SECTION I

2025 ASME Boiler and Pressure Vessel Code

An International Code

Rules for Construction of Power Boilers

ASME
SETTING THE STANDARD

AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

I RULES FOR CONSTRUCTION OF POWER BOILERS

ASME Boiler and Pressure Vessel Committee
on Power Boilers

The American Society of Mechanical Engineers
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FOREWORD*

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 In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

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

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

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

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

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

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

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

responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

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

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

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

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

When required by context in the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

- *Shall* is used to denote a requirement.
- *Should* is used to denote a recommendation.
- *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

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

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

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

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

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

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

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

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

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ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number to which the proposed case applies

(4) the editions of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements.

Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

PREAMBLE

This Code covers rules for construction of power boilers,[1] electric boilers,[2] miniature boilers,[3] high-temperature water boilers,[4] heat recovery steam generators,[5] solar receiver steam generators,[6] certain fired pressure vessels,[7] and liquid phase thermal fluid heaters[8] to be used in stationary service and includes those power boilers used in locomotive, portable, and traction service. Reference to a paragraph includes all the subparagraphs and subdivisions under that paragraph.

The Code does not contain rules to cover all details of design and construction. Where complete details are not given, it is intended that the manufacturer, subject to the acceptance of the Authorized Inspector, shall provide details of design and construction which will be as safe as otherwise provided by the rules in the Code.

The scope of jurisdiction of Section I applies to the boiler proper and to the boiler external piping.

Superheaters, economizers, and other pressure parts connected directly to the boiler without intervening valves shall be considered as parts of the boiler proper, and their construction shall conform to Section I rules.

Boiler external piping shall be considered as that piping which begins where the boiler proper or isolable superheater or isolable economizer terminates at:

(a) the first circumferential joint for welding end connections; or

(b) the face of the first flange in bolted flanged connections; or

(c) the first threaded joint in that type of connection; and which extends up to and including the valve or valves required by this Code.

ASME Code Certification (including Data Forms and stamping the Certification Mark[9] with appropriate Designator[10]), and/or inspection by the Authorized Inspector, when required by this Code, is required for the boiler proper and the boiler external piping.

Construction rules for materials, design, fabrication, installation, and testing of the boiler external piping are contained in ASME B31.1, Power Piping. Piping beyond the valve or valves required by Section I is not within the scope of Section I.

The material for forced-circulation boilers, boilers with no fixed steam and water line, and high-temperature water boilers shall conform to the requirements of the Code. All other requirements shall also be met except where they relate to special features of construction made necessary in boilers of these types, and to accessories that are manifestly not needed or used in connection with such boilers, such as gage glasses and water columns.

Reheaters receiving steam which has passed through part of a turbine or other prime mover and separately fired steam superheaters which are not integral with the boiler are considered fired pressure vessels and their construction shall comply with Code requirements for superheaters, including safety devices. Piping between the reheater connections and the turbine or other prime mover is not within the scope of the Code. Steam piping to the inlet connections and from the outlet connections of nonintegral separately fired superheaters is not within the scope of this Code.

Economizers that are located outside the limits of boiler external piping are considered fired pressure vessels. Piping to and from the connections to such economizers is not within the scope of this Code.

A pressure vessel in which steam is generated by the application of heat resulting from the combustion of fuel (solid, liquid, or gaseous) or from solar radiation shall be classed as a fired steam boiler.

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[1] Power boiler — a boiler in which steam or other vapor is generated at a pressure of more than 15 psi (100 kPa) for use external to itself.

[2] Electric boiler — a power boiler or a high-temperature water boiler in which the source of heat is electricity.

[3] Miniature boiler — a power boiler or a high-temperature water boiler in which the limits specified in PMB-2 are not exceeded.

[4] High-temperature water boiler — a water boiler intended for operation at pressures in excess of 160 psi (1.1 MPa) and/or temperatures in excess of 250°F (120°C).

[5] Heat recovery steam generator (HRSG) — a boiler that has as its principal source of thermal energy a hot gas stream having high-ramp rates and temperatures such as the exhaust of a gas turbine.

[6] Solar receiver steam generator — a boiler system in which water is converted to steam using solar energy as the principal source of thermal energy. The solar energy is typically concentrated onto the solar receiver through the use of an array of mirrors that focuses solar radiation on the heat transfer surface.

[7] Fired pressure vessel — reheaters, isolable superheaters, economizers located outside the limits of boiler external piping, and nonintegral separately fired superheaters.

[8] Liquid phase thermal fluid heater — a pressure vessel where a fluid other than water is heated but in which no vaporization of the fluid takes place.

[9] Certification Mark — an ASME symbol identifying a product as meeting Code requirements.

[10] Certification Designator (Designator) — the symbol used in conjunction with the Certification Mark for the scope of activity described in a Manufacturer's Certificate of Authorization.

Unfired pressure vessels in which steam is generated shall be classed as unfired steam boilers with the following exceptions:

(a) vessels known as evaporators or heat exchangers

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

Unfired steam boilers shall be constructed under the provisions of Section I or Section VIII.

Liquid phase thermal fluid heaters may be constructed under the provisions of Section I or Section VIII.

Expansion tanks connected to high-temperature water boilers without intervening valves shall be constructed to the requirements of Section I or Section VIII.

A pressure vessel in which an organic fluid is vaporized by the application of heat resulting from the combustion of fuel (solid, liquid, or gaseous) or from solar radiation shall be constructed under the provisions of Section I. Vessels in which vapor is generated incidental to the operation of a processing system, containing a number of pressure vessels such as used in chemical and petroleum manufacture, are not covered by the rules of Section I. Liquified petroleum gas vaporizers are not covered by the rules of Section I.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area.

Page	*Location*	*Change*
xxiv	List of Sections	Title of Section XI, Division 1 revised
xxv	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xxviii	Personnel	Updated
2	PG-5.1	Revised
2	PG-5.3	Revised
3	PG-5.4	PG-5.4.1 and PG-5.4.2 revised
3	PG-5.6.1	Last paragraph revised
3	PG-5.7	Added
4	PG-8.1	Revised
4	PG-8.2.2	Revised
4	PG-8.3	Revised
6	PG-9.4	Revised
6	PG-9.5	Revised
11	PG-12.3	Last paragraph revised
11	PG-13	Revised
11	PG-14	Revised
12	PG-17	Revised
12	PG-19.1	Revised
14	PG-20	Revised
14	PG-20.1	Revised in its entirety
21	PG-27.3	Definition of *R* revised
22	PG-27.4.1	Revised
23	PG-27.4.6	(1) In Note (1), duplicate “lowest” deleted by errata (2) Last paragraph deleted by errata
28	Figure PG-31	In illustration (a), “0.71” corrected by errata to “0.17”
33	PG-34.2	Revised
38	PG-39.4	Revised
39	PG-39.5	Revised in its entirety
39	PG-39.6	Revised
43	PG-43	Revised
43	PG-44	Revised in its entirety
45	PG-47.4	Added
54	Figure PG-58.2-2	“PG-2.1.6” revised to “PG-2.2.7” throughout
63	PG-60.3.6	Revised
65	PG-67.2	Revised in its entirety
66	PG-67.3	Revised
66	PG-67.4	(1) Revised in its entirety (2) Endnote 16 revised
67	Figure PG-67.4	Cross-references revised throughout
68	PG-67.5	Revised
69	PG-68	Revised in its entirety
70	PG-69.1.1	Revised
70	PG-69.1.2	Revised
70	PG-69.2	Revised
72	PG-71.4	Revised

Page	*Location*	*Change*
72	PG-72	Revised in its entirety
74	PG-73.3	Revised in its entirety
78	PG-79	Revised
80	PG-82	Deleted
80	PG-90.1.14	Revised
84	PG-106.4.2	Revised
88	PG-110	Subparagraphs (d), (e)(1), and (e)(2) revised
90	PG-112.2.8	Revised
92	PW-1.2	Revised in its entirety
93	PW-8	Revised
95	PW-11	Revised in its entirety
96	Table PW-11	Revised
97	PW-16.1	Revised
99	PW-16.3	Revised
99	PW-16.5	Revised
99	PW-16.7	Revised
107	PW-27	Revised in its entirety
109	PW-28.1.4	Paragraph designator added
110	PW-29	Revised in its entirety
110	PW-31.3	Revised
111	PW-31.4	Revised
111	Table PW-33	General Note added
111	PW-33.2	Revised
111	PW-33.3	Revised
112	PW-36	Revised in its entirety
112	PW-38	Revised in its entirety
114	PW-39	Revised in its entirety
116	Table PW-39-1	General Notes revised
117	Table PW-39-2	General Notes revised
118	Table PW-39-3	General Notes revised
119	Table PW-39-4	General Notes revised
120	Table PW-39-5	General Notes revised
121	Table PW-39-6	General Notes revised
121	Table PW-39-7	General Notes revised
122	Table PW-39-8	General Notes revised
123	Table PW-39-12	General Note (a) revised
124	Table PW-39-13	General Note (b) revised
125	Table PW-39.2	(1) In second row, misalignment in fifth through tenth entries corrected by errata (2) In penultimate entry under “15E Group 1,” Celsius temperature range corrected by errata
126	PW-40	Revised
128	PW-41	Revised
133	PW-53	Revised in its entirety
136	PW-54.3	Revised in its entirety
144	PR-22	Revised
147	PB-8	Revised
147	PB-9	Revised
149	PB-26	Revised
180	PA-5	Revised
180	PA-6	Revised
181	PWT-5.1	Revised

Page	Location	Change
181	PWT-8	Revised
184	PFT-8	Revised
187	PFT-14	Revised
190	PFT-23.1.3	Definition of S revised
190	PFT-23.2	Revised
192	Figure PFT-23.1	Revised
197	PFT-30.1	Last definition of C added by errata
206	PEB-1	Revised
206	PEB-2.1	Revised
206	PEB-2.4	Revised
207	PEB-11	Revised
207	PEB-12	Revised in its entirety
208	PEB-15	Revised
208	PEB-16	Revised
208	PEB-17	Revised
210	PVG-5.1	Revised
211	PVG-12.4	Revised
212	PFE-1	Revised
212	PFE-3.1	Revised
212	PFE-4	Revised
232	VIII-1	Revised
232	VIII-2	Revised
232	VIII-3	(1) Definition of *control zone* revised (2) Definition of *electric resistance heating element* added
235	VIII-5.4	Revised
235	VIII-5.5	Revised
235	VIII-6	Revised
236	VIII-6.1	Subparagraph (a) revised
236	VIII-6.2	Revised
236	VIII-6.3.1	Revised
238	Figure VIII-6.3.4-1	Title revised
239	Figure VIII-6.3.4-2	Title revised
240	Figure VIII-6.3.4-3	Title revised
237	VIII-6.4.4	Subparagraph (b) revised
237	VIII-6.4.5	In subpara. (a), second paragraph revised
264	A-24	Deleted
264	A-25	Deleted
264	A-26	Deleted
264	A-27	Deleted
264	A-28	Deleted
266	A-65	Second paragraph revised
270	A-69	(1) Under "Area of reinforcement provided in nozzle 4 in the diagonal," first two lines of last equation corrected by errata to "$WL_1{}^2 + WL_2{}^2 = 1.125^2 + 0.5^2$" (2) Under "Net area provided in the nozzle wall fused to the vessel," "Ttn_2Wd_3" corrected by errata to "tn_2Wd_3"
285	A-77	Added
287	Figure A-77-1	Added
288	A-101	Title "Preheating" deleted
297	A-302.7	Revised
298	A-302.11	Revised
298	A-317.2.1	Definitions of D and D_i revised
303	Table A-351	Item (11) revised

Page	*Location*	*Change*
308	Table A-351.1	Item (11) revised
312	Table A-351.2	Item (13) revised
317	Table A-352	Item (10) revised
324	Table A-354	Items (12) and (37) revised
328	Table A-354.1	Item (9) revised
332	Form P-7	Section 7 revised
334	Table A-356	Items (8) and (21) revised
336	Form P-8	Revised
337	Table A-358	Item (17) revised
342	Table A-359	Item (10) revised
344	Table A-360	Revised
373	E-1	Revised
373	E-2	Revised
374	Table E-3-2	General Note (b) revised
374	Table E-3-3	General Note (c) revised
373	E-4	Revised
373	E-5	Revised
374	E-7	Subparagraph (c) revised
375	E-8	Revised

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

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PART PG
GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION

GENERAL

PG-1 SCOPE

The requirements of Part PG apply to the following:

(a) power boiler

(b) high-pressure, high-temperature water boilers

(c) liquid phase thermal fluid heaters

(d) parts and appurtenances of the above

These 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.

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 OF MEASURE

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

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

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

(d) Production, measurement and test equipment, drawings, welding procedure specifications, welding procedure and performance qualifications, and other fabrication documents may be in U.S. Customary, SI, or local customary units in accordance with the fabricator's practice. When values shown in calculations and analysis,

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

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches (in.^{2})	square millimeters (mm^2)
Volume	cubic inches (in.^{3})	cubic millimeters (mm^3)
Section modulus	cubic inches (in.^{3})	cubic millimeters (mm^3)
Moment of inertia of section	inches^4 (in.^{4})	millimeters^4 (mm^4)
Mass (weight)	pound mass (lbm)	kilograms (kg)
Force (load)	pound force (lbf)	newtons (N)
Bending moment	inch-pound force (in.-lbf)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pound force per square inch (psi) [Note (1)]	megapascals (MPa) [Note (2)]
Energy (e.g., Charpy impact values)	foot-pound force (ft-lbf)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (°R)	kelvin (K)
Fracture toughness	ksi square root inches (ksi$\sqrt{\text{in.}}$)	MPa square root meters (MPa$\sqrt{\text{m}}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

NOTES:
(1) "psig" shall be used to describe gage pressure.
(2) "MPaG" shall be used to describe gage pressure.

fabrication documents or measurement and test equipment are in different units, any conversions necessary for verification of Code compliance, and to ensure that dimensional consistency is maintained, shall be in accordance with the following:

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

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

(e) Conversion of units, using the precision specified above shall be performed to ensure that dimensional consistency is maintained. Conversion factors between U.S. Customary and SI units may be found in Nonmandatory Appendix A, A-391 through A-393. Whenever local customary units are used, the Manufacturer shall provide the source of the conversion factors which shall be subject to verification and acceptance by the Authorized Inspector or Certified Individual.

(f) 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.

(g) 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 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 material specifications in Section II and shall be limited to those listed in the tables of Section II, Part D. (25)

Materials listed in the tables in Section II, Part D shall not be used at temperatures above those for which stress values are limited for Section I construction. Specific additional requirements described in PG-5 through PG-14 shall be met as applicable.

The Manufacturer shall ensure that the correct material has been received and properly identified before proceeding with construction (see Nonmandatory Appendix A, A-302.4).

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 it is desired to use materials other than those listed in Section II, data should be submitted to the Boiler and Pressure Vessel Committee in accordance with the (25)

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.

(25) **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 material 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. If 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, PMB-5.5, 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.

(25) **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.

(d) The use of provision (c) shall be noted in the Remarks section on the Manufacturer's Data Report. Information to be noted shall describe the affected component, its design condition, and its location in sufficient detail to be able to positively locate it after assembly in the boiler.

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-5.7 When size requirements in this Section are (25) expressed in terms of the dimensionless designator nominal pipe size (NPS) or diamètre nominal (DN), the outside diameter as published in ASME B36.10, Table 2-1 shall be used to determine applicability to other product forms, such as, but not limited to tubing.

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

(25) **PG-8.1** Except for the limited usage permitted by PG-8.2 and PG-8.3, cast material used in vessels and vessel parts shall conform to one of the specifications listed in PG-9 with maximum allowable stress values given in Section II, Part D, Subpart 1, Tables 1A and 1B.

Allowable stress values shall be multiplied by the applicable casting quality factor given in PG-25 except cast iron.

When cast iron is used as allowed in PG-11.1 for standard pressure parts, it shall conform to either ASME B16.1 or ASME B16.4.

Material conforming to ASTM A126 may be used subject to all requirements of that particular standard. Such usage is also subject 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.

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

(25) **PG-8.3 Cast Nodular Iron.** Cast nodular iron as designated in SA-395 may be used for boiler and superheater connections under pressure. Examples include 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.

(25) **PG-9.4** Bimetallic tubes that have a core of an acceptable boiler and superheater material and 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 under tolerances 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.

(25) **PG-9.5** ERW products shall be limited to a maximum thickness of ½ in. (13 mm) for internal pressure applications. For external pressure applications, ERW products shall be limited to a maximum thickness of ½ 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.

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 (Including Brazed) 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. When brazing is performed, it shall meet the requirements of Part PB 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 (including brazing) 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 (including brazing) 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 the Inspector 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 (including brazed) 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]

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.

(25) **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 the tables in Section II, Part D for Section I construction. If allowable stresses are not listed for Section I construction but are listed for Section VIII, Division 1 construction, the allowable stresses for Section VIII, Division 1 may be used. 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 (25)

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 either 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 (25)

PG-14.1 Rivets shall conform to SA-31.

PG-14.1.1 In lieu of SA-31, it is permissible to substitute bar which is converted to rivets from SA-36 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
(b) the "rivet flattening tests" for SA-31 Grades A and B
(c) the "bar bend tests" for SA-31 Grade B

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

(a) Number of Tests and Retests
(b) Specimen Preparation
(c) Test Methods
(d) Inspection
(e) 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 $\frac{1}{4}$ 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 $\frac{5}{16}$ 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 $\frac{1}{4}$ in. (6 mm) or the minimum wall thickness of Standard wall pipe listed in ASME B36.10M, Table 1. The minimum thickness requirements stipulated above are exclusive of any allowances for corrosion, erosion, and forming.

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 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 (25)

A boiler and parts thereof may be designed and fabricated by a combination of the methods of fabrication given in this Section. The rules applying to the respective methods of fabrication shall be followed. The boiler shall be 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]

PG-19.1 Cold-formed areas of austenitic alloy pressure-retaining components shall be heat treated when both of the following conditions exist: (25)

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

(b) The design metal temperature and the forming strains exceed the limits shown in Table PG-19.

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

Grade	UNS Number	Limitations in Lower Temperature Range					Limitations in Higher Temperature Range			Minimum Heat-Treatment Temperature When Design Temperature and Forming Strain Limits Are Exceeded [Notes (1), (2)]	
		For Design Temperature									
		Exceeding		But Less Than or Equal to		And Forming Strains Exceeding	For Design Temperature Exceeding		And Forming Strains Exceeding		
		°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-19.2, the forming strain limits shall be half those tabulated in this table (see PG-19.3).

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%.

Heat treatment shall be performed at the temperature given in Table PG-19 for the greater of 20 min/in. (20 min/25 mm) of thickness or 10 min.

PG-19.2 Forming strains shall be calculated as follows:

(a) Cylinders formed from plate

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

(b) Spherical or dished heads formed from plate

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

(c) 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-19.3 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-19.4 For flares, swages, or upsets, heat treatment in accordance with Table PG-19 shall apply, regardless of the amount of strain.

PG-19.5 If the finishing-forming temperature is above the minimum heat-treating temperature given in Table PG-19, postforming heat treatment required by this paragraph is not mandatory.

(25) PG-20 COLD FORMING OF CARBON, CARBON-MOLYBDENUM, AND CREEP STRENGTH ENHANCED FERRITIC STEELS

The cold-formed areas of pressure-retaining components shall be heat treated and examined as described below and as required in Table PG-20, as applicable when the pressure parts were manufactured from any of the following:

(a) carbon steel
(b) carbon-molybdenum steel
(c) creep strength enhanced ferritic steel

Cold forming is defined as any forming method that is performed at a temperature below 1,300°F (705°C) and produces strain in the material. The calculations of strain shall be made in accordance with PG-19.

PG-20.1 Carbon and Carbon-Molybdenum Tube and Pipe. (25) Postforming heat treatment of carbon and carbon-molybdenum tube and pipe cold-formed bends that convey water or steam is required as specified in this paragraph. Tube and pipe that convey fluids or vapor other than water or steam are exempted from these rules. (See Part PTFH for alternate fluids.)

Postforming heat treatment shall consist of one of the following:

(a) a subcritical anneal performed at a temperature of at least 1,250°F (675°C)
(b) a full anneal
(c) a normalizing heat treatment

See SA-941 for definition of heat treatments. Hold times shall be at least 30 min/in. (30 min/25 mm) of thickness but not less than 10 min. Heat treatment may be performed locally, provided the entire strained area of the cold-formed bend is subjected to the required heat treatment.

The following paragraphs define requirements based on boiler location, strain, and material condition and shall be considered.

PG-20.1.1 The cold-formed areas of carbon and carbon-molybdenum tube and pipe that convey water or steam shall be heat treated after cold forming when all the following conditions are met:

(a) when the tube and pipe are located external to the boiler membraned wall or boiler metal encased enclosure.
(b) when the design temperature of the cold-formed areas is between 620°F (327°C) and 750°F (399°C).
(c) when the straight tube or pipe starting material to be formed is in either of the following conditions:
(1) subcritical annealed, full annealed, or normalized heat-treated condition and the strain developed in the cold-formed areas exceeds 12½%
(2) unheat-treated or hot finished condition and the strain developed in the cold-formed areas exceeds 5%

PG-20.1.2 The postforming heat treatment of carbon steel only, meeting all the conditions specified in PG-20.1.1, may be exempted when all the following conditions are met:

(a) The straight tube or pipe starting material to be formed has been subject to an annealing or normalizing heat treatment (see SA-941 for definition of heat treatments) prior to forming.
(b) The entire bend area is subjected to a magnetic particle examination over 100% of the bend region between the bend tangents as follows:
(1) The magnetic particle examination shall be in accordance with Nonmandatory Appendix A, A-260, with the following acceptance standard: Any relevant

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

Grade	UNS Number	Limitations in Lower Temperature Range: For Design Temperature Exceeding °F	Exceeding °C	But Less Than or Equal to °F	But Less Than or Equal to °C	And Forming Strains	Limitations in Higher Temperature Range: For Design Temperature Exceeding °F	Exceeding °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 [Notes (2)–(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-19.3 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 in accordance with PG-5.6.1(c)(1).
(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.

linear indication found during this examination that exceeds $\frac{1}{8}$ in. (3 mm) in the longest direction shall be removed using a mechanical abrasive removal method and the abraded area reexamined.

(2) If the ground cavity results in a local thickness that is less than the required design minimum thickness, weld repair of the thinned area is permitted with a compatible filler metal, subject to all the following conditions being met:

(-a) The cavity shall be examined in accordance with PW-40.3.1.

(-b) The repair shall be welded in accordance with PW-28.

(-c) The repair weld shall be subjected to a postweld heat treatment in accordance with the requirements of PW-39 for that material. Postweld heat treatment exemptions do not apply.

PG-20.2 Creep Strength Enhanced Ferritic Material. Postforming heat treatment of creep strength enhanced material shall be in accordance with Table PG-20.

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). 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

(a) For ASTM E446

Imperfection Category	Severity Level	
	Up to and Including 1 in. (25 mm) Thick	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

(b) 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 1½ in. × 6 in. (38 mm × 150 mm) or less, or any circular area having a diameter of 3½ 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 ¼ in. (6 mm) long for thicknesses up to ¾ in. (19 mm) inclusive, more than one-third of the thickness in length for thicknesses from ¾ in. to 2¼ in. (19 mm to 57 mm), and more than ¾ in. (19 mm) long for thicknesses over 2¼ 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 $^{3}/_{16}$ 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 4½ 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 ¼ 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.

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 and PG-27.2.2 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. The equations below apply primarily to tubing used in applications such as boiler tubes, superheater and reheater tubes, and

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 [Notes (1)–(6)]																			
C-Mo [Note (7)]	...	...	...	1.00	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Cr-Mo [Notes (8), (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) [Notes (9), (10), (11)]	...	...	...	...	...	1.00	0.95	0.91	0.86	0.82	0.77	NP	NP	NP	NP	NP	NP	NP	NP	NP
CSEF (subcrit.) [Notes (9), (11), (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) [Notes (13), (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.

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:

(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.

(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–½ Mo steel above 850°F (454°C).

(8) The Cr-Mo steels include ½Cr–½Mo, 1Cr–½Mo, 1¼Cr–½Mo–Si, 2¼Cr–1Mo, 3Cr–1Mo, and 5Cr–½Mo. 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.

	Weld Strength Reduction Factor					
Materials	**950°F (510°C)**	**1,000°F (538°C)**	**1,050°F (566°C)**	**1,100°F (593°C)**	**1,150°F (621°C)**	**1,200°F (649°C)**
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.

economizer tubes in which groups of such tubular elements are arranged within some enclosure for the purpose of transferring heat through the tubes. Pipe used in a tubing application may be designed using the equations provided in this paragraph.

For plain tubes or bimetallic tubes when the strength of 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-27.4.7 through 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, and PG-27.4.7 through 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-27.3 Symbols. Symbols used in the preceding (25) equations are defined as follows:

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)
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), plus any portion of C that might pertain to the inside radius
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.

(25) **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

(a) 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 equal to the lesser of w or the ligament efficiency from PG-52 or PG-53.

(b) If any part of the longitudinal seam weld is penetrated by the openings that form the ligaments, E shall be equal to the product of w times the ligament efficiency.

(c) For longitudinally welded cylinders fabricated from materials that are exempt from the requirements of PG-26 and Table PG-26, E shall equal that for seamless cylinders considering ligament efficiency when applicable.

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.

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, in. (mm) [Note (2)]
$D \le 3/4$ 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)
11½	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 1¼ in. (32 mm) O.D. and smaller
(b) 0.105 in. (2.67 mm) for tubes above 1¼ 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.

(25) **PG-27.4.6**

y = a coefficient having values as follows:

Value of T_{TD} [Note (1)]	Values of y [Note (2)]		
	y = 0.4	y = 0.5	y = 0.7
T_{TD} ≤ 900°F (480°C)	DT ≤ 900°F (480°C)	DT = 950°F (510°C)	DT ≥ 1,000°F (540°C)
T_{TD} > 900°F (480°C)	DT ≤ T_{TD}	DT = T_{TD} + 50°F (28°C)	DT ≥ T_{TD} + 100°F (56°C)

GENERAL NOTE: DT = design temperature

NOTES:
(1) T_{TD} = the lowest temperature value listed in the maximum allowable stress tables from Section II, Part D [see Notes – Time–Dependent Properties for respective table] at which the allowable stress values are obtained from time-dependent properties.
(2) Values of y between temperatures listed may be determined by interpolation.

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.

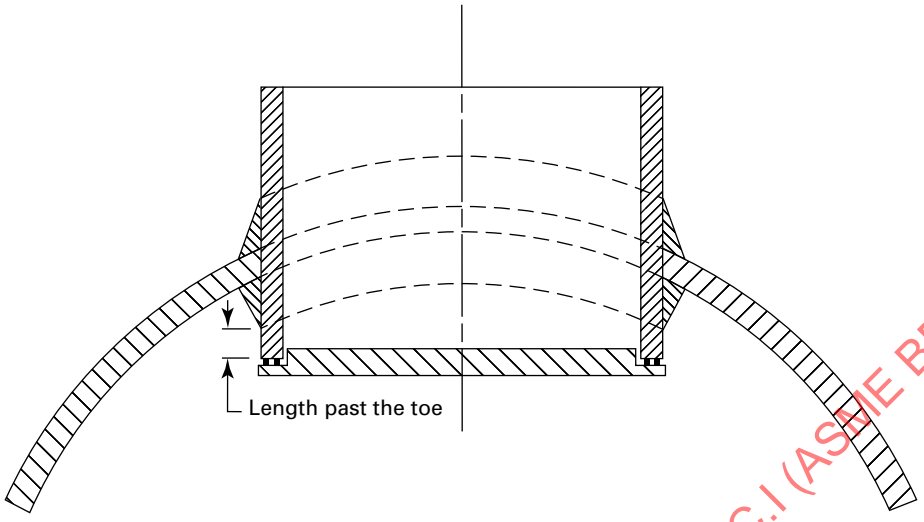
PG-28.1.1.2 Temperatures in excess of the maximum temperature given on the external pressure charts are not permitted.

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:

$$D = a^2/b$$

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



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

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:

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
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

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 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:

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

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 $\frac{1}{8}$ 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 For heads made to an approximate ellipsoidal shape, the tolerance specified in PG-81 shall apply.

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

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

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.

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

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 1.5S.

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)

K = influence coefficient for Figure PG-31, illustration (s)
= 0.2 in. (5 mm)

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

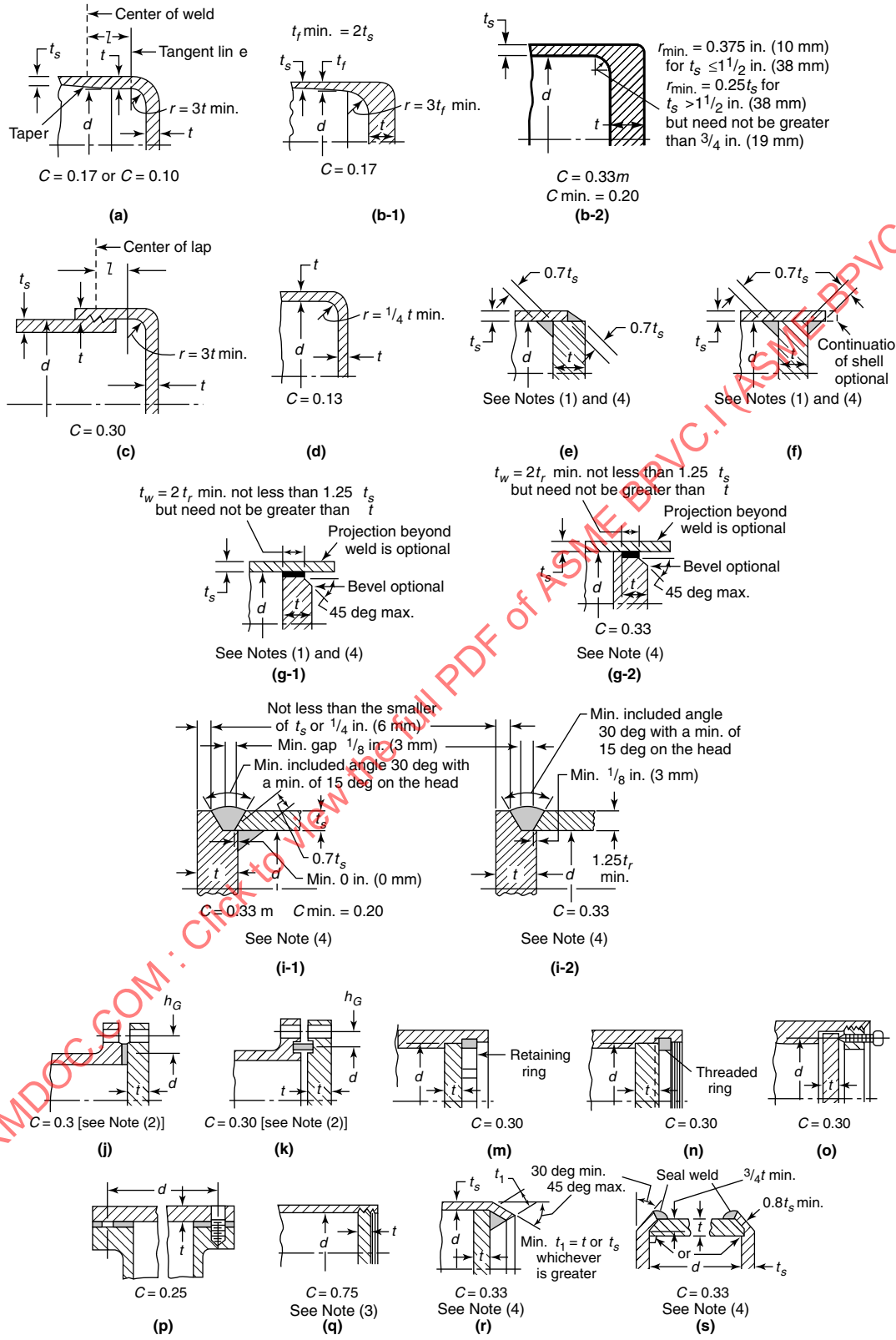
S = maximum allowable stress value, using values given in Section II, Part D, Subpart 1, Table 1A

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)

(25)

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.