

**ASME B31.3-2002**  
(Revision of ASME B31.3-1999)

# PROCESS PIPING

ASME CODE FOR PRESSURE PIPING, B31  
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A N A M E R I C A N N A T I O N A L S T A N D A R D

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## FOREWORD

Responding to evident need and at the request of The American Society of Mechanical Engineers, the American Standards Association initiated Project B31 in March 1926, with ASME as sole administrative sponsor. The breadth of the field involved required that membership of the Sectional Committee be drawn from some 40 engineering societies, industries, government bureaus, institutes, and trade associations.

Initial publication in 1935 was as the American Tentative Standard Code for Pressure Piping. Revisions from 1942 through 1955 were published as American Standard Code for Pressure Piping, ASA B31.1. It was then decided to publish as separate documents the various industry Sections, beginning with ASA B31.8-1955, Gas Transmission and Distribution Piping Systems. The first Petroleum Refinery Piping Code Section was designated ASA B31.3-1959. ASA B31.3 revisions were published in 1962 and 1966.

In 1967–1969, the American Standards Association became first the United States of America Standards Institute, then the American National Standards Institute. The Sectional Committee became American National Standards Committee B31 and the Code was renamed the American National Standard Code for Pressure Piping. The next B31.3 revision was designated ANSI B31.3-1973. Addenda were published through 1975.

A draft Code Section for Chemical Plant Piping, prepared by Section Committee B31.6, was ready for approval in 1974. It was decided, rather than have two closely related Code Sections, to merge the Section Committees and develop a joint Code Section, titled Chemical Plant and Petroleum Refinery Piping. The first edition was published as ANSI B31.3-1976.

In this Code, responsibility for piping design was conceptually integrated with that for the overall processing facility, with safeguarding recognized as an effective safety measure. Three categories of Fluid Service were identified, with a separate Chapter for Category M Fluid Service. Coverage for nonmetallic piping was introduced. New concepts were better defined in five Addenda, the last of which added Appendix M, a graphic aid to selection of the proper Fluid Service category.

The Standards Committee was reorganized in 1978 as a Committee operating under ASME procedures with ANSI accreditation. It is now the ASME Code for Pressure Piping, B31 Committee. Section committee structure remains essentially unchanged.

The second edition of Chemical Plant and Petroleum Refinery Piping was compiled from the 1976 Edition and its five Addenda, with nonmetal requirements editorially relocated to a separate Chapter. Its new designation was ANSI/ASME B31.3-1980.

Section Committee B31.10 had a draft Code for Cryogenic Piping ready for approval in 1981. Again, it was decided to merge the two Section Committees and develop a more inclusive Code with the same title. The work of consolidation was partially completed in the ANSI/ASME B31.3-1984 Edition.

Significant changes were made in Addenda to the 1984 Edition: integration of cryogenic requirements was completed; a new stand-alone Chapter on high-pressure piping was added; and coverage of fabrication, inspection, testing, and allowable stresses was reorganized. The new Edition was redesignated as ASME/ANSI B31.3-1987 Edition.

Addenda to subsequent Editions, published at three-year intervals, have been primarily to keep the Code up-to-date. New Appendices have been added, however, on requirements for bellows expansion joints, estimating service life, submittal of Inquiries, aluminum flanges, and quality control in the 1990, 1993, and 1999 Editions, all designated as ASME B31.3.

In a program to clarify the application of all Sections of the Code for Pressure Piping, changes are being made in the Introduction and Scope statements of B31.3, and its title is changed to Process Piping.

Under direction of ASME Codes and Standards management, metric units of measurement are being emphasized. With certain exceptions, SI metric units are listed first in the 1996 Edition and are designated as the standard. Instructions for conversion are given where metric data are not available. U.S. customary units also are given. By agreement, either system may be used.

In this Edition of the Code, SI metric units are given first, with U.S. customary units in parentheses. Appendices H and X, the tables in Appendices A and

K, and Tables C-1, C-3, and C-6 in Appendix C are exceptions. Values in metric units are to be regarded as the standard, unless otherwise agreed between the contracting parties. Instructions are given, in those tables that have not been converted for converting tabular data in U.S. units to appropriate SI units.

Interpretations are published on the ASME Web site. (Go to [www.asme.org](http://www.asme.org); click on Codes and Standards;

click on Committee Pages; click on B31 Code for Pressure Piping; then click on B31.3 Process Piping Section Committee.).

Code Cases are published on the ASME Web site. (Go to [www.asme.org](http://www.asme.org); click on Codes and Standards; click on Committee Pages; click on B31 Code for Pressure Piping; then click on B31.3 Process Piping Section Committee.).

# ASME CODE FOR PRESSURE PIPING, B31

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# INTRODUCTION

02

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections, each an American National Standard, under the direction of ASME Committee B31, Code for Pressure Piping.

Rules for each Section reflect the kinds of piping installations considered during its development, as follows:

**B31.1 Power Piping:** piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems;

**B31.3 Process Piping:** piping typically found in petroleum refineries, chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants, and related processing plants and terminals;

**B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids:** piping transporting products which are predominately liquid between plants and terminals and within terminals, pumping, regulating, and metering stations;

**B31.5 Refrigeration Piping:** piping for refrigerants and secondary coolants;

**B31.8 Gas Transportation and Distribution Piping Systems:** piping transporting products which are predominately gas between sources and terminals, including compressor, regulating, and metering stations; gas gathering pipelines;

**B31.9 Building Services Piping:** piping typically found in industrial, institutional, commercial, and public buildings, and in multi-unit residences, which does not require the range of sizes, pressures, and temperatures covered in B31.1;

**B31.11 Slurry Transportation Piping Systems:** piping transporting aqueous slurries between plants and terminals and within terminals, pumping, and regulating stations.

This is the B31.3 Process Piping Code Section. Hereafter, in this Introduction and in the text of this Code Section B31.3, where the word *Code* is used without specific identification, it means this Code Section.

It is the owner's responsibility to select the Code Section which most nearly applies to a proposed piping installation. Factors to be considered by the owner include: limitations of the Code Section; jurisdictional

requirements; and the applicability of other codes and standards. All applicable requirements of the selected Code Section shall be met. For some installations, more than one Code Section may apply to different parts of the installation. The owner is also responsible for imposing requirements supplementary to those of the Code if necessary to assure safe piping for the proposed installation.

Certain piping within a facility may be subject to other codes and standards, including but not limited to:

**ANSI Z223.1 National Fuel Gas Code:** piping for fuel gas from the point of delivery to the connection of each fuel utilization device;

**NFPA Fire Protection Standards:** fire protection systems using water, carbon dioxide, halon, foam, dry chemical, and wet chemicals;

**NFPA 99 Health Care Facilities:** medical and laboratory gas systems;

**Building and plumbing codes,** as applicable, for potable hot and cold water, and for sewer and drain systems.

The Code sets forth engineering requirements deemed necessary for safe design and construction of pressure piping. While safety is the basic consideration, this factor alone will not necessarily govern the final specifications for any piping installation. The designer is cautioned that the Code is not a design handbook; it does not do away with the need for the designer or for competent engineering judgment.

To the greatest possible extent, Code requirements for design are stated in terms of basic design principles and formulas. These are supplemented, as necessary, with specific requirements to assure uniform application of principles and to guide selection and application of piping elements. The Code prohibits designs and practices known to be unsafe and contains warnings where caution, but not prohibition, is warranted.

This Code Section includes:

(a) references to acceptable material specifications and component standards, including dimensional requirements and pressure-temperature ratings;

(b) requirements for design of components and assemblies, including piping supports;

(c) requirements and data for evaluation and limitation of stresses, reactions, and movements associated with pressure, temperature changes, and other forces;

(d) guidance and limitations on the selection and application of materials, components, and joining methods;

(e) requirements for the fabrication, assembly, and erection of piping; and

(f) requirements for examination, inspection, and testing of piping.

ASME Committee B31 is organized and operates under procedures of The American Society of Mechanical Engineers which have been accredited by the American National Standards Institute. The Committee is a continuing one, and keeps all Code Sections current with new developments in materials, construction, and industrial practice. New editions are published at intervals of two years.

Code users will note that clauses in the Code are not necessarily numbered consecutively. Such discontinuities result from following a common outline, insofar as practical, for all Code Sections. In this way, corresponding material is correspondingly numbered in most Code Sections, thus facilitating reference by those who have occasion to use more than one Section.

It is intended that this Edition of Code Section B31.3 not be retroactive. Unless agreement is specifically made between contracting parties to use another issue, or the regulatory body having jurisdiction imposes the use of another issue, the latest Edition issued at least 6 months prior to the original contract date for the first phase of activity covering a piping installation shall be the governing document for all design, materials, fabrication, erection, examination, and testing for the piping until the completion of the work and initial operation.

Users of this Code are cautioned against making use of Code revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the piping is to be installed.

The B31 Committee has established an orderly procedure to consider requests for interpretation and revision of Code requirements. To receive consideration, such request must be in writing and must give full particulars in accordance with Appendix Z.

The approved reply to an inquiry will be sent directly to the inquirer. In addition, the question and reply will be published as part of an Interpretation supplement.

A Case is the prescribed form of reply when study indicates that the Code wording needs clarification, or when the reply modifies existing requirements of the Code or grants permission to use new materials or alternative constructions. Proposed Cases are published in *Mechanical Engineering* for public review. In addition, the Case will be published as part of a Case supplement.

A Case is normally issued for a limited period. If at the end of that period it has been incorporated in the Code, or if no further use of its provisions is anticipated, it will be allowed to expire. Otherwise, it will be renewed for a limited period.

A request for revision of the Code will be placed on the Committee's agenda. Further information or active participation on the part of the proponent may be requested during consideration of a proposed revision.

Materials ordinarily are listed in the Stress Tables only when sufficient usage in piping within the scope of the Code has been shown. Requests for listing shall include evidence of satisfactory usage and specific data to permit establishment of allowable stresses, maximum and minimum temperature limits, and other restrictions. Additional criteria can be found in the guidelines for addition of new materials in the ASME Boiler and Pressure Vessel Code, Section II and Section VIII, Division 1, Appendix B. (To develop usage and gain experience, unlisted materials may be used in accordance with para. 323.1.2.). Metric versions of Tables A-1 and A-2 are in the course of preparation. Please refer to the B31.3 Process Piping web site at [www.asme.org](http://www.asme.org).

## SUMMARY OF CHANGES

Changes given below are identified on the pages by a margin note, **02**, placed next to the affected area.

| <i>Page</i> | <i>Location</i>                 | <i>Change</i>                                                                                                  |
|-------------|---------------------------------|----------------------------------------------------------------------------------------------------------------|
| xxiii—xxiv  | Introduction                    | Corrected by errata and editorially revised                                                                    |
| 13          | 301.10                          | Reference added                                                                                                |
| 15, 16      | 302.3.2(d)(3), (8) (e), and (f) | Revised by errata                                                                                              |
| 22          | 304.2.3(d)(2)                   | Corrected by errata                                                                                            |
| 40          | 319.4.1                         | Equation (16) revised                                                                                          |
| 44          | 321.4                           | Reference added                                                                                                |
| 49, 50      | Table 323.2.2A<br>Fig. 323.2.2A | Added<br>Caption editorially revised                                                                           |
| 77          | Table 341.3.2                   | Revised in its entirety                                                                                        |
| 176, 177    | Table A-1                       | ASTM Specification A 358 added                                                                                 |
| 242, 244    | Table D-300                     | (1) Description for <i>extruded welding tee</i><br>corrected<br>(2) In Note (4), definition of $T_c$ corrected |
| 245         | Appendix E                      | ASTM Specification D 3140 deleted                                                                              |
| 251         | F301.10                         | Added                                                                                                          |
| 253         | F321                            | Added                                                                                                          |
| 270         | Appendix J                      | Definition of $T_c$ corrected                                                                                  |
| 293         | Appendix Q                      | Footnote corrected by errata                                                                                   |

## CHAPTER I SCOPE AND DEFINITIONS

### 300 GENERAL STATEMENTS

(a) *Identification.* This Process Piping Code is a Section of the American Society of Mechanical Engineers Code for Pressure Piping, ASME B31, an American National Standard. It is published as a separate document for convenience of Code users.

(b) *Responsibilities*

(1) *Owner.* The owner of a piping installation shall have overall responsibility for compliance with this Code, and for establishing the requirements for design, construction, examination, inspection, and testing which will govern the entire fluid handling or process installation of which the piping is a part. The owner is also responsible for designating piping in certain fluid services and for determining if a specific Quality System is to be employed. [See paras. 300(d)(4), (d)(5), (e), and Appendix Q.]

(2) *Designer.* The designer is responsible to the owner for assurance that the engineering design of piping complies with the requirements of this Code and with any additional requirements established by the owner.

(3) *Manufacturer, Fabricator, and Erector.* The manufacturer, fabricator, and erector of piping are responsible for providing materials, components, and workmanship in compliance with the requirements of this Code and of the engineering design.

(4) *Owner's Inspector.* The owner's Inspector (see para. 340) is responsible to the owner for ensuring that the requirements of this Code for inspection, examination, and testing are met. If a Quality System is specified by the owner to be employed, the owner's inspector is responsible for verifying that it is implemented.

(c) *Intent of the Code*

(1) It is the intent of this Code to set forth engineering requirements deemed necessary for safe design and construction of piping installations.

(2) This Code is not intended to apply to the operation, examination, inspection, testing, maintenance, or repair of piping that has been placed in service. The provisions of this Code may optionally be applied

for those purposes, although other considerations may also be necessary.

(3) Engineering requirements of this Code, while considered necessary and adequate for safe design, generally employ a simplified approach to the subject. A designer capable of applying a more rigorous analysis shall have the latitude to do so; however, the approach must be documented in the engineering design and its validity accepted by the owner. The approach used shall provide details of design, construction, examination, inspection, and testing for the design conditions of para. 301, with calculations consistent with the design criteria of this Code.

(4) Piping elements should, insofar as practicable, conform to the specifications and standards listed in this Code. Piping elements neither specifically approved nor specifically prohibited by this Code may be used provided they are qualified for use as set forth in applicable Chapters of this Code.

(5) The engineering design shall specify any unusual requirements for a particular service. Where service requirements necessitate measures beyond those required by this Code, such measures shall be specified by the engineering design. Where so specified, the Code requires that they be accomplished.

(6) Compatibility of materials with the service and hazards from instability of contained fluids are not within the scope of this Code. See para. F323.

(d) *Determining Code Requirements*

(1) Code requirements for design and construction include fluid service requirements, which affect selection and application of materials, components, and joints. Fluid service requirements include prohibitions, limitations, and conditions, such as temperature limits or a requirement for safeguarding (see para. 300.2 and Appendix G). Code requirements for a piping system are the most restrictive of those which apply to any of its elements.

(2) For metallic piping not in Category M or high pressure fluid service, Code requirements are found in Chapters I through VI (the base Code), and fluid service requirements are found in:

(a) Chapter III for materials;

(b) Chapter II, Part 3, for components;

(c) Chapter II, Part 4, for joints.

(3) For nonmetallic piping and piping lined with nonmetals, all requirements are found in Chapter VII. (Paragraph designations begin with “A.”)

(4) For piping in a fluid service designated by the owner as Category M (see para. 300.2 and Appendix M), all requirements are found in Chapter VIII. (Paragraph designations begin with “M.”)

(5) For piping in a fluid service designated by the owner as Category D (see para. 300.2 and Appendix M), piping elements restricted to Category D Fluid Service in Chapters I through VII, as well as elements suitable for other fluid services, may be used.

(6) Metallic piping elements suitable for Normal Fluid Service in Chapters I through VI may also be used under severe cyclic conditions unless a specific requirement for severe cyclic conditions is stated.

(e) *High Pressure Piping.* Chapter IX provides alternative rules for design and construction of piping designated by the owner as being in High Pressure Fluid Service.

(1) These rules apply only when specified by the owner, and only as a whole, not in part.

(2) Chapter IX rules do not provide for Category M Fluid Service. See para. K300.1.4.

(3) Paragraph designations begin with “K.”

(f) *Appendices.* Appendices of this Code contain Code requirements, supplementary guidance, or other information. See para. 300.4 for a description of the status of each Appendix.

### 300.1 Scope

Rules for the Process Piping Code Section B31.3<sup>1</sup> have been developed considering piping typically found in petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals.

#### 300.1.1 Content and Coverage

(a) This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

(b) This Code applies to piping for all fluids, including:

- (1) raw, intermediate, and finished chemicals;
- (2) petroleum products;
- (3) gas, steam, air, and water;

<sup>1</sup> B31 references here and elsewhere in this Code are to the ASME B31 Code for Pressure Piping and its various Sections, which are identified and briefly described in the Introduction.

(4) fluidized solids;

(5) refrigerants; and

(6) cryogenic fluids.

(c) See Fig. 300.1.1 for a diagram illustrating the application of B31.3 piping at equipment. The joint connecting piping to equipment is within the scope of B31.3.

**300.1.2 Packaged Equipment Piping.** Also included within the scope of this Code is piping which interconnects pieces or stages within a packaged equipment assembly.

**300.1.3 Exclusions.** This Code excludes the following:

(a) piping systems designed for internal gage pressures at or above zero but less than 105 kPa (15 psi), provided the fluid handled is nonflammable, nontoxic, and not damaging to human tissue as defined in 300.2, and its design temperature is from  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) through  $186^{\circ}\text{C}$  ( $366^{\circ}\text{F}$ );

(b) power boilers in accordance with BPV Code<sup>2</sup> Section I and boiler external piping which is required to conform to B31.1;

(c) tubes, tube headers, crossovers, and manifolds of fired heaters, which are internal to the heater enclosure; and

(d) pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal piping and connections for external piping.

### 300.2 Definitions

Some of the terms relating to piping are defined below. For welding terms not shown here, definitions in accordance with ANSI/AWS Standard A3.0 apply.

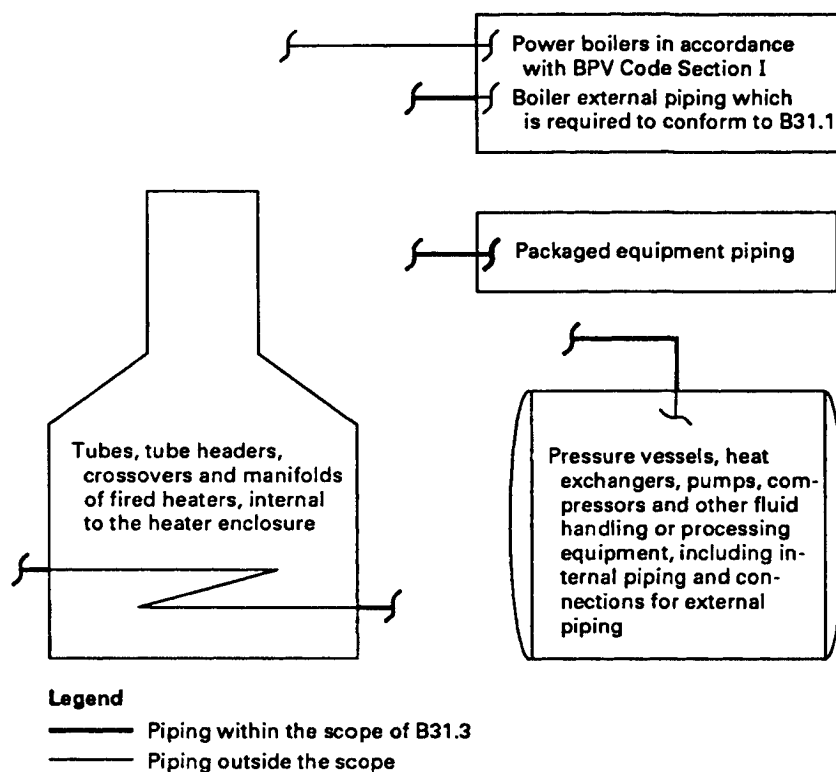
*air-hardened steel:* a steel that hardens during cooling in air from a temperature above its transformation range

*anneal heat treatment:* see *heat treatment*

*arc cutting:* a group of cutting processes wherein the severing or removing of metals is effected by melting with the heat of an arc between an electrode and the base metal. (Includes carbon-arc cutting, metal-arc

<sup>2</sup> BPV Code references here and elsewhere in this Code are to the ASME Boiler and Pressure Vessel Code and its various Sections as follows:

Section I, Power Boilers  
Section II, Materials, Part D  
Section V, Nondestructive Examination  
Section VIII, Pressure Vessels, Divisions 1 and 2  
Section IX, Welding and Brazing Qualifications



GENERAL NOTE: The means by which piping is attached to equipment is within the scope of the applicable piping code.

FIG. 300.1.1 DIAGRAM ILLUSTRATING APPLICATION OF B31.3 PIPING AT EQUIPMENT

cutting, gas metal-arc cutting, gas tungsten-arc cutting, plasma-arc cutting, and air carbon-arc cutting.) See also *oxygen-arc cutting*.

**arc welding (AW):** a group of welding processes which produces coalescence of metals by heating them with an arc or arcs, with or without the application of pressure and with or without the use of filler metal

**assembly:** the joining together of two or more piping components by bolting, welding, bonding, screwing, brazing, soldering, cementing, or use of packing devices as specified by the engineering design

**automatic welding:** welding with equipment which performs the welding operation without adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

**backing filler metal:** see *consumable insert*

**backing ring:** material in the form of a ring used to support molten weld metal

**balanced piping system:** see para. 319.2.2(a)

**base material:** the material to be brazed, soldered, welded, or otherwise fused

**basic allowable stress:** see *stress terms frequently used*

**bolt design stress:** see *stress terms frequently used*

**bonded joint:** a permanent joint in nonmetallic piping made by one of the following methods:

(a) **adhesive joint:** a joint made by applying an adhesive to the surfaces to be joined and pressing them together

(b) **butt-and-wrapped joint:** a joint made by butting together the joining surfaces and wrapping the joint with plies of reinforcing fabric saturated with resin

(c) **heat fusion joint:** a joint made by heating the surfaces to be joined and pressing them together to achieve fusion

(d) **hot gas welded joint:** a joint made by simultaneously heating the surfaces to be joined and a filler

material with a stream of hot air or hot inert gas, then pressing the surfaces together and applying the filler material to achieve fusion

(e) *solvent cemented joint*: a joint made by using a solvent cement to soften the surfaces to be joined and pressing them together

(f) *electrofusion joint*: a joint made by heating the surfaces to be joined using an electrical resistance wire coil, which remains embedded in the joint.

*bonder*: one who performs a manual or semiautomatic bonding operation

*bonding operator*: one who operates machine or automatic bonding equipment

*bonding procedure*: the detailed methods and practices involved in the production of a bonded joint

*bonding procedure specification (BPS)*: the document which lists the parameters to be used in the construction of bonded joints in accordance with the requirements of this Code

*branch connection fitting*: an integrally reinforced fitting welded to a run pipe and connected to a branch pipe by a butt welding, socket welding, threaded, or flanged joint; includes a branch outlet fitting conforming to MSS SP-97

*brazing*: a welding process using a nonferrous filler metal having a melting point below that of the base metals, but above 427°C (800°F). The filler metal is not distributed in the joint by capillary attraction. (Bronze welding, formerly used, is a misnomer for this term.)

*brazing*: a metal joining process wherein coalescence is produced by use of a nonferrous filler metal having a melting point above 427°C (800°F), but lower than that of the base metals being joined. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

*butt joint*: a joint between two members aligned approximately in the same plane

*Category D*: see *fluid service*

*Category M*: see *fluid service*

*caulked joint*: a joint in which suitable material (or materials) is either poured or compressed by the use of tools into the annular space between a bell (or hub) and spigot (or plain end), thus comprising the joint seal

*chemical plant*: an industrial plant for the manufacture or processing of chemicals, or of raw materials or

intermediates for such chemicals. A chemical plant may include supporting and service facilities, such as storage, utility, and waste treatment units.

*cold spring*: see para. 319.2.4

*connections for external piping*: those integral parts of individual pieces of equipment which are designed for attachment of external piping

*consumable insert*: preplaced filler metal which is completely fused into the root of the joint and becomes part of the weld

*damaging to human tissues*: for the purposes of this Code, this phrase describes a fluid service in which exposure to the fluid, caused by leakage under expected operating conditions, can harm skin, eyes, or exposed mucous membranes so that irreversible damage may result unless prompt restorative measures are taken. (Restorative measures may include flushing with water, administration of antidotes, or medication.)

*design minimum temperature*: see para. 301.3.1

*design pressure*: see para. 301.2

*design temperature*: see para. 301.3

*designer*: the person or organization in responsible charge of the engineering design

*displacement stress range*: see para. 319.2.3

*elements*: see *piping elements*

*engineering design*: the detailed design governing a piping system, developed from process and mechanical requirements, conforming to Code requirements, and including all necessary specifications, drawings, and supporting documents

*equipment connection*: see *connections for external piping*

*erection*: the complete installation of a piping system in the locations and on the supports designated by the engineering design including any field assembly, fabrication, examination, inspection, and testing of the system as required by this Code

*examination, examiner*: see paras. 341.1 and 341.2

*examination, types of*: see para. 344.1.3 for the following:

- (a) 100% examination
- (b) random examination
- (c) spot examination
- (d) random spot examination

*extruded outlet header:* see para. 304.3.4

*fabrication:* the preparation of piping for assembly, including cutting, threading, grooving, forming, bending, and joining of components into subassemblies. Fabrication may be performed in the shop or in the field.

*face of weld:* the exposed surface of a weld on the side from which the welding was done

*filler material:* the material to be added in making metallic or nonmetallic joints

*fillet weld:* a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint. (See also *size of weld* and *throat of a fillet weld*.)

*flammable:* for the purposes of this Code, describes a fluid which under ambient or expected operating conditions is a vapor or produces vapors that can be ignited and continue to burn in air. The term thus may apply, depending on service conditions, to fluids defined for other purposes as *flammable* or *combustible*.

*fluid service:* a general term concerning the application of a piping system, considering the combination of fluid properties, operating conditions, and other factors which establish the basis for design of the piping system. See Appendix M.

(a) *Category D Fluid Service:* a fluid service in which all the following apply:

(1) the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in para. 300.2;

(2) the design gage pressure does not exceed 1035 kPa (150 psi); and

(3) the design temperature is from  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) through  $186^{\circ}\text{C}$  ( $366^{\circ}\text{F}$ ).

(b) *Category M Fluid Service:* a fluid service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken

(c) *High Pressure Fluid Service:* a fluid service for which the owner specifies the use of Chapter IX for piping design and construction; see also para. K300

(d) *Normal Fluid Service:* a fluid service pertaining to most piping covered by this Code, i.e., not subject to the rules for Category D, Category M, or High Pressure Fluid Service

*full fillet weld:* a fillet weld whose size is equal to the thickness of the thinner member joined

*fusion:* the melting together of filler material and base material, or of base material only, which results in coalescence

*gas metal-arc welding (GMAW):* an arc-welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas, or gas mixture. Some variations of this process are called MIG or  $\text{CO}_2$  welding (nonpreferred terms)

*gas tungsten-arc welding (GTAW):* an arc-welding process which produces coalescence of metals by heating them with an arc between a single tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used. (This process has sometimes been called TIG welding.)

*gas welding:* a group of welding processes wherein coalescence is produced by heating with a gas flame or flames, with or without the application of pressure, and with or without the use of filler material

*groove weld:* a weld made in the groove between two members to be joined

*heat affected zone:* that portion of the base material which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, forming, or cutting

*heat treatment:* terms used to describe various types and processes of heat treatment (sometimes called post-weld heat treatment) are defined as follows:

(a) *annealing:* heating to and holding at a suitable temperature and then cooling at a suitable rate for such purposes as: reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure, or obtaining desired mechanical, physical, or other properties

(b) *normalizing:* a process in which a ferrous metal is heated to a suitable temperature above the transformation range and is subsequently cooled in still air at room temperature

(c) *preheating:* see *preheating* (separate term)

(d) *quenching:* rapid cooling of a heated metal

(e) *recommended or required heat treatment:* the application of heat to a metal section subsequent to a cutting, forming, or welding operation, as provided in para. 331

(f) *solution heat treatment*: heating an alloy to a suitable temperature, holding at that temperature long enough to allow one or more constituents to enter into solid solution, and then cooling rapidly enough to hold the constituents in solution

(g) *stress-relief*: uniform heating of a structure or portion thereof to a sufficient temperature to relieve the major portion of the residual stresses, followed by uniform cooling slowly enough to minimize development of new residual stresses

(h) *tempering*: reheating a hardened metal to a temperature below the transformation range to improve toughness

(i) *transformation range*: a temperature range in which a phase change is initiated and completed

(j) *transformation temperature*: a temperature at which a phase change occurs

*High Pressure Fluid Service*: see *fluid service*

*indication, linear*: in magnetic particle, liquid penetrant or similar examination, a closed surface area marking or denoting a discontinuity requiring evaluation, whose longest dimension is at least three times the width of the indication

*indication, rounded*: in magnetic particle, liquid penetrant or similar examination, a closed surface area marking or denoting a discontinuity requiring evaluation, whose longest dimension is less than three times the width of the indication

*in-process examination*: see para. 344.7

*inspection, Inspector*: see para. 340

*joint design*: the joint geometry together with the required dimensions of the welded joint

*listed*: for the purposes of this Code, describes a material or component which conforms to a specification in Appendix A, Appendix B, or Appendix K or to a standard in Table 326.1, A326.1, or K326.1

*manual welding*: a welding operation performed and controlled completely by hand

*may*: a term which indicates that a provision is neither required nor prohibited

*mechanical joint*: a joint for the purpose of mechanical strength or leak resistance, or both, in which the mechanical strength is developed by threaded, grooved, rolled, flared, or flanged pipe ends; or by bolts, pins, toggles, or rings; and the leak resistance is developed

by threads and compounds, gaskets, rolled ends, caulking, or machined and mated surfaces

*miter*: two or more straight sections of pipe matched and joined in a plane bisecting the angle of junction so as to produce a change in direction

*nominal*: a numerical identification of dimension, capacity, rating, or other characteristic used as a designation, not as an exact measurement

*NPS*: nominal pipe size (followed, when appropriate, by the specific size designation number without an inch symbol)

*Normal Fluid Service*: see *fluid service*

*normalizing*: see *heat treatment*

*notch-sensitive*: describes a metal subject to reduction in strength in the presence of stress concentration. The degree of notch sensitivity is usually expressed as the strength determined in a notched specimen divided by the strength determined in an unnotched specimen, and can be obtained from either static or dynamic tests.

*oxygen-arc cutting (OAC)*: an oxygen-cutting process that uses an arc between the workpiece and a consumable electrode, through which oxygen is directed to the workpiece. For oxidation-resistant metals, a chemical flux or metal powder is used to facilitate the reaction.

*oxygen cutting (OC)*: a group of thermal cutting processes that severs or removes metal by means of the chemical reaction between oxygen and the base metal at elevated temperature. The necessary temperature is maintained by the heat from an arc, an oxyfuel gas flame, or other source.

*oxygen gouging*: thermal gouging that uses an oxygen cutting process variation to form a bevel or groove

*packaged equipment*: an assembly of individual pieces or stages of equipment, complete with inter-connecting piping and connections for external piping. The assembly may be mounted on a skid or other structure prior to delivery.

*petroleum refinery*: an industrial plant for processing or handling of petroleum and products derived directly from petroleum. Such a plant may be an individual gasoline recovery plant, a treating plant, a gas processing plant (including liquefaction), or an integrated refinery having various process units and attendant facilities.

*pipe*: a pressure-tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated *pipe* in applicable material specifications. Materials

designated *tube* or *tubing* in the specifications are treated as pipe when intended for pressure service. Types of pipe, according to the method of manufacture, are defined as follows:

(a) *electric resistance-welded pipe*: pipe produced in individual lengths or in continuous lengths from coiled skelp and subsequently cut into individual lengths, having a longitudinal butt joint wherein coalescence is produced by the heat obtained from resistance of the pipe to the flow of electric current in a circuit of which the pipe is a part, and by the application of pressure

(b) *furnace butt welded pipe, continuous welded*: pipe produced in continuous lengths from coiled skelp and subsequently cut into individual lengths, having its longitudinal butt joint forge welded by the mechanical pressure developed in passing the hot-formed and edge-heated skelp through a set of round pass welding rolls

(c) *electric-fusion welded pipe*: pipe having a longitudinal butt joint wherein coalescence is produced in the preformed tube by manual or automatic electric-arc welding. The weld may be single (welded from one side) or double (welded from inside and outside) and may be made with or without the addition of filler metal.

(d) *double submerged-arc welded pipe*: pipe having a longitudinal butt joint produced by at least two passes, one of which is on the inside of the pipe. Coalescence is produced by heating with an electric arc or arcs between the bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular fusible material on the work. Pressure is not used and filler metal for the inside and outside welds is obtained from the electrode or electrodes.

(e) *seamless pipe*: pipe produced by piercing a billet followed by rolling or drawing, or both

(f) *spiral welded pipe*: pipe having a helical seam with either a butt, lap, or lock-seam joint which is welded using either an electrical resistance, electric fusion or double-submerged arc welding process

*pipe-supporting elements*: pipe-supporting elements consist of fixtures and structural attachments as follows:

(a) *fixtures*: fixtures include elements which transfer the load from the pipe or structural attachment to the supporting structure or equipment. They include hanging type fixtures, such as hanger rods, spring hangers, sway braces, counterweights, turnbuckles, struts, chains, guides, and anchors; and bearing type fixtures, such as saddles, bases, rollers, brackets, and sliding supports.

(b) *structural attachments*: structural attachments include elements which are welded, bolted, or clamped

to the pipe, such as clips, lugs, rings, clamps, clevises, straps, and skirts

*piping*: assemblies of piping components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows. Piping also includes pipe-supporting elements, but does not include support structures, such as building frames, bents, foundations, or any equipment excluded from this Code (see para. 300.1.3).

*piping components*: mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, in-line portions of instruments, and separators.

*piping elements*: any material or work required to plan and install a piping system. Elements of piping include design specifications, materials, components, supports, fabrication, examination, inspection, and testing.

*piping installation*: designed piping systems to which a selected Code Edition and Addenda apply

*piping system*: interconnected piping subject to the same set or sets of design conditions

*plasma arc cutting (PAC)*: an arc cutting process that uses a constricted arc and removes molten metal with a high velocity jet of ionized gas issuing from the constricting orifice

*preheating*: the application of heat to the base material immediately before or during a forming, welding, or cutting process. See para. 330.

*postweld heat treatment*: see *heat treatment*

*procedure qualification record (PQR)*: a document listing all pertinent data, including the essential variables employed and the test results, used in qualifying the procedure specification

*process unit*: an area whose boundaries are designated by the engineering design within which reactions, separations, and other processes are carried out. Examples of installations which are *not* classified as process units are loading areas or terminals, bulk plants, compounding plants, and tank farms and storage yards.

*quench annealing*: see *solution heat treatment* under *heat treatment*

*quenching*: see *heat treatment*

*reinforcement:* see paras. 304.3 and A304.3. See also *weld reinforcement*.

*root opening:* the separation between the members to be joined, at the root of the joint

*safeguarding:* provision of protective measures of the types outlined in Appendix G, where deemed necessary. See Appendix G for detailed discussion.

*seal bond:* a bond intended primarily to provide joint tightness against leakage in nonmetallic piping

*seal weld:* a weld intended primarily to provide joint tightness against leakage in metallic piping

*semiautomatic arc welding:* arc welding with equipment which controls only the filler metal feed. The advance of the welding is manually controlled.

*severe cyclic conditions:* conditions applying to specific piping components or joints in which  $S_E$  computed in accordance with para. 319.4.4 exceeds  $0.8S_A$  (as defined in para. 302.3.5), and the equivalent number of cycles ( $N$  in para. 302.3.5) exceeds 7000; or other conditions which the designer determines will produce an equivalent effect

*shall:* a term which indicates that a provision is a Code requirement

*shielded metal-arc welding (SMAW):* an arc welding process which produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

*should:* a term which indicates that a provision is recommended as good practice but is not a Code requirement

*size of weld:*

(a) *fillet weld:* the leg lengths (the leg length for equal-leg welds) of the sides, adjoining the members welded, of the largest triangle that can be inscribed within the weld cross section. For welds between perpendicular members, the definitions in Fig. 328.5.2A apply.

NOTE: When the angle between members exceeds 105 deg, size is of less significance than effective throat (see also *throat of a fillet weld*).

(b) *groove weld:* the joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are the same.

*slag inclusion:* nonmetallic solid material entrapped in weld metal or between weld metal and base metal

*soldering:* a metal joining process wherein coalescence is produced by heating to suitable temperatures and by using a nonferrous alloy fusible at temperatures below 427°C (800°F) and having a melting point below that of the base metals being joined. The filler metal is distributed between closely fitted surfaces of the joint by capillary attraction. In general, solders are lead-tin alloys and may contain antimony, bismuth, and other elements.

*solution heat treatment:* see *heat treatment*

*stress ratio:* see Fig. 323.2.2B.

*stress relief:* see *heat treatment*

*stress terms frequently used:*

(a) *basic allowable stress:* this term, symbol  $S$ , represents the stress value for any material determined by the appropriate stress basis in para. 302.3.2

(b) *bolt design stress:* this term represents the design stress used to determine the required cross-sectional area of bolts in a bolted joint

(c) *hydrostatic design basis:* selected properties of plastic piping materials to be used in accordance with ASTM D 2837 or D 2992 to determine the HDS [see (d) below] for the material

(d) *hydrostatic design stress (HDS):* the maximum continuous stress due to internal pressure to be used in the design of plastic piping, determined from the hydrostatic design basis by use of a service (design) factor

*submerged arc welding (SAW):* an arc welding process which produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

*tack weld:* a weld made to hold parts of a weldment in proper alignment until the final welds are made

*tempering:* see *heat treatment*

*thermoplastic:* a plastic which is capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature

*thermosetting resin:* a resin capable of being changed into a substantially infusible or insoluble product when

cured at room temperature, or by application of heat, or by chemical means

*throat of a fillet weld:*

(a) *theoretical throat:* the perpendicular distance from the hypotenuse of the largest right triangle that can be inscribed in the weld cross section to the root of the joint

(b) *actual throat:* the shortest distance from the root of a fillet weld to its face

(c) *effective throat:* the minimum distance, minus any reinforcement (convexity), between the weld root and the face of a fillet weld

*toe of weld:* the junction between the face of a weld and the base material

*tube:* see *pipe*

*tungsten electrode:* a nonfiller-metal electrode used in arc welding or cutting, made principally of tungsten

*unbalanced piping system:* see para. 319.2.2(b)

*undercut:* a groove melted into the base material adjacent to the toe or root of a weld and left unfilled by weld material

*visual examination:* see para. 344.2.1

*weld:* a localized coalescence of material wherein coalescence is produced either by heating to suitable temperatures, with or without the application of pressure, or by application of pressure alone, and with or without the use of filler material

*weld reinforcement:* weld material in excess of the specified weld size

*welder:* one who performs a manual or semi-automatic welding operation. (This term is sometimes erroneously used to denote a welding machine.)

*welding operator:* one who operates machine or automatic welding equipment

*welding procedure:* the detailed methods and practices involved in the production of a weldment

*welding procedure specification (WPS):* the document which lists the parameters to be used in construction of weldments in accordance with requirements of this Code

*weldment:* an assembly whose component parts are joined by welding

### 300.3 Nomenclature

Dimensional and mathematical symbols used in this Code are listed in Appendix J, with definitions and location references to each. Lowercase and uppercase English letters are listed alphabetically, followed by Greek letters.

### 300.4 Status of Appendices

Table 300.4 indicates for each Appendix of this Code whether it contains Code requirements, guidance, or supplemental information. See the first page of each Appendix for details.

**TABLE 300.4**  
**STATUS OF APPENDICES IN B31.3**

| Appendix | Title                                                     | Status            |
|----------|-----------------------------------------------------------|-------------------|
| A        | Stress Tables for Metallic Piping and Bolting Materials   | Requirements      |
| B        | Stress Tables and Allowable Pressure Tables for Nonmetals | Requirements      |
| C        | Physical Properties of Piping Materials                   | Requirements (1)  |
| D        | Flexibility and Stress Intensification Factors            | Requirements (1)  |
| E        | Reference Standards                                       | Requirements      |
| F        | Precautionary Considerations                              | Guidance (2)      |
| G        | Safeguarding                                              | Guidance (2)      |
| H        | Sample Calculations for Branch Reinforcement              | Guidance          |
| J        | Nomenclature                                              | Information       |
| K        | Allowable Stress for High Pressure Piping                 | Requirements (3)  |
| L        | Aluminum Alloy Pipe Flanges                               | Specification (5) |
| M        | Guide to Classifying Fluid Services                       | Guidance (2)      |
| Q        | Quality System Program                                    | Guidance (2)      |
| V        | Allowable Variations in Elevated Temperature Service      | Guidance (2)      |
| X        | Metallic Bellows Expansion Joints                         | Requirements      |
| Z        | Preparation of Technical Inquiries                        | Requirements (4)  |

**NOTES:**

- (1) Contains default requirements, to be used unless more directly applicable data are available.
- (2) Contains no requirements but Code user is responsible for considering applicable items.
- (3) Contains requirements applicable only when use of Chapter IX is specified.
- (4) Contains administrative requirements.
- (5) Contains pressure-temperature ratings, materials, dimensions, and markings of forged aluminum alloy flanges.

## CHAPTER II DESIGN

### PART 1 CONDITIONS AND CRITERIA

#### 301 DESIGN CONDITIONS

Paragraph 301 states the qualifications of the Designer, defines the temperatures, pressures, and forces applicable to the design of piping, and states the consideration that shall be given to various effects and their consequent loadings. See also Appendix F, para. F301.

##### 301.1 Qualifications of the Designer

The Designer is the person(s) in charge of the engineering design of a piping system and shall be experienced in the use of this Code.

The qualifications and experience required of the Designer will depend on the complexity and criticality of the system and the nature of the individual's experience. The owner's approval is required if the individual does not meet at least one of the following criteria.

(a) Completion of an engineering degree, requiring four or more years of full-time study, plus a minimum of 5 years experience in the design of related pressure piping.

(b) Professional Engineering registration, recognized by the local jurisdiction, and experience in the design of related pressure piping.

(c) Completion of an engineering associates degree, requiring at least 2 years of full-time study, plus a minimum of 10 years experience in the design of related pressure piping.

(d) Fifteen years experience in the design of related pressure piping. Experience in the design of related pressure piping is satisfied by piping design experience that includes design calculations for pressure, sustained and occasional loads, and piping flexibility.

##### 301.2 Design Pressure

###### 301.2.1 General

(a) The design pressure of each component in a piping system shall be not less than the pressure at

the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service, except as provided in para. 302.2.4.

(b) The most severe condition is that which results in the greatest required component thickness and the highest component rating.

(c) When more than one set of pressure-temperature conditions exist for a piping system, the conditions governing the rating of components conforming to listed standards may differ from the conditions governing the rating of components designed in accordance with para. 304.

(d) When a pipe is separated into individualized pressure-containing chambers (including jacketed piping, blanks, etc.), the partition wall shall be designed on the basis of the most severe coincident temperature (minimum or maximum) and differential pressure between the adjoining chambers expected during service, except as provided in para. 302.2.4.

##### 301.2.2 Required Pressure Containment or Relief

(a) Provision shall be made to safely contain or relieve (see para. 322.6.3) any pressure to which the piping may be subjected. Piping not protected by a pressure relieving device, or that can be isolated from a pressure relieving device, shall be designed for at least the highest pressure that can be developed.

(b) Sources of pressure to be considered include ambient influences, pressure oscillations and surges, improper operation, decomposition of unstable fluids, static head, and failure of control devices.

(c) The allowances of para. 302.2.4(f) are permitted, provided that the other requirements of para. 302.2.4 are also met.

##### 301.3 Design Temperature

The design temperature of each component in a piping system is the temperature at which, under the coincident pressure, the greatest thickness or highest component rating is required in accordance with para. 301.2. (To satisfy the requirements of para. 301.2,

different components in the same piping system may have different design temperatures.)

In establishing design temperatures, consider at least the fluid temperatures, ambient temperatures, solar radiation, heating or cooling medium temperatures, and the applicable provisions of paras. 301.3.2, 301.3.3, and 301.3.4.

**301.3.1 Design Minimum Temperature.** The design minimum temperature is the lowest component temperature expected in service. This temperature may establish special design requirements and material qualification requirements. See also paras. 301.4.4 and 323.2.2.

### 301.3.2 Uninsulated Components

(a) For fluid temperatures below 65°C (150°F), the component temperature shall be taken as the fluid temperature unless solar radiation or other effects result in a higher temperature.

(b) For fluid temperatures 65°C (150°F) and above, unless a lower average wall temperature is determined by test or heat transfer calculation, the temperature for uninsulated components shall be no less than the following values:

- (1) valves, pipe, lapped ends, welding fittings, and other components having wall thickness comparable to that of the pipe: 95% of the fluid temperature;
- (2) flanges (except lap joint) including those on fittings and valves: 90% of the fluid temperature;
- (3) lap joint flanges: 85% of the fluid temperature;
- (4) bolting: 80% of the fluid temperature.

**301.3.3 Externally Insulated Piping.** The component design temperature shall be the fluid temperature unless calculations, tests, or service experience based on measurements support the use of another temperature. Where piping is heated or cooled by tracing or jacketing, this effect shall be considered in establishing component design temperatures.

**301.3.4 Internally Insulated Piping.** The component design temperature shall be based on heat transfer calculations or tests.

### 301.4 Ambient Effects

See Appendix F, para. F301.4.

**301.4.1 Cooling: Effects on Pressure.** The cooling of a gas or vapor in a piping system may reduce the pressure sufficiently to create an internal vacuum. In such a case, the piping shall be capable of withstanding the external pressure at the lower temperature, or provision shall be made to break the vacuum.

**301.4.2 Fluid Expansion Effects.** Provision shall be made in the design either to withstand or to relieve increased pressure caused by the heating of static fluid in a piping component. See also para. 322.6.3(b)(2).

**301.4.3 Atmospheric Icing.** Where the design minimum temperature of a piping system is below 0°C (32°F), the possibility of moisture condensation and buildup of ice shall be considered and provisions made in the design to avoid resultant malfunctions. This applies to surfaces of moving parts of shutoff valves, control valves, pressure relief devices including discharge piping, and other components.

**301.4.4 Low Ambient Temperature.** Consideration shall be given to low ambient temperature conditions for displacement stress analysis.

### 301.5 Dynamic Effects

See Appendix F, para. F301.5.

**301.5.1 Impact.** Impact forces caused by external or internal conditions (including changes in flow rate, hydraulic shock, liquid or solid slugging, flashing, and geysering) shall be taken into account in the design of piping.

**301.5.2 Wind.** The effect of wind loading shall be taken into account in the design of exposed piping. The method of analysis may be as described in ASCE 7, Minimum Design Loads for Buildings and Other Structures, or the Uniform Building Code.

**301.5.3 Earthquake.** Piping shall be designed for earthquake-induced horizontal forces. The method of analysis may be as described in ASCE 7 or the Uniform Building Code.

**301.5.4 Vibration.** Piping shall be designed, arranged, and supported so as to eliminate excessive and harmful effects of vibration which may arise from such sources as impact, pressure pulsation, turbulent flow vortices, resonance in compressors, and wind.

**301.5.5 Discharge Reactions.** Piping shall be designed, arranged, and supported so as to withstand reaction forces due to let-down or discharge of fluids.

### 301.6 Weight Effects

The following weight effects, combined with loads and forces from other causes, shall be taken into account in the design of piping.

**301.6.1 Live Loads.** These loads include the weight of the medium transported or the medium used for test. Snow and ice loads due to both environmental and operating conditions shall be considered.

**301.6.2 Dead Loads.** These loads consist of the weight of piping components, insulation, and other superimposed permanent loads supported by the piping.

### 301.7 Thermal Expansion and Contraction Effects

The following thermal effects, combined with loads and forces from other causes, shall be taken into account in the design of piping. See also Appendix F, para. F301.7.

**301.7.1 Thermal Loads Due to Restraints.** These loads consist of thrusts and moments which arise when free thermal expansion and contraction of the piping are prevented by restraints or anchors.

**301.7.2 Loads Due to Temperature Gradients.** These loads arise from stresses in pipe walls resulting from large rapid temperature changes or from unequal temperature distribution as may result from a high heat flux through a comparatively thick pipe or stratified two-phase flow causing bowing of the line.

**301.7.3 Loads Due to Differences in Expansion Characteristics.** These loads result from differences in thermal expansion where materials with different thermal expansion coefficients are combined, as in bimetallic, lined, jacketed, or metallic–nonmetallic piping.

### 301.8 Effects of Support, Anchor, and Terminal Movements

The effects of movements of piping supports, anchors, and connected equipment shall be taken into account in the design of piping. These movements may result from the flexibility and/or thermal expansion of equipment, supports, or anchors; and from settlement, tidal movements, or wind sway.

### 301.9 Reduced Ductility Effects

The harmful effects of reduced ductility shall be taken into account in the design of piping. The effects may, for example, result from welding, heat treatment, forming, bending, or low operating temperatures, including the chilling effect of sudden loss of pressure on highly volatile fluids. Low ambient temperatures expected during operation shall be considered.

### 301.10 Cyclic Effects

Fatigue due to pressure cycling, thermal cycling, and other cyclic loadings shall be considered in the design of piping. See Appendix F, para. F301.10.

### 301.11 Air Condensation Effects

At operating temperatures below  $-191^{\circ}\text{C}$  ( $-312^{\circ}\text{F}$ ) in ambient air, condensation and oxygen enrichment occur. These shall be considered in selecting materials, including insulation, and adequate shielding and/or disposal shall be provided.

## 302 DESIGN CRITERIA

### 302.1 General

Paragraph 302 states pressure-temperature ratings, stress criteria, design allowances, and minimum design values together with permissible variations of these factors as applied to the design of piping.

### 302.2 Pressure-Temperature Design Criteria

**302.2.1 Listed Components Having Established Ratings.** Except as limited elsewhere in the Code, pressure-temperature ratings contained in standards for piping components listed in Table 326.1 are acceptable for design pressures and temperatures in accordance with this Code. The provisions of this Code may be used at the owner's responsibility to extend the pressure-temperature ratings of a component beyond the ratings of the listed standard.

**302.2.2 Listed Components Not Having Specific Ratings.** Some of the standards for components in Table 326.1 (e.g., ASME B16.9, B16.11, and B16.28) state that pressure-temperature ratings are based on straight seamless pipe. Except as limited in the standard or elsewhere in this Code, such a component, made of a material having the same allowable stress as the pipe shall be rated using not more than 87.5% of the nominal thickness of seamless pipe corresponding to the schedule, weight, or pressure class of the fitting, less all allowances applied to the pipe (e.g., thread depth and/or corrosion allowance).

#### 302.2.3 Unlisted Components

(a) Components not listed in Table 326.1, but which conform to a published specification or standard, may be used within the following limitations.

(1) The designer shall be satisfied that composition, mechanical properties, method of manufacture,

and quality control are comparable to the corresponding characteristics of listed components.

(2) Pressure design shall be verified in accordance with para. 304.

(b) Other unlisted components shall be qualified for pressure design as required by para. 304.7.2.

**302.2.4 Allowances for Pressure and Temperature Variations.** Occasional variations of pressure and/or temperature may occur in a piping system. Such variations shall be considered in selecting design pressure (para. 301.2) and design temperature (para. 301.3). The most severe coincident pressure and temperature shall determine the design conditions unless all of the following criteria are met.

(a) The piping system shall have no pressure containing components of cast iron or other nonductile metal.

(b) Nominal pressure stresses shall not exceed the yield strength at temperature (see para. 302.3 of this Code and  $S_y$  data in BPV Code, Section II, Part D, Table Y-1).

(c) Combined longitudinal stresses shall not exceed the limits established in para. 302.3.6.

(d) The total number of pressure-temperature variations above the design conditions shall not exceed 1000 during the life of the piping system.

(e) In no case shall the increased pressure exceed the test pressure used under para. 345 for the piping system.

(f) Occasional variations above design conditions shall remain within one of the following limits for pressure design.

(1) Subject to the owner's approval, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than:

(a) 33% for no more than 10 hr at any one time and no more than 100 hr/yr; or

(b) 20% for no more than 50 hr at any one time and no more than 500 hr/yr.

The effects of such variations shall be determined by the designer to be safe over the service life of the piping system by methods acceptable to the owner. (See Appendix V.)

(2) When the variation is self-limiting (e.g., due to a pressure relieving event), and lasts no more than 50 hr at any one time and not more than 500 hr/year, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than 20%.

(g) The combined effects of the sustained and cyclic

variations on the serviceability of all components in the system shall have been evaluated.

(h) Temperature variations below the minimum temperature shown in Appendix A are not permitted unless the requirements of para. 323.2.2 are met for the lowest temperature during the variation.

(i) The application of pressures exceeding pressure-temperature ratings of valves may under certain conditions cause loss of seat tightness or difficulty of operation. The differential pressure on the valve closure element should not exceed the maximum differential pressure rating established by the valve manufacturer. Such applications are the owner's responsibility.

### 302.2.5 Ratings at Junction of Different Services.

When two services that operate at different pressure-temperature conditions are connected, the valve segregating the two services shall be rated for the more severe service condition. If the valve will operate at a different temperature due to its remoteness from a header or piece of equipment, this valve (and any mating flanges) may be selected on the basis of the different temperature, provided it can withstand the required pressure tests on each side of the valve. For piping on either side of the valve, however, each system shall be designed for the conditions of the service to which it is connected.

## 302.3 Allowable Stresses and Other Stress Limits

**302.3.1 General.** The allowable stresses defined in paras. 302.3.1(a), (b), and (c) shall be used in design calculations unless modified by other provisions of this Code.

(a) *Tension.* Basic allowable stresses  $S$  in tension for metals and design stresses  $S$  for bolting materials, listed in Tables A-1 and A-2, respectively, are determined in accordance with para. 302.3.2.

In equations elsewhere in the Code where the product  $SE$  appears, the value  $S$  is multiplied by one of the following quality factors:<sup>1</sup>

(1) casting quality factor  $E_c$  as defined in para. 302.3.3 and tabulated for various material specifications in Table A-1A, and for various levels of supplementary examination in Table 302.3.3C; or

(2) longitudinal weld joint factor  $E_j$  as defined in 302.3.4 and tabulated for various material specifications

<sup>1</sup> If a component is made of castings joined by longitudinal welds, both a casting and a weld joint quality factor shall be applied. The equivalent quality factor  $E$  is the product of  $E_c$ , Table A-1A, and  $E_j$ , Table A-1B.

and classes in Table A-1B, and for various types of joints and supplementary examinations in Table 302.3.4.

The stress values in Tables A-1 and A-2 are grouped by materials and product forms, and are for stated temperatures up to the limit provided in para. 323.2.1(a). Straight line interpolation between temperatures is permissible. The temperature intended is the design temperature (see para. 301.3).

(b) *Shear and Bearing*. Allowable stresses in shear shall be 0.80 times the basic allowable stress in tension tabulated in Table A-1 or A-2. Allowable stress in bearing shall be 1.60 times that value.

(c) *Compression*. Allowable stresses in compression shall be no greater than the basic allowable stresses in tension as tabulated in Appendix A. Consideration shall be given to structural stability.

**302.3.2 Bases for Design Stresses.**<sup>2</sup> The bases for establishing design stress values for bolting materials and allowable stress values for other metallic materials in this Code are as follows.

(a) *Bolting Materials*. Design stress values at temperature for bolting materials shall not exceed the lowest of the following:

(1) except as provided in (3) below, the lower of one-fourth of specified minimum tensile strength at room temperature ( $S_T$ ) and one-fourth of tensile strength at temperature;

(2) except as provided in (3) below, the lower of two-thirds of specified minimum yield strength at room temperature ( $S_Y$ ) and two-thirds of yield strength at temperature;

(3) at temperatures below the creep range, for bolting materials whose strength has been enhanced by heat treatment or strain hardening, the lower of one-fifth of  $S_T$  and one-fourth of  $S_Y$  (unless these values are lower than corresponding values for annealed material, in which case the annealed values shall be used);

<sup>2</sup> These bases are the same as those for BPV Code, Section VIII, Division 2, given in Section II, Part D. Stress values in B31.3, Appendix A, at temperatures below the creep range generally are the same as those listed in Section II, Part D, Tables 2A and 2B, and in Table 3 for bolting, corresponding to those bases. They have been adjusted as necessary to exclude casting quality factors and longitudinal weld joint quality factors. Stress values at temperatures in the creep range generally are the same as those in Section II, Part D, Tables 1A and 1B, corresponding to the bases for section VIII, Division 1. Stress values for temperatures above those for which values are listed in the BPV Code, and for materials not listed in the BPV Code, are based on those listed in Appendix A of the 1966 Edition of ASA B31.3. Such values will be revised when reliable mechanical property data for elevated temperatures and/or for additional materials become available to the Committee.

(4) two-thirds of the “yield strength at temperature” [see para. 302.3.2(f)];

(5) 100% of the average stress for a creep rate of 0.01% per 1000 hr;

(6) 67% of the average stress for rupture at the end of 100,000 hr;

(7) 80% of minimum stress for rupture at the end of 100,000 hr.

(b) *Cast Iron*. Basic allowable stress values at temperature for cast iron shall not exceed the lower of the following:

(1) one-tenth of the specified minimum tensile strength at room temperature;

(2) one-tenth of the tensile strength at temperature [see para. 302.3.2(f)].

(c) *Malleable Iron*. Basic allowable stress values at temperature for malleable iron shall not exceed the lower of the following:

(1) one-fifth of the specified minimum tensile strength at room temperature;

(2) one-fifth of the tensile strength at temperature [see para. 302.3.2(f)].

(d) *Other Materials*. Basic allowable stress values at temperature for materials other than bolting materials, cast iron, and malleable iron shall not exceed the lowest of the following:

(1) the lower of one-third of  $S_T$  and one-third of tensile strength at temperature;

(2) except as provided in (3) below, the lower of two-thirds of  $S_Y$  and two-thirds of yield strength at temperature;

(3) for austenitic stainless steels and nickel alloys having similar stress-strain behavior, the lower of two-thirds of  $S_Y$  and 90% of yield strength at temperature [see (e) below];

(4) 100% of the average stress for a creep rate of 0.01% per 1000 hr;

(5) 67% of the average stress for rupture at the end of 100,000 hr;

(6) 80% of the minimum stress for rupture at the end of 100,000 hr;

(7) for structural grade materials, the basic allowable stress shall be 0.92 times the lowest value determined in paras. 302.3.2(d)(1) through (6).

(8) In the application of these criteria, the yield strength at room temperature is considered to be  $S_{YR}$ , and the tensile strength at room temperature is considered to be  $1.1S_{TR}$ .

(e) *Application Limits*. Application of stress values determined in accordance with para. 302.3.2(d)(3) is not recommended for flanged joints and other components in

which slight deformation can cause leakage or malfunction. [These values are shown in italics or boldface in Table A-1, as explained in Note (4) to Appendix A Tables.] Instead, either 75% of the stress value in Table A-1 or two-thirds of the yield strength at temperature listed in the BPV Code, Section II, Part D, Table Y-1 should be used.

- 02 (f) *Unlisted Materials*. For a material which conforms to para. 323.1.2, the tensile (yield) strength at temperature shall be derived by multiplying the average expected tensile (yield) strength at temperature by the ratio of  $S_T$  ( $S_Y$ ) divided by the average expected tensile (yield) strength at room temperature.

### 302.3.3 Casting Quality Factor $E_c$

(a) *General*. The casting quality factors  $E_c$  defined herein shall be used for cast components not having pressure-temperature ratings established by standards in Table 326.1.

(b) *Basic Quality Factors*. Castings of gray and malleable iron, conforming to listed specifications, are assigned a basic casting quality factor  $E_c$  of 1.00 (due to their conservative allowable stress basis). For most other metals, static castings which conform to the material specification and have been visually examined as required by MSS SP-55, Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components — Visual Method, are assigned a basic casting quality factor  $E_c$  of 0.80. Centrifugal castings which meet specification requirements only for chemical analysis, tensile, hydrostatic, and flattening tests, and visual examination are assigned a basic casting quality factor of 0.80. Basic casting quality factors are tabulated for listed specifications in Table A-1A.

(c) *Increased Quality Factors*. Casting quality factors may be increased when supplementary examinations are performed on each casting. Table 302.3.3C states the increased casting quality factors  $E_c$  which maybe used for various combinations of supplementary examination. Table 302.3.3D states the acceptance criteria for the examination methods specified in the Notes to Table 302.3.3C. Quality factors higher than those shown in Table 302.3.3C do not result from combining tests 2a and 2b, or 3a and 3b. In no case shall the quality factor exceed 1.00.

Several of the specifications in Appendix A require machining of all surfaces and/or one or more of these supplementary examinations. In such cases, the appropriate increased quality factor is shown in Table A-1A.

### 302.3.4 Weld Joint Quality Factor, $E_j$

(a) *Basic Quality Factors*. The weld joint quality

TABLE 302.3.3C<sup>4</sup>  
INCREASED CASTING QUALITY FACTORS,  $E_c$

| Supplementary Examination<br>in Accordance With Note(s) | Factor,<br>$E_c$ |
|---------------------------------------------------------|------------------|
| (1)                                                     | 0.85             |
| (2)(a) or (2)(b)                                        | 0.85             |
| (3)(a) or (3)(b)                                        | 0.95             |
| (1) and (2)(a) or (2)(b)                                | 0.90             |
| (1) and (3)(a) or (3)(b)                                | 1.00             |
| (2)(a) or (2)(b) and (3)(a) or (3)(b)                   | 1.00             |

#### NOTES:

- (1) Machine all surfaces to a finish of  $6.3 \mu\text{m } R_a$  (250  $\mu\text{in. } R_a$  per ASME B46.1), thus increasing the effectiveness of surface examination.
- (2) (a) Examine all surfaces of each casting (magnetic material only) by the magnetic particle method in accordance with ASTM E 709. Judge acceptability in accordance with MSS SP-53, using reference photos in ASTM E 125.  
(b) Examine all surfaces of each casting by the liquid penetrant method, in accordance with ASTM E 165. Judge acceptability of flaws and weld repairs in accordance with Table 1 of MSS SP-53, using ASTM E 125 as a reference for surface flaws.
- (3) (a) Fully examine each casting ultrasonically in accordance with ASTM E 114, accepting a casting only if there is no evidence of depth of defects in excess of 5% of wall thickness.  
(b) Fully radiograph each casting in accordance with ASTM E 142. Judge in accordance with the stated acceptance levels in Table 302.3.3D.
- (4) Titles of standards referenced in this Table are as follows:
 

|      |                                                                                                                                             |
|------|---------------------------------------------------------------------------------------------------------------------------------------------|
| ASTM | E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Testing by the Contact Method                                                        |
|      | E 125 Reference Photographs for Magnetic Particle Indications on Ferrous Castings                                                           |
|      | E 142 Method for Controlling Quality of Radiographic Testing                                                                                |
|      | E 165 Practice for Liquid Penetrant Inspection Method                                                                                       |
|      | E 709 Practice for Magnetic Particle Examination                                                                                            |
| ASME | B46.1 Surface Texture (Surface Roughness, Waviness and Lay)                                                                                 |
| MSS  | SP-53 Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components—Magnetic Particle Examination Method |

factors  $E_j$  tabulated in Table A-1B are basic factors for straight or spiral longitudinal welded joints for pressure-containing components as shown in Table 302.3.4.

(b) *Increased Quality Factors*. Table 302.3.4 also indicates higher joint quality factors which may be substituted for those in Table A-1B for certain kinds of welds if additional examination is performed beyond that required by the product specification.

### 302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains

(a) *Internal Pressure Stresses*. Stresses due to internal pressure shall be considered safe when the wallthick-

TABLE 302.3.3D<sup>1</sup>  
ACCEPTANCE LEVELS FOR CASTINGS

| Material Examined Thickness, $T$                    | Applicable Standard | Acceptance Level (or Class) | Acceptable Discontinuities     |
|-----------------------------------------------------|---------------------|-----------------------------|--------------------------------|
| Steel<br>$T \leq 25$ mm<br>(1 in.)                  | ASTM E 446          | 1                           | Types A, B, C                  |
| Steel<br>$T > 25$ mm,<br>$\leq 51$ mm<br>(2 in.)    | ASTM E 446          | 2                           | Types A, B, C                  |
| Steel<br>$T > 51$ mm,<br>$\leq 114$ mm<br>(4½ in.)  | ASTM E 186          | 2                           | Categories A, B, C             |
| Steel<br>$T > 114$ mm,<br>$\leq 305$ mm<br>(12 in.) | ASTM E 280          | 2                           | Categories A, B, C             |
| Aluminum & magnesium                                | ASTM E 155          | ...                         | Shown in reference radiographs |
| Copper, Ni-Cu                                       | ASTM E 272          | 2                           | Codes A, Ba, Bb                |
| Bronze                                              | ASTM E 310          | 2                           | Codes A and B                  |

## NOTE:

(1) Titles of standards referenced in this Table are as follows:

## ASTM

|       |                                                                                       |
|-------|---------------------------------------------------------------------------------------|
| E 155 | Reference Radiographs for Inspection of Aluminum and Magnesium Castings               |
| E 186 | Reference Radiographs for Heavy-Walled [2 to 4-½-in. (51 to 114-mm)] Steel Castings   |
| E 272 | Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Castings        |
| E 280 | Reference Radiographs for Heavy-Walled [4-½ to 12-in. (114 to 305-mm)] Steel Castings |
| E 310 | Reference Radiographs for Tin Bronze Castings                                         |
| E 446 | Reference Radiographs for Steel Castings Up to 2 in. (51 mm) in Thickness             |

ness of the piping component, including any reinforcement, meets the requirements of para. 304.

(b) *External Pressure Stresses.* Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. 304.

(c) *Longitudinal Stresses  $S_L$ .* The sum of longitudinal stresses in any component in a piping system, due to pressure, weight, and other sustained loadings  $S_L$  shall not exceed  $S_h$  in (d) below. The thickness of pipe used in calculating  $S_L$  shall be the nominal thickness  $T$  minus mechanical, corrosion, and erosion allowance  $c$ , for the location under consideration. The loads due to

weight should be based on the nominal thickness of all system components unless otherwise justified in a more rigorous analysis.

(d) *Allowable Displacement Stress Range  $S_A$ .* The computed displacement stress range  $S_E$  in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range  $S_A$  (see paras. 319.2.3 and 319.3.4) calculated by Eq. (1a):

$$S_A = f(1.25S_c + 0.25S_h) \quad (1a)$$

When  $S_h$  is greater than  $S_L$ , the difference between them may be added to the term  $0.25S_h$  in Eq. (1a). In that case, the allowable stress range is calculated by Eq. (1b):

$$S_A = f[1.25(S_c + S_h) - S_L] \quad (1b)$$

In Eqs. (1a) and (1b):

$S_c$  = basic allowable stress<sup>3</sup> at minimum metal temperature expected during the displacement cycle under analysis

$S_h$  = basic allowable stress<sup>3</sup> at maximum metal temperature expected during the displacement cycle under analysis

$f$  = stress range reduction factor,<sup>4</sup> from Table 302.3.5 or calculated by Eq. (1c):<sup>5</sup>

$$f = 6.0(N)^{-0.2} \leq 1.0 \quad (1c)$$

where

$N$  = equivalent number of full displacement cycles during the expected service life of the piping system<sup>6</sup>

When the computed stress range varies, whether from thermal expansion or other conditions,  $S_E$  is defined as the greatest computed displacement stress range. The value of  $N$  in such cases can be calculated by Eq. (1d):

<sup>3</sup> For castings, the basic allowable stress shall be multiplied by the applicable casting quality factor  $E_c$ . For longitudinal welds, the basic allowable stress need not be multiplied by the weld quality factor  $E_j$ .

<sup>4</sup> Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion resistant materials should be considered where a large number of major stress cycles is anticipated.

<sup>5</sup> Equation (1c) does not apply beyond approximately  $2 \times 10^6$  cycles. Selection of  $f$  factors beyond  $2 \times 10^6$  cycles is the designer's responsibility.

<sup>6</sup> The designer is cautioned that the fatigue life of materials operated at elevated temperature may be reduced.

**TABLE 302.3.4**  
**LONGITUDINAL WELD JOINT QUALITY FACTOR,  $E_j$**

| No. | Type of Joint                      |                                                                                     | Type of Seam                                             | Examination                                                        | Factor, $E_j$      |
|-----|------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------------------|--------------------|
| 1   | Furnace butt weld, continuous weld |    | Straight                                                 | As required by listed specification                                | 0.60<br>[Note (1)] |
| 2   | Electric resistance weld           |    | Straight or spiral                                       | As required by listed specification                                | 0.85<br>[Note (1)] |
| 3   | Electric fusion weld               |                                                                                     |                                                          |                                                                    |                    |
|     | (a) Single butt weld               |    | Straight or spiral                                       | As required by listed specification or this Code                   | 0.80               |
|     | (with or without filler metal)     |                                                                                     |                                                          | Additionally spot radiographed per para. 341.5.1                   | 0.90               |
|     |                                    |                                                                                     |                                                          | Additionally 100% radiographed per para. 344.5.1 and Table 341.3.2 | 1.00               |
|     | (b) Double butt weld               |  | Straight or spiral<br>[except as provided in 4(a) below] | As required by listed specification or this Code                   | 0.85               |
|     | (with or without filler metal)     |                                                                                     |                                                          | Additionally spot radiographed per para. 341.5.1                   | 0.90               |
|     |                                    |                                                                                     |                                                          | Additionally 100% radiographed per para. 344.5.1 and Table 341.3.2 | 1.00               |
| 4   | Per specific specification         |                                                                                     |                                                          |                                                                    |                    |
|     | (a) API 5L                         | Submerged arc weld (SAW)<br>Gas metal arc weld (GMAW)<br>Combined GMAW, SAW         | Straight with one or two seams<br>Spiral                 | As required by specification                                       | 0.95               |
|     |                                    |  |                                                          |                                                                    |                    |

**NOTE:**

(1) It is not permitted to increase the joint quality factor by additional examination for joint 1 or 2.

TABLE 302.3.5  
STRESS-RANGE REDUCTION FACTORS,  $f$

| Cycles, $N$               | Factor, $f$ |
|---------------------------|-------------|
| 7,000 and less            | 1.0         |
| Over 7,000 to 14,000      | 0.9         |
| Over 14,000 to 22,000     | 0.8         |
| Over 22,000 to 45,000     | 0.7         |
| Over 45,000 to 100,000    | 0.6         |
| Over 100,000 to 200,000   | 0.5         |
| Over 200,000 to 700,000   | 0.4         |
| Over 700,000 to 2,000,000 | 0.3         |

$$N = N_E + \sum (r_i^5 N_i) \text{ for } i = 1, 2, \dots, n \quad (1d)$$

where

$N_E$  = number of cycles of maximum computed displacement stress range,  $S_E$

$$r_i = S_i / S_E$$

$S_i$  = any computed displacement stress range smaller than  $S_E$

$N_i$  = number of cycles associated with displacement stress range  $S_i$

### 302.3.6 Limits of Calculated Stresses due to Occasional Loads

(a) *Operation.* The sum of the longitudinal stresses due to pressure, weight, and other sustained loadings  $S_L$  and of the stresses produced by occasional loads, such as wind or earthquake, may be as much as 1.33 times the basic allowable stress given in Appendix A. For castings, the basic allowable stress shall be multiplied by the casting quality factor  $E_c$ . Where the allowable stress value exceeds two-thirds of yield strength at temperature, the allowable stress value must be reduced as specified in para. 302.3.2(e). Wind and earthquake forces need not be considered as acting concurrently.

(b) *Test.* Stresses due to test conditions are not subject to the limitations in para. 302.3. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

### 302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread depth or groove depth. See definition for  $c$  in para. 304.1.1(b).

**302.4.1 Mechanical Strength.** When necessary, the wall thickness shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads

from supports, ice formation, backfill, transportation, handling, or other causes. Where increasing the thickness would excessively increase local stresses or the risk of brittle fracture, or is otherwise impracticable, the required strength may be obtained through additional supports, braces, or other means without an increased wall thickness. Particular consideration should be given to the mechanical strength of small pipe connections to piping or equipment.

## PART 2 PRESSURE DESIGN OF PIPING COMPONENTS

### 303 GENERAL

Components manufactured in accordance with standards listed in Table 326.1 shall be considered suitable for use at pressure-temperature ratings in accordance with para. 302.2.1. The rules in para. 304 are intended for pressure design of components not covered in Table 326.1, but may be used for a special or more rigorous design of such components. Designs shall be checked for adequacy of mechanical strength under applicable loadings enumerated in para. 301.

### 304 PRESSURE DESIGN OF COMPONENTS

#### 304.1 Straight Pipe

##### 304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined in accordance with Eq. (2):

$$t_m = t + c \quad (2)$$

The minimum thickness  $T$  for the pipe selected, considering manufacturer's minus tolerance, shall be not less than  $t_m$ .

(b) The following nomenclature is used in the equations for pressure design of straight pipe.

$t_m$  = minimum required thickness, including mechanical, corrosion, and erosion allowances

$t$  = pressure design thickness, as calculated in accordance with para. 304.1.2 for internal pressure or as determined in accordance with para. 304.1.3 for external pressure

$c$  = the sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the

**TABLE 304.1.1**  
**VALUES OF COEFFICIENT  $Y$**   
**FOR  $t < D/6$**

| Materials            | Temperature, °C (°F)   |              |               |               |               |                      |
|----------------------|------------------------|--------------|---------------|---------------|---------------|----------------------|
|                      | ≤ 482<br>(900 & Lower) | 510<br>(950) | 538<br>(1000) | 566<br>(1050) | 593<br>(1100) | ≥ 621<br>(1150 & Up) |
| Ferritic steels      | 0.4                    | 0.5          | 0.7           | 0.7           | 0.7           | 0.7                  |
| Austenitic steels    | 0.4                    | 0.4          | 0.4           | 0.4           | 0.5           | 0.7                  |
| Other ductile metals | 0.4                    | 0.4          | 0.4           | 0.4           | 0.4           | 0.4                  |
| Cast iron            | 0.0                    | ...          | ...           | ...           | ...           | ...                  |

nominal thread depth (dimension  $h$  of ASME B1.20.1, or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

$T$  = pipe wall thickness (measured or minimum per purchase specification)

$d$  = inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specification.

$P$  = internal design gage pressure

$D$  = outside diameter of pipe as listed in tables of standards or specifications or as measured

$E$  = quality factor from Table A-1A or A-1B

$S$  = stress value for material from Table A-1

$Y$  = coefficient from Table 304.1.1, valid for  $t < D/6$  and for materials shown. The value of  $Y$  may be interpolated for intermediate temperatures.

For  $t \geq D/6$ ,

$$Y = \frac{d + 2c}{D + d + 2c}$$

### 304.1.2 Straight Pipe Under Internal Pressure

(a) For  $t < D/6$ , the internal pressure design thickness for straight pipe shall be not less than that calculated in accordance with either Eq. (3a) or Eq. (3b):

$$t = \frac{PD}{2(SE + PY)} \quad (3a)$$

$$t = \frac{P(d + 2c)}{2[SE - P(1 - Y)]} \quad (3b)$$

(b) For  $t \geq D/6$  or for  $P/SE > 0.385$ , calculation of pressure design thickness for straight pipe requires special consideration of factors such as theory of failure, effects of fatigue, and thermal stress.

### 304.1.3 Straight Pipe Under External Pressure.

To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in the BPV Code, Section VIII, Division 1, UG-28 through UG-30 shall be followed, using as the design length  $L$  the running center line length between any two sections stiffened in accordance with UG-29. As an exception, for pipe with  $D_o/t < 10$ , the value of  $S$  to be used in determining  $P_{a2}$  shall be the lesser of the following values for pipe material at design temperature:

(a) 1.5 times the stress value from Table A-1 of this Code; or

(b) 0.9 times the yield strength tabulated in Section II, Part D, Table Y-1 for materials listed therein.

(The symbol  $D_o$  in Section VIII is equivalent to  $D$  in this Code.)

## 304.2 Curved and Mitered Segments of Pipe

**304.2.1 Pipe Bends.** The minimum required thickness  $t_m$  of a bend, after bending, in its finished form, shall be determined in accordance with Eq. (2) and Eq. (3c):

$$t = \frac{PD}{2[(SE/I) + PY]} \quad (3c)$$

where at the intrados (inside bend radius)

$$I = \frac{4(R_1/D) - 1}{4(R_1/D) - 2} \quad (3d)$$

and at the extrados (outside bend radius)

$$I = \frac{4(R_1/D) + 1}{4(R_1/D) + 2} \quad (3e)$$

and at the sidewall on the bend centerline radius,  $I = 1.0$ .

$R_1$  = bend radius of welding elbow or pipe bend

Thickness variations from the intrados to the extrados and along the length of the bend shall be gradual. The

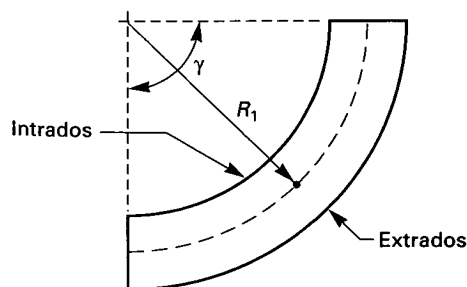


FIG. 304.2.1 NOMENCLATURE FOR PIPE BENDS

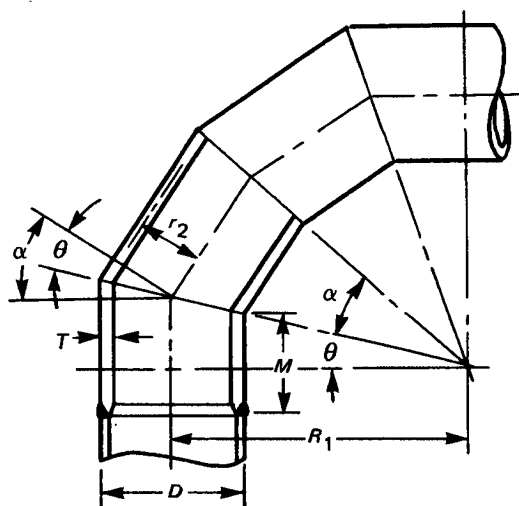


FIG. 304.2.3 NOMENCLATURE FOR MITER BENDS

thickness requirements apply at the mid-span of the bend,  $\gamma/2$ , at the intrados, extrados, and bend centerline radius. The minimum thickness at the end tangents shall not be less than the requirements of para. 304.1 for straight pipe (see Fig. 304.2.1).

**304.2.2 Elbows.** Manufactured elbows not in accordance with para. 303 shall be qualified as required by para. 304.7.2 or designed in accordance with para. 304.2.1.

**304.2.3 Miter Bends.** An angular offset of 3 deg or less (angle  $\alpha$  in Fig. 304.2.3) does not require design consideration as a miter bend. Acceptable methods for pressure design of multiple and single miter bends are given in (a) and (b) below.

(a) *Multiple Miter Bends.* The maximum allowable internal pressure shall be the lesser value calculated from Eqs. (4a) and (4b). These equations are not applicable when  $\theta$  exceeds 22.5 deg.

$$P_m = \frac{SE(T-c)}{r_2} \left( \frac{T-c}{(T-c) + 0.643 \tan \theta \sqrt{r_2(T-c)}} \right) \quad (4a)$$

$$P_m = \frac{SE(T-c)}{r_2} \left( \frac{R_1 - r_2}{R_1 - 0.5r_2} \right) \quad (4b)$$

(b) *Single Miter Bends*

(1) The maximum allowable internal pressure for a single miter bend with angle  $\theta$  not greater than 22.5 deg shall be calculated by Eq. (4a).

(2) The maximum allowable internal pressure for a single miter bend with angle  $\theta$  greater than 22.5 deg shall be calculated by Eq. (4c):

$$P_m = \frac{SE(T-c)}{r_2} \left( \frac{T-c}{(T-c) + 1.25 \tan \theta \sqrt{r_2(T-c)}} \right) \quad (4c)$$

(c) The miter pipe wall thickness  $T$  used in Eqs. (4a), (4b), and (4c) shall extend a distance not less than  $M$  from the inside crotch of the end miter welds where

$$M = \text{the larger of } 2.5(r_2T)^{0.5} \text{ or } \tan \theta (R_1 - r_2)$$

The length of taper at the end of the miter pipe may be included in the distance  $M$ .

(d) The following nomenclature is used in Eqs. (4a), (4b), and (4c) for the pressure design of miter bends:

$c$  = same as defined in para. 304.1.1

$E$  = same as defined in para. 304.1.1

$P_m$  = maximum allowable internal pressure for miter bends

$r_2$  = mean radius of pipe using nominal wall  $\bar{T}$

$R_1$  = effective radius of miter bend, defined as the shortest distance from the pipe center line to the intersection of the planes of adjacent miter joints

$S$  = same as defined in para. 304.1.1

$T$  = miter pipe wall thickness (measured or minimum per purchase specification)

$\theta$  = angle of miter cut

$\alpha$  = angle of change in direction at miter joint  
=  $2\theta$

For compliance with this Code, the value of  $R_1$  shall be not less than that given by Eq. (5):

$$R_1 = \frac{A}{\tan \theta} + \frac{D}{2} \quad (5)$$

where  $A$  has the following empirical values:

(1) for SI metric units:

| $(T - c)$ , mm      | $A$                 |
|---------------------|---------------------|
| $\leq 13$           | 25                  |
| $13 < (T - c) < 22$ | $2(T - c)$          |
| $\geq 22$           | $[2(T - c)/3] + 30$ |

02 (2) for U.S. customary units:

| $(T - c)$ , in.        | $A$                   |
|------------------------|-----------------------|
| $\leq 0.5$             | 1.0                   |
| $0.5 < (T - c) < 0.88$ | $2(T - c)$            |
| $\geq 0.88$            | $[2(T - c)/3] + 1.17$ |

**304.2.4 Curved and Mitered Segments of Pipe Under External Pressure.** The wall thickness of curved and mitered segments of pipe subjected to external pressure may be determined as specified for straight pipe in para. 304.1.3.

### 304.3 Branch Connections

#### 304.3.1 General

(a) Except as provided in (b) below, the requirements in paras. 304.3.2 through 304.3.4 are applicable to branch connections made in accordance with the following methods:

(1) fittings (tees, extruded outlets, branch outlet fittings per MSS SP-97, laterals, crosses);

(2) unlisted cast or forged branch connection fittings (see para. 300.2), and couplings not over DN 80 (NPS 3), attached to the run pipe by welding;

(3) welding the branch pipe directly to the run pipe, with or without added reinforcement, as covered in para. 328.5.4.

(b) The rules in paras. 304.3.2 through 304.3.4 are minimum requirements, valid only for branch connections in which (using the nomenclature of Fig. 304.3.3):

(1) the run pipe diameter-to-thickness ratio ( $D_h/T_h$ ) is less than 100 and the branch-to-run diameter ratio ( $D_b/D_h$ ) is not greater than 1.0;

(2) for run pipe with ( $D_h/T_h$ )  $\geq 100$ , the branch diameter  $D_b$  is less than one-half the run diameter  $D_h$ ;

(3) angle  $\beta$  is at least 45 deg;

(4) the axis of the branch intersects the axis of the run.

(c) Where the provisions of (a) and (b) above are

not met, pressure design shall be qualified as required by para. 304.7.2.

(d) Other design considerations relating to branch connections are stated in para. 304.3.5.

**304.3.2 Strength of Branch Connections.** A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement required to sustain the pressure shall be determined in accordance with para. 304.3.3 or 304.3.4. There are, however, certain branch connections which have adequate pressure strength or reinforcement as constructed. It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure which will be applied to it if:

(a) the branch connection utilizes a listed fitting in accordance with para. 303;

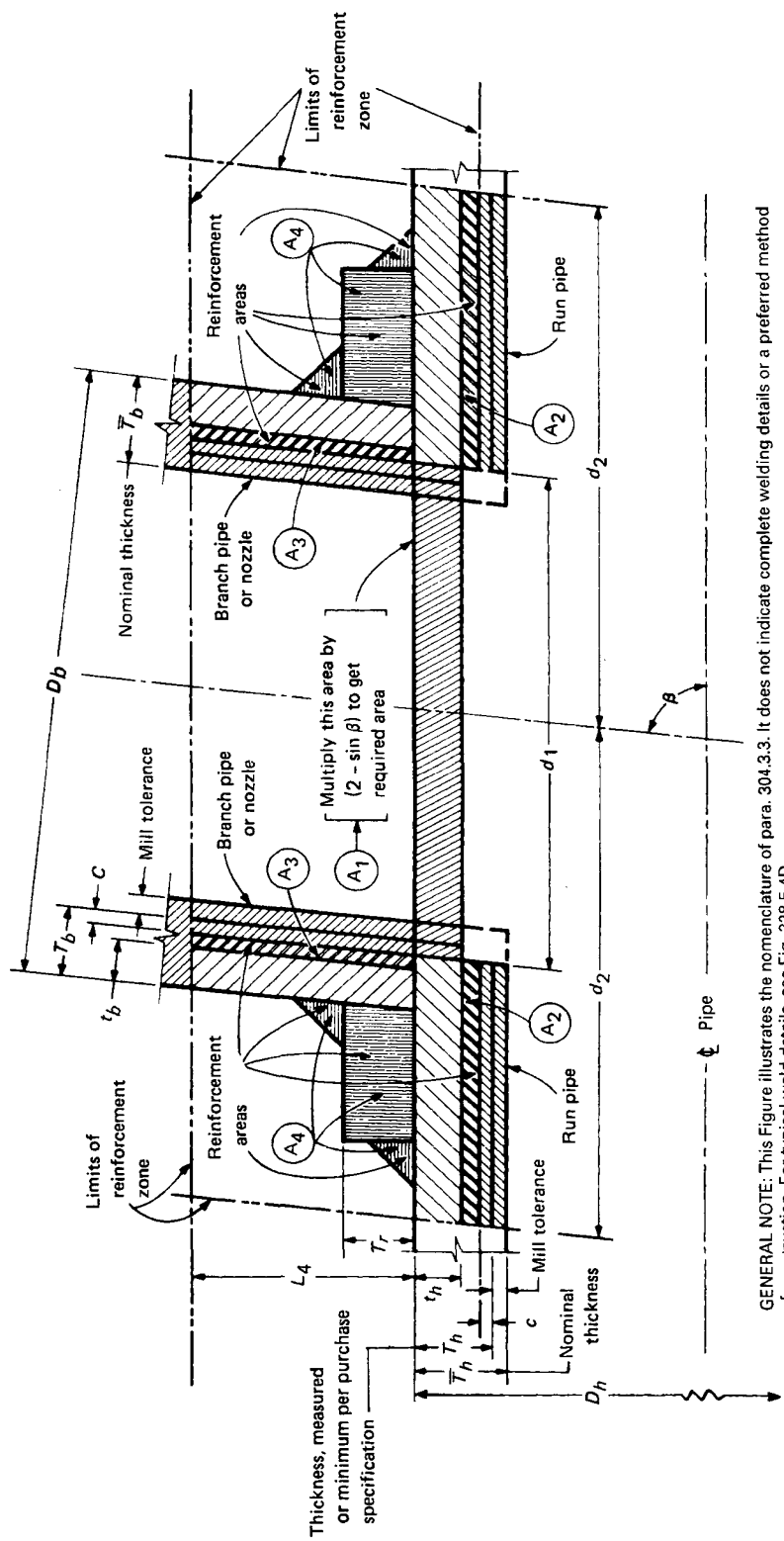
(b) the branch connection is made by welding a threaded or socket welding coupling or half coupling directly to the run in accordance with para. 328.5.4, provided the size of the branch does not exceed DN 50 (NPS 2) nor one-fourth the nominal size of the run. The minimum wall thickness of the coupling anywhere in the reinforcement zone (if threads are in the zone, wall thickness is measured from root of thread to minimum outside diameter) shall be not less than that of the unthreaded branch pipe. In no case shall a coupling or half coupling have a rating less than Class 2000 per ASME B16.11.

(c) the branch connection utilizes an unlisted branch connection fitting (see para. 300.2), provided the fitting is made from materials listed in Table A-1 and provided that the branch connection is qualified as required by para. 304.7.2.

**304.3.3 Reinforcement of Welded Branch Connections.** Added reinforcement is required to meet the criteria in paras. 304.3.3(b) and (c) when it is not inherent in the components of the branch connection. Sample problems illustrating the calculations for branch reinforcement are shown in Appendix H.

(a) *Nomenclature.* The nomenclature below is used in the pressure design of branch connections. It is illustrated in Fig. 304.3.3, which does not indicate details for construction or welding. Some of the terms defined in Appendix J are subject to further definitions or variations, as follows:

$b$  = subscript referring to branch



GENERAL NOTE: This Figure illustrates the nomenclature of para. 304.3.3. It does not indicate complete welding details or a preferred method of construction. For typical weld details, see Fig. 328.5.4D.

FIG. 304.3.3 BRANCH CONNECTION NOMENCLATURE

- $d_1$  = effective length removed from pipe at branch. For branch intersections where the branch opening is a projection of the branch pipe inside diameter (e.g., pipe-to-pipe fabricated branch),  $d_1 = [D_b - 2(T_b - c)]/\sin \beta$
- $d_2$  = "half width" of reinforcement zone  
 =  $d_1$  or  $(T_b - c) + (T_h - c) + d_1/2$ , whichever is greater, but in any case not more than  $D_h$
- $h$  = subscript referring to run or header
- $L_4$  = height of reinforcement zone outside of run pipe  
 =  $2.5(T_h - c)$  or  $2.5(T_b - c) + T_r$ , whichever is less
- $T_b$  = branch pipe thickness (measured or minimum per purchase specification) except for branch connection fittings (see para. 300.2). For such connections the value of  $T_b$  for use in calculating  $L_4$ ,  $d_2$ , and  $A_3$ , is the thickness of the reinforcing barrel (minimum per purchase specification) provided that the barrel thickness is uniform (see Fig. K328.5.4) and extends at least to the  $L_4$  limit (see Fig. 304.3.3).
- $T_r$  = minimum thickness of reinforcing ring or saddle made from pipe. (Use nominal thickness if made from plate.)  
 = 0, if there is no reinforcing ring or saddle
- $t$  = pressure design thickness of pipe, according to the appropriate wall thickness equation or procedure in para. 304.1. For welded pipe, when the branch does not intersect the longitudinal weld of the run, the basic allowable stress  $S$  for the pipe may be used in determining  $t_h$  for the purpose of reinforcement calculation only. When the branch does intersect the longitudinal weld of the run, the product  $SE$  (of the stress value  $S$  and the appropriate weld joint quality factor  $E_j$  from Table A-1B) for the run pipe shall be used in the calculation. The product  $SE$  of the branch shall be used in calculating  $t_b$ .

$\beta$  = smaller angle between axes of branch and run

(b) *Required Reinforcement Area.* The reinforcement area  $A_1$  required for a branch connection under internal pressure is

$$A_1 = t_h d_1 (2 - \sin \beta) \quad (6)$$

For a branch connection under external pressure, area  $A_1$  is one-half the area calculated by Eq. (6), using as  $t_h$  the thickness required for external pressure.

(c) *Available Area.* The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \quad (6a)$$

These areas are all within the reinforcement zone and are further defined below.

(1) Area  $A_2$  is the area resulting from excess thickness in the run pipe wall:

$$A_2 = (2d_2 - d_1)(T_h - t_h - c) \quad (7)$$

(2) Area  $A_3$  is the area resulting from excess thickness in the branch pipe wall:

$$A_3 = 2L_4(T_b - t_b - c)/\sin \beta \quad (8)$$

If the allowable stress for the branch pipe wall is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values of the branch to the run in determining its contributions to area  $A_3$ .

(3) Area  $A_4$  is the area of other metal provided by welds and properly attached reinforcement. [See para. 304.3.3(f).] Weld areas shall be based on the minimum dimensions specified in para. 328.5.4, except that larger dimensions may be used if the welder has been specifically instructed to make the welds to those dimensions.

(d) *Reinforcement Zone.* The reinforcement zone is a parallelogram whose length extends a distance of  $d_2$  on each side of the center line of the branch pipe and whose width starts at the inside surface of the run pipe (in its corroded condition) and extends beyond the outside surface of the run pipe a perpendicular distance  $L_4$ .

(e) *Multiple Branches.* When two or more branch connections are so closely spaced that their reinforcement zones overlap, the distance between centers of the openings should be at least  $1\frac{1}{2}$  times their average diameter, and the area of reinforcement between any two openings shall be not less than 50% of the total that both require. Each opening shall have adequate reinforcement in accordance with paras. 304.3.3(b) and (c). No part of the metal cross section may apply to more than one opening or be evaluated more than once in any combined area. (Consult PFI Standard ES-7 for detailed recommendations on spacing of welded nozzles.)

(f) *Added Reinforcement*

(1) Reinforcement added in the form of a ring or