Part D, Subpart 1, Table 1A or Table 1B, for a bimetallic tube in which the clad strength is to be included (see PG-27.4.10)
$t$ = minimum required thickness (see PG-27.4.7)
$tb$ = minimum required thickness of the base metal for a bimetallic tube in which the clad strength is to be included (see PG-27.4.10)
$tc$ = minimum required thickness of the clad for a bimetallic tube in which the clad strength is to be included (see PG-27.4.10)
$tc'$ = minimum effective clad thickness for strength purposes for a bimetallic tube in which the clad strength is to be included (see PG-27.4.10)
$w$ = weld joint strength reduction factor per PG-26
$y$ = temperature coefficient (see PG-27.4.6)

**PG-27.4** The following paragraphs apply to PG-27 equations as referenced.

**PG-27.4.1**

$E$ = 1.0 for seamless cylinders without openings spaced to form ligaments
= the ligament efficiency per PG-52 or PG-53 for seamless cylinders with ligaments
= $w$, the weld joint strength reduction factor per PG-26, for longitudinally welded cylinders without ligaments

For longitudinally welded cylinders with ligaments located such that no part of the longitudinal weld seam is penetrated by the openings forming the ligament, $E$ shall be taken as the lesser of $w$ or the ligament efficiency from PG-52 or PG-53. If any part of the longitudinal seam weld is penetrated by the openings that form the ligaments, $E$ shall be taken as the product of $w$ times the ligament efficiency.

**PG-27.4.2** The temperature of the metal to be used in selecting the $S$ value for tubes shall not be less than the maximum expected mean wall temperature, i.e., the sum of the outside and inside tube surface temperatures divided by 2. For tubes that do not absorb heat, the metal temperature may be taken as the temperature of the fluid within the tube but not less than the saturation temperature.

**PG-27.4.3** Any additive thickness represented by the general term $C$ may be considered to be applied on the outside, the inside, or both. It is the responsibility of the designer using these equations to make the appropriate selection of diameter or radius to correspond to the intended location and magnitude of this added thickness. The pressure- or stress-related terms in the formula should be evaluated using the diameter (or radius) and the remaining thickness which would exist if the "additive" thickness had not been applied or is imagined to have been entirely removed. (17)

The values of $C$ below do not include any allowance for corrosion and/or erosion, and additional thickness should be provided where they are applicable. Likewise, this allowance for threading and minimum structural stability is not intended to provide for conditions of misapplied external loads or for mechanical abuse.

| Threaded Pipe [Note (1)] | Value of $C$ [Note (2)], in. (mm) |
|---|---|
| $D \leq 3/4$ in. (19 mm) nominal | 0.065 (1.65) |
| $D > 3/4$ in. (19 mm) nominal | Depth of thread $h$ [Note (3)] |

NOTES:
(1) Steel or nonferrous pipe lighter than Schedule 40 of ASME B36.10M, Welded and Seamless Wrought Steel Pipe, shall not be threaded.
(2) The values of $C$ stipulated above are such that the actual stress due to internal pressure in the wall of the pipe is no greater than the values of $S$ given in Section II, Part D, Subpart 1, Table 1A, as applicable in the equations.
(3) The depth of thread $h$ in in. (mm) may be determined from the formula $h = 0.8/n$ ($h = 20/n$), where $n$ is the number of threads per inch (25 mm) or from the following:

| $n$ | $h$ |
|---|---|
| 8 | 0.100 (2.5) |
| $11\frac{1}{2}$ | 0.0696 (1.77) |

**PG-27.4.4**

$e$ = 0.04 (1.0) over a length at least equal to the length of the seat plus 1 in. (25 mm) for tubes expanded into tube seats, except
= 0 for tubes expanded into tube seats provided the thickness of the tube ends over a length of the seat plus 1 in. (25 mm) is not less than the following:

*(a)* 0.095 in. (2.41 mm) for tubes $1\frac{1}{4}$ in. (32 mm) O.D. and smaller

*(b)* 0.105 in. (2.67 mm) for tubes above $1\frac{1}{4}$ in. (32 mm) O.D. and up to 2 in. (50 mm) O.D., incl.

*(c)* 0.120 in. (3.05 mm) for tubes above 2 in. (50 mm) O.D. and up to 3 in. (75 mm) O.D., incl.

*(d)* 0.135 in. (3.43 mm) for tubes above 3 in. (76 mm) O.D. and up to 4 in. (100 mm) O.D., incl.

*(e)* 0.150 in. (3.81 mm) for tubes above 4 in. (100 mm) O.D. and up to 5 in. (125 mm) O.D., incl.

= 0 for tubes strength-welded to tubesheets, headers, and drums. Strength-welded tubes shall comply with the minimum weld sizes of PW-16.

**PG-27.4.5** While the thickness given by the formula is theoretically ample to take care of both bursting pressure and material removed in threading, when steel pipe is threaded and used for steam pressures of 250 psi (1.7 MPa) and over, it shall be seamless and of a weight at least equal to Schedule 80 in order to furnish added mechanical strength.

**PG-27.4.6**

$y$ = a coefficient having values as follows:

| | Temperature, °F (°C) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **900 (480) and Below** | **950 (510)** | **1,000 (540)** | **1,050 (565)** | **1,100 (595)** | **1,150 (620)** | **1,200 (650)** | **1,250 (675) and Above** |
| Ferritic | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Austenitic | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 |
| Alloy 800, 801 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 |
| 800H, N08811 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 |
| 825 | 0.4 | 0.4 | 0.4 | ... | ... | ... | ... | ... |
| N06230 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 |
| N06022 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 |
| N06025 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 |
| N06045 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | 0.7 |
| N06600 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | ... |
| N06601 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | ... |
| N06625 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | ... | ... | ... |
| N06690 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.7 | ... |
| Alloy 617 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 |
| S31803 | 0.4 | ... | ... | ... | ... | ... | ... | ... |

Values of $y$ between temperatures listed may be determined by interpolation. For nonferrous materials not listed, $y = 0.4$.

(17) **PG-27.4.7** If pipe is ordered by its nominal wall thickness, as is customary in trade practice, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness $t$ is determined by the formula, this minimum thickness shall be increased by an amount sufficient to provide the maximum manufacturing tolerance allowed in the applicable pipe specification. The next heavier commercial wall thickness may then be selected from Standard thickness schedules as contained in ASME B36.10M. The manufacturing tolerances are given in the several pipe specifications listed in PG-9.

**PG-27.4.8** When computing the allowable pressure for a pipe of a definite minimum wall thickness, the value obtained by the equations may be rounded up to the next higher unit of 10 psi (0.1 MPa).

**PG-27.4.9** The maximum allowable working pressure $P$ need not include the hydrostatic head loading, PG-22, when used in this equation.

**PG-27.4.10** The following requirements apply to bimetallic tubes when the strength of the clad is included. For additional fabrication requirements, see PW-44. For such bimetallic tubes, the thermal conductivity of the base metal shall be equal to or greater than the thermal conductivity of the clad material. The cladding process shall achieve a metallurgical bond between the clad and the base metal (core tube).

The temperature of the metal to be used in selecting the $Sb$ value for core tubes shall not be less than the maximum expected mean wall temperature calculated using the base metal thermal properties for a tube with the same outside diameter and total wall thickness as the clad tube, i.e., the sum of the outside and inside tube surface temperature of an equivalent core tube, divided by 2.

The temperature of the metal to be used in selecting the $Sc$ value for the clad shall not be less than the maximum expected mean wall temperature of the clad, i.e., the sum of the outside surface temperature and the base metal-clad interface temperature, divided by 2.

The value of $Sc$ shall be taken as that for an annealed wrought material with nominally equivalent strength and composition as the clad. Values applicable to either Section I or Section VIII, Division 1 may be used. If two stress values are listed for a material, the higher value may be used.

The sizing equation is subject to the following constraints:

*(a)* $tb \geq tc$ (excludes clads thicker than core tube)

*(b)* $t < D/4$ (excludes thick-walled tubes)

*(c)* If $\left(\frac{Sc}{Sb}\right) \geq 1$, the ratio is set to 1 in the calculation

*(d)* If $\left(\frac{Sc}{Sb}\right) < 1$, the actual ratio is used in the calculation

## PG-28 COMPONENTS UNDER EXTERNAL PRESSURE

### PG-28.1 Thickness of Cylindrical Components Under External Pressure.

**PG-28.1.1** Design Temperature shall be not less than the mean expected wall temperature.

**PG-28.1.1.1** Temperatures in excess of the maximum temperature listed for each material given in Section II, Part D, Subpart 1, Tables 1A and 1B, are not permitted.

**PG-28.1.1.2** Temperatures in excess of the maximum temperature given on the external pressure charts are not permitted.

**PG-28.1.1.3** Rounding off equation results to the next higher unit of 10 is permitted (see PG-27.4.8).

**PG-28.2 Welded Access or Inspection Openings Under External Pressure.** The maximum allowable working pressure for welded access or inspection openings, with inward projections subjected to external pressure (such as manhole or handhole rings with internal covers), may be determined in accordance with the rules of PG-27 when the following requirements are met. The length of the internal projection of the ring extending past the toe of the attachment weld on the ring, shall not exceed the thickness of the ring. The length past the toe of the weld is measured at the location of the shortest ring projection into the vessel (see Figure PG-28). For elliptical rings the value of $D$ to be used in the procedures of PG-27 shall be determined in accordance with the following equation for elliptical rings:

$$D = a^2 / b$$

where

$a$ = outside major axis of the ellipse
$b$ = outside minor axis of the ellipse

This provision does not apply to flanged in manholes covered by PG-29.3, PG-29.7, and PG-29.12.

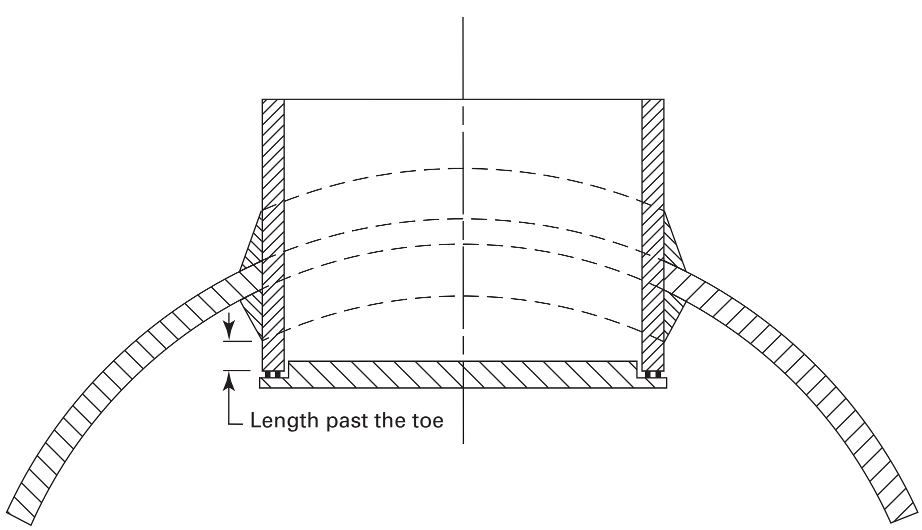
**PG-28.3 Maximum Allowable External Working Pressure for Cylindrical Components.**

**PG-28.3.1** The maximum allowable working pressure of cylindrical components under external pressure shall be as determined by the following rules. External pressure charts for use in determination of minimum requirements are given in Section II, Part D, Subpart 3. Figure numbers shown in this Article are contained in that Subpart. Section I includes design rules for stiffening rings for external pressure design for furnaces only (see PFT-17.11). For stiffening rings for other cylindrical components under external pressure, see PG-16.1.

**PG-28.3.1.1** The following symbols are used in the procedures of this Article: (**17**)

$A$ = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, for the case of cylinders having $D_o/t$ values less than 10, see PG-28.3.1.2(b).
$A_S$ = cross-sectional area of stiffening ring
$B$ = factor determined from the applicable material chart in Section II, Part D, for maximum design metal temperature
$D_o$ = outside diameter of cylindrical component
$E$ = modulus of elasticity of material at design temperature. (For this value see the applicable materials chart in Section II, Part D. Interpolation may be made between the lines for intermediate temperatures.)
$I_S$ = required moment of inertia of stiffening ring about its neutral axis parallel to the axis of the furnace

**Figure PG-28**
**Maximum Internal Projection of Welded Access or Inspection Openings**




GENERAL NOTE: For other acceptable weld configurations, see Figure PW-16.1.

$L$ = total length, of a cylindrical component between lines of support, or design length of a furnace taken as the largest of the following:

*(a)* the greatest center-to-center distance between any two adjacent stiffening rings

*(b)* the distance between the tubesheet and the center of the first stiffening (ring reinforced)

*(c)* the distance from the center of the first stiffening ring to a circumferential line on a formed head at one-third the depth from the head tangent line

$L_s$ = one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder. (See PFT-17.11 for design of stiffening rings.) A line of support is

*(a)* a stiffening ring that meets the requirements of PFT-17.11

*(b)* a circumferential connection to a tubesheet or jacket for a jacketed section of a cylindrical shell

*(c)* a circumferential line on a formed head at one-third the depth of the head from the head tangent line

$P$ = external design pressure

$P_a$ = calculated value of allowable external working pressure for the assumed value of $t$

$S$ = the maximum allowable stress value at design metal temperature

$t$ = minimum required thickness of cylindrical components

$t_S$ = nominal thickness of cylindrical components

(**17**) **PG-28.3.1.2 Cylindrical Components.** The required minimum thickness of a cylindrical component under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure:

*(a)* cylinder having $D_o/t$ values equal to or greater than 10

*Step 1.* Assume a value of $t$ 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. 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 $A$ value 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 the value of $B$, calculate the value of the maximum allowable external pressure, $P_a$, using the following equation:

$$P_a = \frac{4B}{3(D_o/t)}$$

*Step 7.* For values of $A$ falling to the left of the applicable material/temperature line, the value of $P_a$ shall 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 $P$.

*(b)* cylinders having $D_o/t$ values of less than 10

*Step 1.* Using the same procedure as given in (a) above, obtain the value of $B$. For values of $D_o/t$ less than 4, the value of $A$ shall 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 of $P_{a1}$ using the following equation:

$$P_{a1} = \left[\frac{2.167}{D_o/t} - 0.0833\right]B$$

*Step 3.* Calculate a value of $P_{a2}$ using the following equation:

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

where $S_B$ is the lesser of 2 times the maximum allowable stress values at design metal temperature from Section II, Part D, Subpart 1, Tables 1A and 1B; or, 1.8 times the yield strength of the material at Design Metal Temperature from Section II, Part D, Subpart 1, Table Y-1.

*Step 4.* The smaller of the values of $P_{a1}$ calculated in Step 2, or $P_{a2}$ calculated in Step 3 shall be used for the maximum allowable external pressure $P_a$. 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 $P$.

**PG-28.3.1.3** The design pressure or maximum allowable working pressure shall be not less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the cylindrical component at any time.

**PG-28.3.1.4** When necessary, furnaces shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in PG-22 other than pressure and temperature.

## PG-29 DISHED HEADS

**PG-29.1** The thickness of a blank unstayed dished head with the pressure on the concave side, when it is a segment of a sphere, shall be calculated by the following equation:

$$t = 5PL / 4.8Sw$$

where

$L$ = radius to which the head is dished, measured on the concave side of the head
$P$ = maximum allowable working pressure (hydrostatic head loading need not be included)
$S$ = maximum allowable working stress, using values given in Section II, Part D, Subpart 1, Table 1A
$t$ = minimum thickness of head
$w$ = weld joint strength reduction factor per PG-26

**PG-29.1.1** If local thin areas are present in the spherical portion of the dished head, the required thickness may be less than the thickness determined in PG-29.1 provided the requirements of Mandatory Appendix IV are met.

**PG-29.2** The radius to which a head is dished shall be not greater than the outside diameter of flanged portion of the head. Where two radii are used the longer shall be taken as the value of $L$ in the equation.

**PG-29.3** When a head dished to a segment of a sphere has a flanged-in manhole or access opening that exceeds 6 in. (150 mm) in any dimension, the thickness shall be increased by not less than 15% of the required thickness for a blank head computed by the above formula, but in no case less than $^1/_8$ in. (3 mm) additional thickness over a blank head. Where such a dished head has a flanged opening supported by an attached flue, an increase in thickness over that for a blank head is not required. If more than one manhole is inserted in a head, the thickness of which is calculated by this rule, the minimum distance between the openings shall be not less than one-fourth of the outside diameter of the head.

**PG-29.4** Except as otherwise provided for in PG-29.3, PG-29.7, and PG-29.12, all openings which require reinforcement, placed in a head dished to a segment of a sphere, or in an ellipsoidal head, or in a full-hemispherical head, including all types of manholes except those of the integral flanged-in type, shall be reinforced in accordance with the rules in PG-33.

When so reinforced, the thickness of such a head may be the same as for a blank unstayed head.

**PG-29.5** Where the radius $L$ to which the head is dished is less than 80% of the outside diameter of the head, the thickness of a head with a flanged-in manhole opening shall be at least that found by making $L$ equal to 80% of the outside diameter of the head and with the added thickness for the manhole. This thickness shall be the minimum thickness of a head with a flanged-in manhole opening for any form of head and the maximum allowable working stress shall not exceed the values given in Section II, Part D, Subpart 1, Table 1A.

**PG-29.6** No head, except a full-hemispherical head, shall be of a lesser thickness than that required for a seamless shell of the same diameter.

**PG-29.7** A blank head of a semiellipsoidal form in which half the minor axis or the depth of the head is at least equal to one-quarter of the inside diameter of the head shall be made at least as thick as the required thickness of a seamless shell of the same diameter as provided in PG-27 or A-317. If a flanged-in manhole that meets the Code requirements is placed in an ellipsoidal head, the thickness of the head shall be the same as for a head dished to a segment of a sphere (see PG-29.1 and PG-29.5) with a dish radius equal to eight-tenths the outside diameter of the head and with the added thickness for the manhole as specified in PG-29.3.

**PG-29.8** When heads are made to an approximate ellipsoidal shape, the inner surface of such heads must lie outside and not inside of a true ellipse drawn with the major axis equal to the inside diameter of the head and one-half the minor axis equal to the depth of the head. The maximum variation from this true ellipse shall not exceed 0.0125 times the inside diameter of the head.

**PG-29.9** Unstayed dished heads with the pressure on the convex side shall have a maximum allowable working pressure equal to 60% of that for heads of the same dimensions with the pressure on the concave side.

Head thicknesses obtained by using the equations in PG-29.11 for hemispherical heads and PG-29.7 for blank semiellipsoidal heads do not apply to heads with pressure on the convex side.

**PG-29.11** The thickness of a blank unstayed full-hemispherical head with the pressure on the concave side shall be calculated by the following equation:

$$t = \frac{PL}{2Sw - 0.2P}$$

where

$L$ = radius to which the head was formed, measured on the concave side of the head
$P$ = maximum allowable working pressure
$S$ = maximum allowable working stress, using values given in Section II, Part D, Subpart 1, Table 1A
$t$ = minimum thickness of head
$w$ = weld joint strength reduction factor per PG-26

The above equation shall not be used when the required thickness of the head given by this formula exceeds 35.6% of the inside radius, and instead, the following equation shall be used:

$$t = L\left(Y^{1/3} - 1\right)$$

where

$$Y = \frac{2\left(Sw + P\right)}{2Sw - P}$$

Joints in full-hemispherical heads including the joint to the shell shall be governed by and meet all the requirements for longitudinal joints in cylindrical shells, except that in a buttwelded joint attaching a head to a shell the middle lines of the plate thicknesses need not be in alignment.

If local thin areas are present in the full-hemispherical head, the required thickness may be less than the thickness determined above provided the requirements of Mandatory Appendix IV are met.

**PG-29.12** If a flanged-in manhole that meets the Code requirements is placed in a full-hemispherical head, the thickness of the head shall be the same as for a head dished to a segment of a sphere (see PG-29.1 and PG-29.5), with a dish radius equal to eight-tenths the outside diameter of the head and with the added thickness for the manhole as specified in PG-29.3.

**PG-29.13** The corner radius of an unstayed dished head measured on the concave side of the head shall be not less than three times the thickness of the material in the head; but in no case less than 6% of the outside diameter of the head. In no case shall the thinning-down due to the process of forming, of the knuckle portion of any dished head consisting of a segment of a sphere encircled by a part of a torus constituting the knuckle portion (torispherical), exceed 10% of the thickness required by the formula in PG-29.1. Other types of heads shall have a thickness after forming of not less than that required by the applicable equation.

**PG-29.14** If a dished head concave to pressure is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that allowable for flat heads as given by the equation in PG-31, using $C$ = 0.25.

## PG-30 STAYED DISHED HEADS

**PG-30.1** When dished heads are of a thickness less than called for by PG-29, they shall be stayed as flat surfaces, no allowance being made in such staying for the holding power due to the spherical form unless all of the following conditions are met:

**PG-30.1.1** That they be at least two-thirds as thick as called for by the rules for unstayed dished heads.

**PG-30.1.2** That they be at least $^7/_8$ in. (22 mm) in thickness.

**PG-30.1.3** That through-stays be used attached to the dished head by outside and inside nuts.

**PG-30.1.4** That the maximum allowable working pressure shall not exceed that calculated by the rules for an unstayed dished head plus the pressure corresponding to the strength of the stays or braces secured by the formula for braced or stayed surfaces given in PG-46, using 1.3 for the value of $C$.

**PG-30.2** If a stayed dished head concave to pressure is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that allowable for flat heads as given by the formula in PG-31, using $C$ = 0.25.

## PG-31 UNSTAYED FLAT HEADS AND COVERS

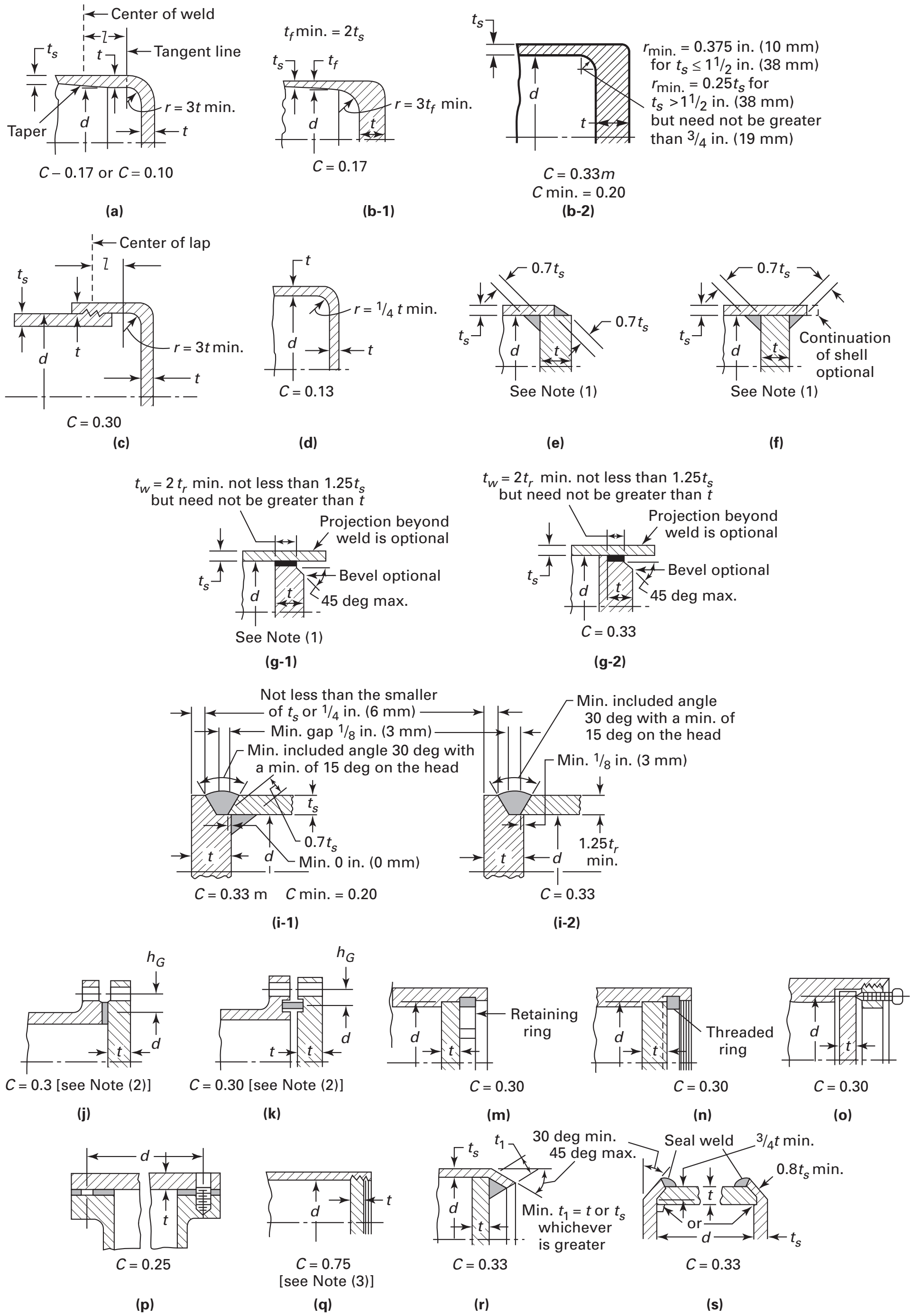
**PG-31.1** The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular[6] heads and covers. Some acceptable types of flat heads and covers are shown in Figure PG-31. In this figure, the dimensions of the welds do not include any allowances for corrosion and/or erosion; additional weld metal should be provided where these allowances are applicable. (**17**)

**PG-31.2** The notations used in this paragraph and in Figure PG-31 are defined as follows: (**17**)

$C$ = a factor depending on the method of attachment of head and on the shell, pipe, or header dimensions, and other items as listed in PG-31.4 below, dimensionless. The factors for welded covers also include a factor of 0.667 that effectively increases the allowable stress for such constructions to 1.5$S$.

(17)

## Figure PG-31
## Some Acceptable Types of Unstayed Flat Heads and Covers




GENERAL NOTE: The above illustrations are diagrammatic only. Other designs that meet the requirements of PG-31 will be acceptable.

NOTES:
(1) For illustrations (e), (f), and (g-1) circular covers, $C = 0.33m$, $C$ min. = 0.20; noncircular covers, $C = 0.33$.
(2) Use PG-31.3.2 eq. (2) or PG-31.3.3 eq. (5).
(3) When pipe threads are used, see Table PG-39.

$D$ = long span of noncircular heads or covers measured perpendicular to short span
$d$ = diameter, or short span, measured as indicated in Figure PG-31
$h_G$ = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, as shown in Figure PG-31, illustrations (j) and (k)
$L$ = perimeter of noncircular bolted head measured along the centers of the bolt holes
$l$ = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure PG-31, illustrations (a) and (c)
$m$ = the ratio $t_r/t_s$, dimensionless
$P$ = maximum allowable working pressure
$r$ = inside corner radius on a head formed by flanging or forging
$S$ = maximum allowable stress value, using values given in Section II, Part D, Subpart 1, Table 1A
$t$ = minimum required thickness of flat head or cover
$t_1$ = throat dimension of the closure weld, as indicated in Figure PG-31, illustration (r)
$t_f$ = nominal thickness of the flange on a forged head, at the large end, as indicated in Figure PG-31, illustration (b-1)
$t_h$ = nominal thickness of flat head or cover
$t_r$ = thickness required for pressure of seamless shell, pipe, or header
$t_s$ = minimum specified thickness of shell, pipe, or header
$t_w$ = thickness through the weld joining the edge of a head to the inside of a drum, pipe, or header, as indicated in Figure PG-31, illustrations (g-1) and (g-2)
$W$ = total bolt load, as further defined in PG-31.3.2
$Z$ = a factor for noncircular heads and covers that depends on the ratio of short span to long span, as given in PG-31.3, dimensionless

**PG-31.3** The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements.[7]

**PG-31.3.1** Circular blind flanges of ferrous materials conforming to ASME B16.5 shall be acceptable for the diameters and pressure–temperature ratings in Table 2 of that Standard when of the types shown in Figure PG-31, illustrations (j) and (k).

**PG-31.3.2** The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by the following equation:

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

except when the head, cover, or blind flange is attached by bolts causing an edge moment [Figure PG-31, illustrations (j) and (k)] in which case the thickness shall be calculated by the following equation:

$$t = d\sqrt{\left(CP/S\right) + \left(1.9Wh_G/Sd^3\right)} \tag{2}$$

When using eq. (2) the thickness $t$ shall be calculated for both design conditions and gasket seating, and the greater of the two values shall be used. For design conditions, the value of $P$ shall be the maximum allowable working pressure, the value of $S$ at design temperature shall be used, and $W$ shall be the sum of the bolt loads required to resist the end pressure load and to maintain tightness of the gasket.[8] For gasket seating, $P$ equals zero, the value of $S$ at atmospheric temperature shall be used, and $W$ shall be the average of the required bolt load and the load available from the bolt area actually used.

**PG-31.3.3** 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 equation:

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

where

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

with the limitation that $Z$ need not be greater than $2\frac{1}{2}$.

Equation (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment [Figure PG-31, illustrations (j) and (k)]. For noncircular heads of this type, the required thickness shall be calculated by the following equation:

$$t = d\sqrt{\left(ZCP/S\right) + \left(6Wh_G/SLd^2\right)} \tag{5}$$

When using eq. (5), the thickness $t$ shall be calculated in the same way as specified above for eq. PG-31.3.2(2).

**PG-31.4** For the types of construction shown in Figure PG-31, the minimum values of $C$ to be used in eqs. PG-31.3.2(1), PG-31.3.2(2), PG-31.3.3(3), and PG-31.3.3(5) are:[9] (17)

Figure PG-31, illustration (a): $C$ = 0.17 for flanged circular and noncircular heads forged integral with or butt-welded to the shell, pipe, or header, 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 PW.

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

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

When $C$ = 0.10 is used, the slope of the tapered sections shall be no greater than 1:3.

Figure PG-31, illustration (b-1): $C$ = 0.17 for circular and noncircular heads forged integral with or buttwelded to the shell, pipe, or header, where the corner radius on the inside is not less than three times the thickness of the flange and where the welding meets all the requirements for circumferential joints given in Part PW.

Figure PG-31, illustration (b-2): $C$ = 0.33$m$ but not less than 0.20 for forged circular and noncircular heads integral with or butt welded to the shell, pipe, or header, where the hubbed flange thickness is not less than the shell thickness, and the corner radius on the inside is not less than the following:

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

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

The hub may be formed by machining a forged blank or by direct forging action. This illustration shall not be used with plate, bar, or rod. The welding shall meet all requirements for circumferential joints in Part PW.

Figure PG-31, illustration (c): $C$ = 0.30 for circular flanged plates screwed over the end of the shell, pipe, or header, with inside corner radius not less than 3$t$, 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 4, 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.

Figure PG-31, illustration (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 nor 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 0.25$t$; and the construction is obtained by special techniques of upsetting and spinning the end of the shell, pipe, or header, such as are employed in closing header ends.

Figure PG-31, illustrations (e), (f), and (g-1): $C$ = 0.33$m$ but not less than 0.20 for circular plates and $C$ = 0.33 for noncircular plates welded to the inside of a drum, pipe, or header, and otherwise meeting the requirements for the respective types of welded boiler drums, including postweld heat treatment when required for the drum, but omitting volumetric examination. 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 illustrations (e) and (f) shall be at least 0.7$t_s$. The size of the weld $t_w$ in illustration (g-1) 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 figure.

Figure PG-31, illustration (g-2): $C$ = 0.33 for circular plates, welded to the inside of a drum, pipe, or header, and otherwise meeting the requirements for the respective types of welded boiler drums, including postweld heat treatment when required for the drum, but omitting volumetric examination. When the weld is not deposited at the inner face of the header, the thickness of the head that remains unwelded shall be in addition to the thickness of the head calculated per PG-31.3.2. The drum or header shall be limited to NPS 4 or less.

$C$ = 0.33 for noncircular plates, welded to the inside of a drum, pipe, or header, and otherwise meeting the requirements for the respective types of welded boiler drums, including postweld heat treatment when required for the drum, but omitting volumetric examination. The throat thickness of the fillet welds in Figure PG-31, illustrations (e) and (f) shall be at least 0.7$t_s$. The size of the weld $t_w$ in illustration (g-1) 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 figure.

Figure PG-31, illustration (i): $C$ = 0.33$m$ but not less than 0.20 for circular plates welded to the end of the drum, pipe, or header, when an inside weld with minimum throat thickness of 0.7$t_s$ is used. The width at the bottom of the welding groove shall be not less than $^1/_8$ in. (3 mm) and the exposed edge not less than $t_s$ or $^1/_4$ in. (6 mm), whichever is smaller. The inside fillet weld may be omitted, providing $t_s$ is not less than 1.25$t_r$ and the factor $C$ is taken as 0.33.

Figure PG-31, illustrations (j) and (k): $C$ = 0.3 for circular and noncircular heads and covers bolted to the shell, flange, or side plate as indicated in the figures. Note that eq. PG-31.3.2(2) or eq. PG-31.3.3(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 illustration (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, and not less than

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

for noncircular heads and covers.

Figure PG-31, illustrations (m), (n), and (o): $C$ = 0.3 for a circular plate inserted into the end of a shell, pipe, or header 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 4. Seal welding may be used, if desired.

Figure PG-31, illustration (p): $C$ = 0.25 for circular and noncircular covers bolted with a full-face gasket to shell, flanges, or side plates.

Figure PG-31, illustration (q): $C$ = 0.75 for circular plates screwed into the end of a shell, pipe, or header having an inside diameter $d$ not exceeding 12 in. (300 mm); or for heads having an integral flange screwed over the end of a shell, pipe, or header 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 4. If a tapered pipe thread is used, the requirements of Table PG-39 shall be met. Seal welding may be used, if desired.

Figure PG-31, illustration (r): $C$ = 0.33 for circular plates having a dimension $d$ not exceeding 18 in. (450 mm) inserted into the shell, pipe, or header and welded as shown, and otherwise meeting the requirements for welded boiler drums including postweld heat treatment but omitting volumetric examination. The end of the shell, pipe, or header 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 the shell, pipe, or header, whichever is greater.

Figure PG-31, illustration (s): $C$ = 0.33 for circular beveled plates having a diameter, $d$, not exceeding 18 in. (450 mm) inserted into a shell, pipe, or header, 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 working pressure for this construction shall not exceed $P = 5S/d$ ($P = 125S/d$).

## OPENINGS AND COMPENSATION[10]

### PG-32 OPENINGS IN SHELLS, HEADERS, AND DISHED HEADS

**PG-32.1** The rules for openings and compensation in PG-32 through PG-39 shall apply to all openings in shells, headers, and dished heads except as otherwise provided in PG-29.3, PG-29.7, PG-29.12, PG-32.1.2, PG-32.1.4, PG-32.1.5, and PFT-40.

**PG-32.1.1** The notations used throughout PG-32.1 are defined as follows: (17)

$D$ = the outside diameter of the shell, header, or dished head containing the opening, in. (mm)

$d$ = diameter of a finished opening, in. (mm)(see PG-33.3)

$d_{max}$ = the maximum permissible finished opening diameter for an uncompensated opening, in. (mm) (see PG-32.1.4)

$K$ = for openings in

*(a)* cylindrical shells and headers and dished heads, $K = K_1$

*(b)* full-hemispherical heads, $K = K_2$

$K_1$ = lesser of 0.990 or $PD/(1.82St)$

$K_2$ = lesser of 0.990 or $PD/(3.64St)$

$L_{co}$ = the distance between centers of two openings measured on the surface of the head, shell, or header, in. (mm)

$P$ = the maximum allowable working pressure

$S$ = the maximum allowable stress value, taken from Section II, Part D, Subpart 1, Tables 1A and 1B

$t$ = the nominal thickness of the head, shell, or header, in. (mm)

$X_1$, $X_2$ = the limits of compensation parallel to the vessel wall (see PG-36.2) of any two finished openings under construction, in. (mm)

**PG-32.1.2 Multiple Openings.** Groups of openings may be designed in accordance with the rules for ligaments in PG-52 or PG-53. Multiple openings that are not designed as ligaments shall comply with PG-38.

**PG-32.1.3 Single Openings.** Single openings are defined as openings that have a minimum center-to-center distance between adjacent openings not less than $L_{co}$, where (17)

$$L_{co} = X_1 + X_2$$

**PG-32.1.4 Openings in Shells and Headers.** No calculation need be made to determine the availability of compensation for a single opening (see PG-32.1.3), not covered by PG-38, PG-52, or PG-53, in shells or headers when the diameter of the finished opening, $d$, as defined in PG-33.3 does not exceed the larger of (a) or (b) below. (17)

*(a)* the value of $d_{max}$ as follows:

*(U.S. Customary Units)*

$$d_{\max} = 2.75\left[Dt\left(1 - K\right)\right]^{1/3}$$

*(SI Units)*

$$d_{\max} = 8.08\left[Dt\left(1 - K\right)\right]^{1/3}$$

*(b)* the smaller of one-fourth the inside diameter of the shell or header or $2\frac{3}{8}$ in. (60 mm)

**PG-32.1.5 Openings in Dished Heads.** No calculation need be made to determine the availability of compensation for a single opening in dished heads under the same conditions stipulated for openings in shells and headers in PG-32.1.4, provided the following additional requirements are met.

**PG-32.1.5.1** The openings shall be located completely within the center portion of a dished head bounded by the tangent line between the spherically dished portion and the knuckle radius, but not closer than the thickness of the head to the edge of this circle or to a flanged-in manway. For a 2:1 ellipsoidal head, the opening shall be located completely within the center portion of the head bounded by a circle equal to 80% of the inside diameter, but not closer than the thickness of the head to the edge of this circle.

(**17**) **PG-32.1.5.2** For dished heads other than full-hemispherical heads, the maximum allowable opening diameter shall not exceed that permitted in PG-32.1.4 using $K = K_1$ for an equivalent shell constructed of the same material, outside diameter, and the maximum allowable working pressure of the head.

(**17**) **PG-32.1.5.3** For full-hemispherical heads, the maximum allowable opening diameter shall not exceed that permitted in PG-32.1.4 using $K = K_2$ for an equivalent shell constructed of the same material, outside diameter, and the maximum allowable working pressure of the head.

**PG-32.2 Shape of Openings.**[11]

**PG-32.2.1** Openings in cylindrical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround.[12]

When the long dimension of an elliptical or obround opening exceeds twice the short dimension, the compensation across the short dimension shall be increased as necessary to provide against excessive distortion due to twisting moment.

**PG-32.2.2** Openings may be of other shapes than those given in PG-32.2.1, 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 PG-18.

**PG-32.3 Size of Openings.**

**PG-32.3.1** Properly reinforced openings in cylindrical and spherical shells are not limited as to size and shall comply with the provisions that follow, and with the additional provisions given under PG-32.3.2.

**PG-32.3.2** The rules given herein for compensation apply to openings not exceeding the following dimensions:

*(a)* for vessels 60 in. (1 500 mm) inside diameter and less, one-half the vessel inside diameter but not over 20 in. (500 mm)

*(b)* for vessels over 60 in. (1 500 mm) inside diameter, one-third the vessel inside diameter but not over 40 in. (1 000 mm)

**PG-32.3.3** Larger openings should be given special attention and may be provided with compensation in any suitable manner that complies with the intent of the Code rules. It is recommended that the compensation provided be distributed close to the opening. (A provision of about two-thirds of the required compensation within a distance of three-fourths times the limit established in PG-36.2 on each side of the opening as measured from the center of the opening is suggested.) Special consideration should be given to the fabrication details used and the inspection employed on critical openings; compensation often may be advantageously obtained by use of a thicker shell plate for a vessel course or inserted locally around the opening; welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations. Appropriate proof testing may be advisable in extreme cases of large openings approaching full vessel diameter, openings of unusual shape, etc.

## PG-33 COMPENSATION REQUIRED FOR OPENINGS IN SHELLS AND DISHED HEADS

**PG-33.1 General.** The rules in this subparagraph apply to all openings other than flanged-in openings in dished heads covered by PG-29.3, PG-29.7, and PG-29.12; openings in flat heads covered by PG-35; and openings covered within PG-32.1.2, PG-32.1.4, and PG-32.1.5.

When required, compensation shall be provided in such amount and distribution that the requirements for area of compensation 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.