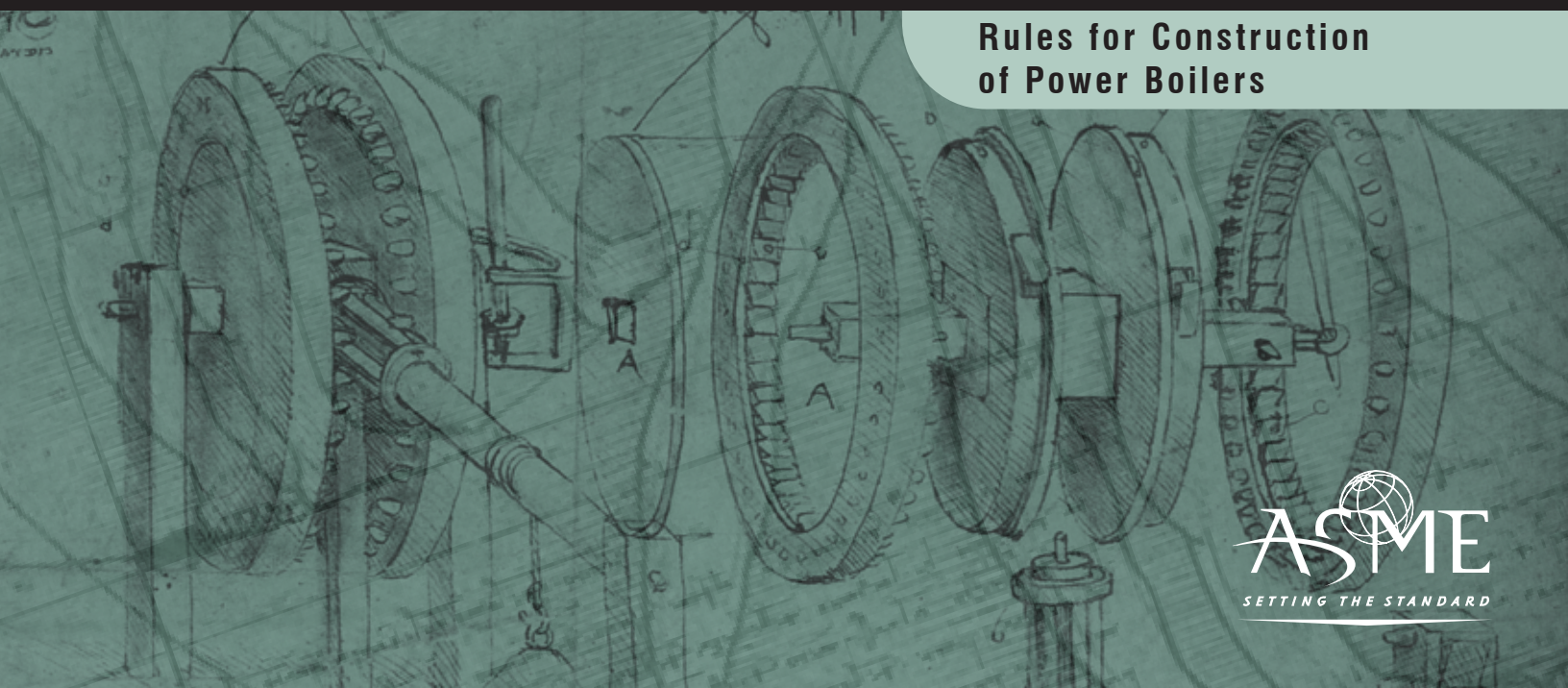
ASME BPVC.I-2017

SECTION I

2017 ASME Boiler and Pressure Vessel Code

An International Code

Rules for Construction of Power Boilers



ASME

SETTING THE STANDARD

AN INTERNATIONAL CODE

2017 ASME Boiler & Pressure Vessel Code

2017 Edition July 1, 2017

I

RULES FOR CONSTRUCTION OF POWER BOILERS

ASME Boiler and Pressure Vessel Committee
on Power Boilers

The American Society of Mechanical Engineers

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2017

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The Standards Committee that approved the code or standard was balanced to assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

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The endnotes and preamble in this document (if any) are part of this American National Standard.

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Certification Mark

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

INTERPRETATIONS

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

CODE CASES

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

FOREWORD[*]

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

(a) Committee on Power Boilers (I)

(b) Committee on Materials (II)

(c) Committee on Construction of Nuclear Facility Components (III)

(d) Committee on Heating Boilers (IV)

(e) Committee on Nondestructive Examination (V)

(f) Committee on Pressure Vessels (VIII)

(g) Committee on Welding, Brazing, and Fusing (IX)

(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)

(i) Committee on Nuclear Inservice Inspection (XI)

(j) Committee on Transport Tanks (XII)

(k) Technical Oversight Management Committee (TOMC)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1 INTRODUCTION

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

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

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

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

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

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

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

(3) Code Interpretations

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

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

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

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

2 INQUIRY FORMAT

Submittals to the Committee should include the following information:

(a) Purpose. Specify one of the following:

(1) request for revision of present Code requirements

(2) request for new or additional Code requirements

(3) request for Code Case

(4) request for Code Interpretation

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

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

3 CODE REVISIONS OR ADDITIONS

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

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

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

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

4 CODE CASES

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

5 CODE INTERPRETATIONS

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

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

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

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

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

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

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

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

(3) a request seeking the rationale for Code requirements

6 SUBMITTALS

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

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

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

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

(17)

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January 1, 2017

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PREAMBLE (17)

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 water gages 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.

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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.

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.

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.

SUMMARY OF CHANGES

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

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

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

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

Page	*Location*	*Change (Record Number)*
xviii	List of Sections	Updated
xxiii	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	Revised in its entirety *(13-2222)*
xxvi	Personnel	Updated
xlv	Preamble	Revised and new footnote 8 added *(10-854, 16-1331)*
1	PG-1	Revised *(10-854)*
1	PG-2.4	Deleted *(10-854)*
7	PG-11.1	Revised second paragraph *(14-1971)*
10	PG-12.2	Revised *(15-2438)*
11	PG-16.7	Added *(15-337)*
13	Table PG-19	Title revised *(16-1150)*
16	PG-25.2.4	First paragraph revised *(14-2209)*
17	PG-27.3	Revised nomenclature for *R (15-2913)*
20	PG-27.4.3	Second paragraph revised *(16-517)*
21	PG-27.4.7	Revised *(15-195)*
22	PG-28.3.1.1	Revised nomenclature for *A (15-1749)*
23	PG-28.3.1.2	Steps 3, 4, and 7 revised *(15-275)*
25	PG-31.1	Revised *(16-517)*
25	PG-31.2	Revised nomenclature for t_f *(11-1354)*
26	Figure PG-31	Illustration (b-2) added *(11-1354)*
27	PG-31.4	Revised *(11-1354)*
29	PG-32.1.1	Revised *(14-153)*
29	PG-32.1.3	Revised *(14-153)*
29	PG-32.1.4	Revised *(13-447)*
30	PG-32.1.5.2	Revised *(14-153)*
30	PG-32.1.5.3	Revised *(14-153)*

Page	Location	Change (Record Number)
31	PG-33.3	Revised nomenclature for t and t_n and deleted endnote 13 *(15-337)*
33	Figure PG-33.2	In Notes (1) and (2), t_{xi} corrected by errata to t_x *(15-1666)*
34	PG-36.4.2	Revised *(15-2281)*
35	PG-38	*(1)* Revised PG-38.1, PG-38.2, and PG-38.4; added new PG-38.3; former PG-38.3 renumbered as PG-38.5 *(13-447)* *(2)* Added Figure PG-38.2-1 *(13-447)* *(3)* Former Figure PG-38 redesignated as Figure PG-38.4-1 and revised *(13-447)*
37	Table PG-39	Reformatted for clarity *(14-2302)*
37	PG-42.1	Note revised *(15-1782)*
40	Figure PG-42.1	Second arrow inserted next to "Radius of at least $0.05t_{\min}$" and Note (2) revised *(15-996)*
39	PG-43	Revised *(15-337)*
42	PG-50	Added *(14-2354)*
42	PG-52.1	Revised *(13-447)*
45	PG-53.1	Revised *(13-447)*
45	PG-53.2	Revised *(13-447)*
51	Figure PG-58.3.1(b)	*(1)* In illustrations (2) and (3), gate valves corrected by errata to check valves *(15-1954)* *(2)* Note (1) reference added by errata *(15-1954, 15-2257)*
52	Figure PG-58.3.1(c)	Lines to safety valves corrected by errata as dashed lines *(15-1878)*
53	Figure PG-58.3.2	Editorial correction
57	PG-60.1.1.3	Revised *(15-2438)*
58	PG-60.3.1	Revised *(14-1985)*
61	PG-67.2	Revised *(11-819)*
61	PG-67.2.1.6	Revised *(11-819)*
66	PG-69.1.1	Revised *(11-819)*
66	PG-69.1.4	Revised *(11-819)*
66	PG-69.1.5	Revised *(11-819)*
66	PG-69.1.6	Deleted *(11-819)*
68	PG-69.2.2	Revised *(11-819, 15-1784)*
70	PG-69.2.3	In subpara. (a), second paragraph revised, and nomenclature for *P* in subpara. (b) revised *(11-819, 15-1784)*
74	PG-72.1	Revised *(15-1784)*
74	PG-72.3	Deleted *(09-1324)*
74	PG-72.4	Deleted *(09-1324)*
75	PG-73.2.10	Subparagraph (d) revised *(15-1784)*
76	PG-73.4.3	First paragraph and subpara. (d) revised *(14-239, 15-1784)*
76	PG-73.4.4	Revised *(15-828, 15-1784)*

Page	*Location*	*Change (Record Number)*
77	PG-73.5.1	Revised *(15-1784)*
77	PG-73.5.2	Revised *(11-819, 15-1784)*
77	PG-73.5.2.1	Revised *(11-819)*
78	PG-73.5.2.2.2	Revised *(14-304)*
78	PG-73.5.3	Subparagraph (a) revised *(11-819)*
79	PG-73.8	Added *(09-1324)*
79	PG-75	Revised *(13-1489)*
79	PG-77	Revised title and added introductory text *(14-207)*
80	PG-77.5	Added *(14-207)*
82	PG-90.1.11	Revised *(13-129)*
82	PG-91	Revised *(15-1148)*
82	PG-93.1	Revised *(15-2438)*
85	PG-106.5	Revised *(15-2912)*
85	PG-106.6	Revised *(15-2912)*
86	PG-106.8.1	Revised *(15-1753)*
88	PG-110	Revised subparas. (d) and (e)(3) *(11-819, 15-828)*
100	Figure PW-16.1	*(1)* For illustrations (u-2) and (v-2), "3 in. (75 mm) pipe" revised to "NPS 3 (DN 80)" *(15-2070)* *(2)* For illustrations (w-2) and (x), "3 in." revised to "NPS 3" *(15-2070)*
105	PW-16.5	Revised *(15-2054)*
105	PW-16.8	Revised *(16-435)*
108	PW-17	Added *(11-1354)*
108	PW-19.3	Revised *(14-1971, 14-2083)*
106	Figure PW-16.8	Title revised *(16-435)*
108	Figure PW-17-1	Added *(11-1354)*
110	PW-28.1.2	Subparagraph (b) revised *(15-166)*
110	PW-28.4	Revised *(16-1500)*
112	PW-38.3	Added *(13-129)*
113	PW-39.2.1	Revised *(16-106)*
113	PW-39.3	Revised *(13-129)*
114	Table PW-39-1	General Notes revised *(15-1826)*
118	Table PW-39-5	Entry for second column and Note (1) revised *(15-1738)*
121	Table PW-39-8	General Note (b) added *(14-799)*
124	PW-40.3.1	Revised *(15-2438)*
124	PW-40.3.2	Revised *(15-2438)*
129	PW-50	PW-50.1, PW-50.2, and PW-50.3, and endnote 25 revised *(11-1851, 14-2209)*

Page	*Location*	*Change (Record Number)*
130	PW-51.4	Revised *(14-1901)*
130	PW-52.1	Revised *(13-2131)*
131	PW-53.2	Endnote (26) revised *(16-2679)*
134	PW-53.8.1	Nomenclature for *U* revised *(16-609)*
135	PW-54.1	Revised *(15-353)*
135	PW-54.2	Revised *(15-353)*
135	PW-54.3.3	Revised *(15-2438)*
135	PW-54.4	Added *(15-353)*
136	PR-7	Revised *(15-174)*
137	PR-8.2.2	Second equation revised *(16-1638)*
147	PB-29.3	Revised *(16-1500)*
164	PL-30.4	Added *(15-1564)*
165	Figure PL-30.4.2-1	Added *(15-1564)*
165	Table PL-30.4.5-1	Added *(15-1564)*
170	Figure PL-36.9-2	Second illustration revised *(15-1683)*
175	PL-54	Added *(11-1071)*
177	Part PA	Added *(14-2261)*
206	Part PTFH	Added *(10-854)*
210	PHRSG-3.1	Subparagraph (c) revised *(15-1748)*
247	A-68	Revised *(15-162)*
255	A-70.1.1	Revised *(15-162)*
255	A-70.2.1	Revised *(15-162)*
260	A-75	“[D]oiler” corrected by errata to “boiler” *(15-2454)*
268	Figure A-250.3.6-1	“Minimum” corrected by errata to “Maximum” in Note (2) *(16-386)*
274	A-302.11	Revised *(16-1500)*
274	A-302.14.1	Revised *(15-2345)*
276	A-317.3	Subparagraph (c) revised *(16-517)*
278	Form P-2	Revised *(16-1099)*
280	Table A-351	Line (36) revised *(16-1099)*
282	Form P-2A	Revised *(16-1099)*
285	Table A-351.1	Line (28) revised *(16-1099)*
287	Form P-2B	Revised *(16-1099)*
289	Table A-351.2	Line (42) revised *(16-1099)*
291	Form P-3	Revised *(16-1099)*
294	Table A-352	Line (29) revised *(16-1099)*
296	Form P-3A	Revised *(14-2420, 16-1099)*

Page	*Location*	*Change (Record Number)*
298	Table A-353	Line (10) revised *(16-1099)*
299	Form P-4	Revised *(15-1371, 16-1099)*
301	Table A-354	Lines (29) and (33) revised *(16-1099, 16-2261)*
302	Form P-4A	Revised *(15-1371, 16-1099)*
304	Table A-354.1	Lines (1), (2), and (14) revised; line (3a) renumbered as (4d); lines (4b) and (4c) added *(15-1371, 16-1099)*
305	Form P-4B	Revised *(15-1371, 16-1099)*
306	Table A-354.2	Lines (1), (2), and (16) revised; line (3a) renumbered as (4d); lines (4b) and (4c) added *(15-1371, 16-1099)*
307	Form P-5	Revised *(16-1099)*
309	Form P-6	Revised *(16-1099)*
313	Table A-357	Editorially revised
316	Form PL-1	Revised *(16-1099)*
320	Table A-359	Line (23) revised *(16-1099)*
321	Table A-360	Revised *(11-1071, 11-1851, 15-996, 15-1825, 15-1875, 15-1879, 16-66, 16-687, 16-688, 16-1377, 16-1397)*
323	Figure A-370	Updated by ASME Conformity Assessment
324	A-381	Revised in its entirety *(14-2310)*
325	A-382	Revised in its entirety *(14-2310)*
327	A-383	Revised in its entirety *(14-2310)*
335	Nonmandatory Appendix C	Added *(13-129, 15-351)*
355	Nonmandatory Appendix D	Added *(14-2327)*
359	Nonmandatory Appendix E	Added *(13-2131)*

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
09-1324	Deleted PG-72.3 and PG-72.4. Added new PG-73.8.
10-854	Added new Part PTFH to define the applicable requirements in Section I for liquid phase thermal fluid heaters, and revised Preamble.
11-819	Revised PG-67.2.1.6 (and reference PG-67.2.1.6 in PG-67.2) to allow isolable economizer overpressure of 10%. Revised PG-69.1.1, PG-69.1.4, PG-69.1.5, PG-69.2.2, and PG-69.2.3 to add capacity certification test requirements for liquids. Revised PG-73.5.2 and PG-73.5.3 to add testing requirements for liquid relief valves. Revised PG-110 to add stamping requirements for liquid relief valves. Deleted PG-69.1.6 as it is no longer necessary with the introduction of liquid relief valves in Section I.
11-1071	Added new PL-54 to add pressure relief valve requirements for locomotive boilers.
11-1354	– Added new illustration (b-2) and changed the label of illustration (b) to (b-1) in Figure PG-31. – Revised PG-31.4 to reference new illustration (b-2) in Figure PG-31. – Added new PW-17 and Figure PW-17.
11-1851	Deleted “such as the ASNT Central Certification Program (ACCP)” in PW-50.1 and removed reference to document ACCP-CP-1 in Table A-360. Deleted “ACCP” from Endnote 25.
13-129	Added new Nonmandatory Appendix C to cover local heating of P-No. 15E materials when using electric resistance heating. Revised PW-38 and PW-39 to invoke new Nonmandatory Appendix C for local heat treatment of P-No. 15E materials when using electric resistance heating. Revised PG-90.1.11 to add reference to new Nonmandatory Appendix C into the list of heat treatments that the Authorized Inspector is required to verify.
13-447	Revised PG-32.1.4, PG-38.1, PG-38.2, PG-38.4, PG-52.1, PG-53.1, and PG-53.2. Added new PG-38.3 and redesignated and moved existing PG-38.3 to PG-38.5. Added new Figure PG-38.1-1 and new Figure PG-38.2-1. Revised and redesignated Figure PG-38 as Figure PG-38.4-1 and added a centerline to each of the attachments.
13-1489	Revised PG-75.
13-2131	Added new Nonmandatory Appendix E, which covers alternate method of ultrasonic examination.
13-2222	Revised the front guidance on interpretations in its entirety.
14-153	– In PG-32.1.1, deleted terms A and B; corrected cross-reference in $d_{\max}$; added terms K_1 and K_2 and revised the notation for K; replaced L_h and L_s with L_{co}; replaced X with X_1 and X_2. – In PG-32.1.3, replaced equation for L_h and L_s with the single equation for L_{co}. – Revised PG-32.1.5.2 to incorporate new K_1 term, and revised PG-32.1.5.3 to incorporate the new K_2 term.
14-207	Revised PG-77 to include rules for identification of pressure part material other than plate during construction.
14-239	Revised PG-73.4.3(d) to clarify actions that need to be taken within the 60-day period following a failure of one of the replacement valves that is tested after a pressure relief valve fails to relieve at or above its rated capacity.
14-304	Revised PG-73.5.2.2.2 from “hydraulic or pneumatic lift assist device” to “auxiliary lift assist device.”
14-799	Added Cautionary Note to Table PW-39-8.
14-1901	Revised PW-51.4 to include guidelines for retention of digital images of radiographic film in lieu of the radiographic film.
14-1971	Revised PG-11.1 to clarify the exemption of welded shells and heads from the requirements stipulated in PG-11.1 to PG-11.4.
14-1985	Revised PG-60.3.1 to clarify what may be installed between the required gages and the drum or water column and between any water column and the drum.
14-2083	Revised PW-19.3 to clarify limits on projection of welded stays.

Record Number	Change
14-2209	Revised PG-25.2.4 and PW-50 to add reference to Section V, Mandatory Appendix II for additional mandatory requirements that must be incorporated into the employer's written practice if the NDE techniques of CR, DR, TOFD, or PAUT are used.
14-2261	Incorporated Code Case 2559-1 into new Part PA of Section I.
14-2302	Reformatted Table PG-39.
14-2310	– Revised A-381 to regroup calculations into subparagraphs for better presentations; to provide external pressure table information along with the Figure method; to correct editorial errors; and to identify given information and move the given information before calculations. – Revised A-382 to regroup calculations into subparagraphs for better presentations; to provide external pressure calculation examples using tables and log-log interpolations; to correct editorial errors. – Revised A-383 to regroup calculations into subparagraphs for better presentations; to provide external pressure calculation examples using tables and log-log interpolations; to add the design temperature; to correct some calculation errors and editorial errors.
14-2327	Added new Nonmandatory Appendix D to provide guidelines for boiler designers to consider when dealing with damage mechanisms such as corrosion, erosion, and oxidation of boiler tubes in coal-fired plants.
14-2354	Added PG-50.
14-2420	Removed units from Form P-3A.
15-162	Revised A-68, A-70.1.1, and A-70.2.1.
15-166	Revised PW-28.1.2(b) to clarify rules for qualifying WPS for material with low ductility.
15-174	Revised PR-7(a) to remove SA-202.
15-195	Added the word “maximum” to the second sentence of PG-27.4.7 to read “...sufficient to provide the maximum manufacturing tolerance allowed....”
15-275	Revised PG-28.3 to include the use of tables in Section II, Part D, Subpart 3. Previously, only figures were mentioned in PG-28.3.
15-337	Added new PG-16.7. Deleted Endnote 13. Revised the definitions of t and t_n in PG-33.3. Revised PG-43 to clarify that corrosion and erosion allowances are to be included in the minimum nozzle neck thickness requirements.
15-351	– Added a new paragraph PW-38.3, recommending that preheat of P-No.15E materials be performed in accordance with this new appendix. Added a new paragraph to the end of PW-39.3 recommending that the PWHT of P-No. 15E materials be performed in accordance with new Nonmandatory Appendix C, and recommending that the new appendix may be used as guidance for other materials. – Revised PG-90.1.11 to include reference to new Nonmandatory Appendix C. – Designated new appendix as Nonmandatory Appendix C. Revised C-1 to address the nonmandatory nature of the new appendix. Revised Table C-4-2 to correct a table error for NPS 4 schedule 120 pipe. Revised the definition of the heat loss area in the notes to the formula in C-4.2. Added to the requirement that limits the maximum gap between heating pads, that this may be exceeded provided a monitoring thermocouple is weld affixed in the center of the gap.
15-353	Revised PW-54.1 to clarify that welded pressure parts are to be subjected to the hydrostatic test with the completed boiler as required by PG-99. Revised PW-54.2 and PW-54.3 by replacing “part” with “boiler.” Added new PW-54.4 to reference A-64 as guidance when supplying repair or replacement parts.
15-828	Corrected capitalization of the term “Designated Organization” as it appears in various locations in Section I.
15-996	Revised Figure PG-42.1 to revise Note (2) and to add second arrow to “Radius of at least $0.05t_{\min}$.”
15-1148	Revised PG-91 for consistency with ASME QAI-1.
15-1371	Revised Forms P-4, P-4A, and P-4B to provide sufficient room for name and address.
15-1564	Added PL-30.4 to cover fillet-welded staybolts.
15-1666	Errata correction. See Summary of Changes for details.
15-1683	Revised Figure PL-36.9-2 to change reference from PG-27 to PFT-27.

Record Number	Change
15-1738	Revised Table PW-39-5 to lower the minimum PWHT temperature for P-No. 15E material.
15-1748	Revised PHRSG-3.1(c) to clarify the intent that condensate need only be evacuated for all conditions where condensate is present in the superheater or reheater.
15-1749	Revised PG-28.3.1.1, under nomenclature for A, to change reference to PG-28.3.1.2(b).
15-1753	Revised PG-106.8.1 to clarify that the word "part" may be eliminated when using the "PRT" Designator.
15-1782	Revised Note in PG-42.1 from "ASME B31.1" to "this Section."
15-1784	Revised "Manufacturer" to "manufacturer" and "Assembler" to "assembler" as appropriate in PG-67 through PG-73.
15-1825	Revised Table A-360 to reference CA-1, latest edition.
15-1826	Revised Table PW-39-1 to add new General Note (a) and to revise General Note (b).
15-1875	Revised Table A-360 to reference ASTM E446-15.
15-1878	Errata correction. See Summary of Changes for details.
15-1879	Revised Table A-360 to add ASME B16.47-2011, Large Diameter Steel Flanges.
15-1954	Errata correction. See Summary of Changes for details.
15-2054	Revised PW-16.5 to reference ASME B16.11, Table 8, for fitting sizes smaller than NPS $^1/_2$.
15-2070	Revised Figure PW-16.1 to change "3 in. (75 mm) pipe" to "NPS 3 (DN 80)" and "3 in." to "NPS 3."
15-2257	Errata correction. See Summary of Changes for details.
15-2281	Revised second paragraph of PG-36.4.2 to be consistent with the definition of h.
15-2345	Revised reference in A-302.14.1 from "PG-73.3" to "PG-73.4."
15-2438	Revised "nonmagnetic" to "nonferromagnetic" in PG-12.2, PG-60.1.1.3, PG-93.1, PW-40.3.1, PW-40.3.2, and PW-54.3.3.
15-2454	Errata correction. See Summary of Changes for details.
15-2912	Revised PG-106.5 and PG-106.6 to allow application of Certification Mark by methods other than those mentioned as long as they are clearly legible.
15-2913	Revised definition of R in PG-27.3.
16-66	Revised Table A-360 to reference ASME B36.10M-2015.
16-106	Revised PW-39.2.1 to reference only the lower P-Number tables and to clarify that the PWHT exemptions described in the general notes of the lower P-Number tables do not apply to this type of weld.
16-386	Errata correction. See Summary of Changes for details.
16-435	Revised PW-16.8 and title of Figure PW-16.8.
16-517	Revised PG-27.4.3, PG-31.1, and A-317.3(c) as they relate to new PG-16.7. Revised PG-27.4.3, PG-31.1, and A-317.3(c) by changing "expected" to "applicable" and "required" to "as applicable" as related to corrosion and/or erosion allowances.
16-609	Revised PW-53.8.1 to change "psi" to "ksi (MPa)."
16-687	Revised Table A-360 to reference ASTM E186-2015.
16-688	Revised Table A-360 to reference ASTM E280-2015.
16-1099	Revised all Manufacturer's Data Reports to change "National Board Commission Number and Endorsement" to "National Board Authorized Inspector Commission Number."
16-1150	Revised title of Table PG-19 to "Post Cold-Forming Strain Limits and Heat-Treatment Requirements for Austenitic Materials and Nickel-Based Alloys."
16-1331	Revised Preamble by deleting the words speaking to BPV I rules on the application of the ASME Certification Mark to piping beyond the Section I scope.
16-1377	Revised Table A-360 to reference ASME B31.1-2016.
16-1397	Revised Table A-360 to reference ASTM PTC 25-2014 and ASME B16.1-2015.
16-1500	Revised A-302.11 to reference the applicable paragraphs in Section I regarding retention of records. Revised PW-28.4 and PB-29.3 to require retention of qualification maintenance records for no more than five years.
16-1638	Revised second equation in PR-8.2.2 so that numerator reads "$2(0.75SE_t)$."
16-2261	Revised item (33) in Table A-354 to update cross-reference to PG-112.2.4(b)(3).
16-2679	Revised endnote (26) in PW-53.2.

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

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

Subparagraph Breakdowns/Nested Lists Hierarchy

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

Footnotes

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

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

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

Cross-References

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

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

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PART PG
GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION

GENERAL

(17) PG-1 SCOPE

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

PG-2 SERVICE LIMITATIONS

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

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

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

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

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

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

(b) No steam is generated within the coil.

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

(d) Pipe size does not exceed NPS $^{3}/_{4}$ (DN 20).

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

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

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

(17) **PG-2.4**

DELETED

PG-3 REFERENCED STANDARDS

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

PG-4 UNITS

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

In general, it is expected that a single system of units shall be used for all aspects of design except where unfeasible or impractical. When components are manufactured at different locations where local customary units are different than those used for the general design, the local units may be used for the design and documentation of that component. Similarly, for proprietary components or those uniquely associated with a system of units different than that used for the general design, the alternate units may be used for the design and documentation of that component.

For any single equation, all variables shall be expressed in a single system of units. When separate equations are provided for U.S. Customary and SI units, those equations must be executed using variables in the units associated with the specific equation. Data expressed in other units shall be converted to U.S. Customary or SI units for use in these equations. The result obtained from execution of these equations may be converted to other units.

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

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