PROPOSED REVISION OF:

[redacted] B31.1-~~2016~~ 20XX

(Revision of [redacted] B31.1-~~2014~~ 2016)

Power Piping

Code for Pressure Piping, B31

TENTATIVE
SUBJECT TO REVISION OR WITHDRAWAL
Specific Authorization Required for Reproduction or Quotation
ASME Codes and Standards

The Code sets specifies engineering requirements deemed necessary for safe design, construction, operation and maintenance of pressure piping. While safety is the overriding consideration, this factor alone will not necessarily govern the final specifications for any piping installation or operation. The Code is not a design handbook. Many decisions that must be made to produce a safe piping installation and to maintain system integrity are not specified in detail within this Code. The Code does not serve as a substitute for sound engineering judgment by the owner and the designer.

(16)

INTRODUCTION

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 have been developed considering the need for application of specific requirements for various types of pressure piping. Applications considered for each Code Section include

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 Liquids and Slurries: piping transporting products that are predominately liquid between plants and terminals and within terminals, pumping, regulating, and metering stations

B31.5 Refrigeration Piping and Heat Transfer Components: piping for refrigerants and secondary coolants

B31.8 Gas Transmission and Distribution Piping Systems: piping transporting products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations; and 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

B31.12 Hydrogen Piping and Pipelines: piping in gaseous and liquid hydrogen service, and pipelines in gaseous hydrogen service

This is the B31.1 Power Piping Code Section. Hereafter, in this Introduction and in the text of this Code Section B31.1, 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 that 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 selected Code Section, 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

– ASME Boiler and Pressure Vessel Code, Section III: nuclear power piping

– ANSI Z223.1/NFPA 54 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 85 Boiler and Combustion Systems Hazards Code

– 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 system. The designer is cautioned that the Code is not a design handbook; it does not eliminate 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 ensure 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.

~~The specific design requirements of the Code usually revolve around a simplified engineering approach to a subject. It is intended that a designer capable of applying more complete and rigorous analysis to special or unusual problems shall have latitude in the development of such designs and the evaluation of complex or combined stresses. In such cases the designer is responsible for demonstrating the validity of his approach~~.

This Code Section includes the following:

(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 pipe 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

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

(*g*) requirements for operation and maintenance of piping systems

It is intended that this edition of Code Section B31.1 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 system or systems 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 revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the piping is to be installed.

Code users will note that clauses in the Code are not necessarily numbered consecutively. Such discontinuities result from following a common outline, insofar as practicable, 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.

The Code is under the direction of ASME Committee B31, Code for Pressure Piping, which 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 to five years.

When no Section of the ASME Code for Pressure Piping, specifically covers a piping system, at the user's discretion, he/she may select any Section determined to be generally applicable. However, it is cautioned that supplementary requirements to the Section chosen may be necessary to provide for a safe piping system for the intended application. Technical limitations of the various Sections, legal requirements, and possible applicability of other codes or standards are some of the factors to be considered by the user in determining the applicability of any Section of this Code.

The Committee has established an orderly procedure to consider requests for interpretation and revision of Code requirements. To receive consideration, inquiries must be in writing and must give full particulars (see Mandatory Appendix H covering preparation of technical inquiries). The Committee will not respond to inquiries requesting assignment of a Code Section to a piping installation.

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 issued to the applicable Code Section.

A Case is the prescribed form of reply to an inquiry 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. The Case will be published as part of a Case Supplement issued to the applicable Code Section.

The ASME B31 Standards Committee took action to eliminate Code Case expiration dates effective September 21, 2007. This means that all Code Cases in effect as of this date will remain available for use until annulled by the ASME B31 Standards Committee.

Materials are listed in the Stress Tables only when sufficient usage in piping within the scope of the Code has been shown. Materials may be covered by a Case. 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. (To develop usage and gain experience, unlisted materials may be used in accordance with para. 123.1.)

Requests for interpretation and suggestions for revision should be addressed to the Secretary, ASME B31 Committee, Two Park Avenue, New York, NY 10016-5990.

The Code generally specifies a simplified approach for many of its requirements.

(a) For design and construction, a designer may choose to use a more rigorous analysis to develop design and construction requirements. When the designer decides to take this approach, the designer shall provide to the owner details and calculations demonstrating that design, construction, examination, and testing are consistent with the criteria of this Code. These details shall be adequate for the owner to verify the validity of the approach and shall be approved by the owner. The details shall be documented in the engineering design.

(b) For operation and maintenance, an owner may choose to use a more rigorous approach to develop operation and maintenance requirements. When the owner decides to take this approach, the owner shall provide details and calculations demonstrating that such alternative practices are consistent with the general philosophy of this Code. The details shall be documented in the operating records and retained for the lifetime of the facility.

Where service requirements necessitate measures beyond those required by this Code, such measures shall be specified by the engineering design.

POWER PIPING

Chapter I
Scope and Definitions

100 GENERAL

This Power Piping Code is one of several Sections of the American Society of Mechanical Engineers Code for Pressure Piping, B31. This Section is published as a separate document for convenience.

Standards and specifications specifically incorporated by reference into this Code are shown in Table 126.1. It is not considered practical to refer to a dated edition of each of the standards and specifications in this Code. Instead, the dated edition references are included in an Addenda and will be revised yearly.

100.1 Scope

Rules for this Code Section have been developed considering the needs for applications that include piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems.

100.1.1 This Code prescribes requirements for the design, materials, fabrication, erection, test, inspection, operation, and maintenance of piping systems.

Piping as used in this Code includes pipe, flanges, bolting, gaskets, valves, pressure-relieving valves/devices, fittings, and the pressure-containing portions of other piping components, whether manufactured in accordance with Standards listed in Table 126.1 or specially designed. It also includes hangers and supports and other equipment items necessary to prevent overstressing the pressure-containing components.

Rules governing piping for miscellaneous appurtenances, such as water columns, remote water level indicators, pressure gages, gage glasses, etc., are included within the scope of this Code, but the requirements for boiler appurtenances shall be in accordance with Section I of the ASME Boiler and Pressure Vessel Code, PG-60.

The users of this Code are advised that in some areas legislation may establish governmental jurisdiction over the subject matter covered by this Code. However, any such legal requirement shall not relieve the owner of his inspection responsibilities specified in para. 136.1.

100.1.2 Power piping systems as covered by this Code apply to all piping and their component parts except as excluded in para. 100.1.3. They include but are not limited to steam, water, oil, gas, and air services. **(16)**

(A) This Code covers boiler external piping as defined below for power boilers and high-temperature, high-pressure water boilers in which steam or vapor is generated at a pressure of more than 15 psig [100 kPa (gage)]; and high temperature water is generated at pressures exceeding 160 psig [1 103 kPa (gage)] and/or temperatures exceeding 250°F (120°C).

Boiler external piping shall be considered as piping that begins where the boiler proper terminates at

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

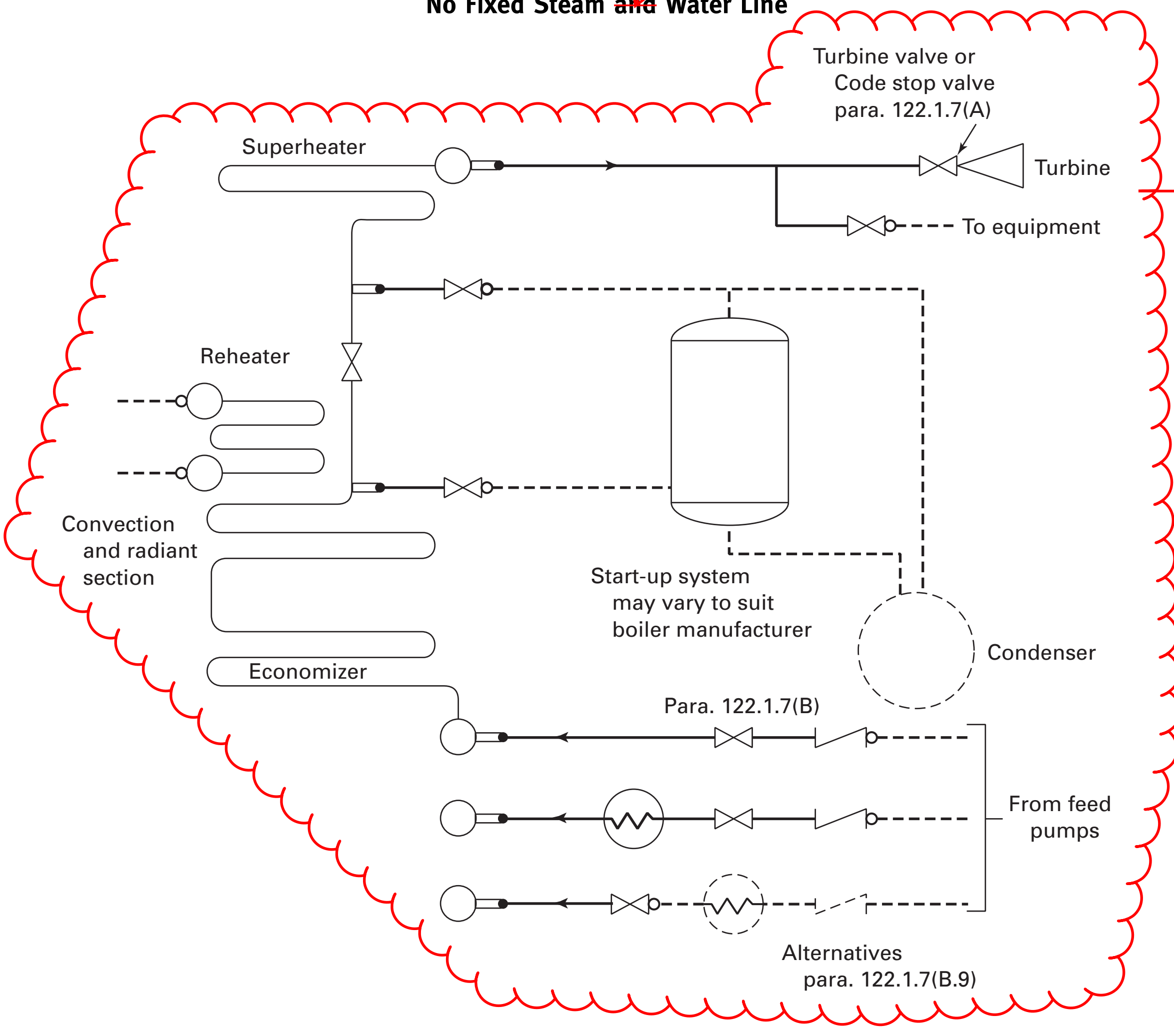
(2) the face of the first flange in bolted flanged connections; or

(3) the first threaded joint in that type of connection; and that extends up to and including the valve or valves required by para. 122.1.

The terminal points themselves are considered part of the boiler external piping. The terminal points and piping external to power boilers are illustrated by Figs. 100.1.2(A.1), 100.1.2(A.2), 100.1.2(B.1), 100.1.2(B.2), 100.1.2(B.3), and 100.1.2~~(C).~~ (C.1), and 100.1.2(C.2).

Piping between the terminal points and the valve or valves required by para. 122.1 shall be provided with Data Reports, inspection, and stamping as required by Section I of the ASME Boiler and Pressure Vessel Code. All welding and brazing of this piping shall be performed by manufacturers or contractors authorized to use the ASME Certification Mark and appropriate Designators shown in ~~Figs. PG-105.1 through PG-109 of Section I of the ASME Boiler and Pressure Vessel Code~~. ASME CA-1, Conformity Assessment Requirements The installation of boiler external piping by mechanical means may be performed by an organization not holding an ASME Certification Mark. However, the holder of a valid ASME Certification Mark, Certificate of Authorization, with an “S,” “A,” or “PP” Designator shall be responsible for the documentation and hydrostatic test, regardless of the method of assembly. The quality control system requirements of Section I of the or

Fig. 100.1.2(A.1) Code Jurisdictional Limits for Piping — An Example of Forced Flow Steam Generators With No Fixed Steam ~~and~~ Water Line



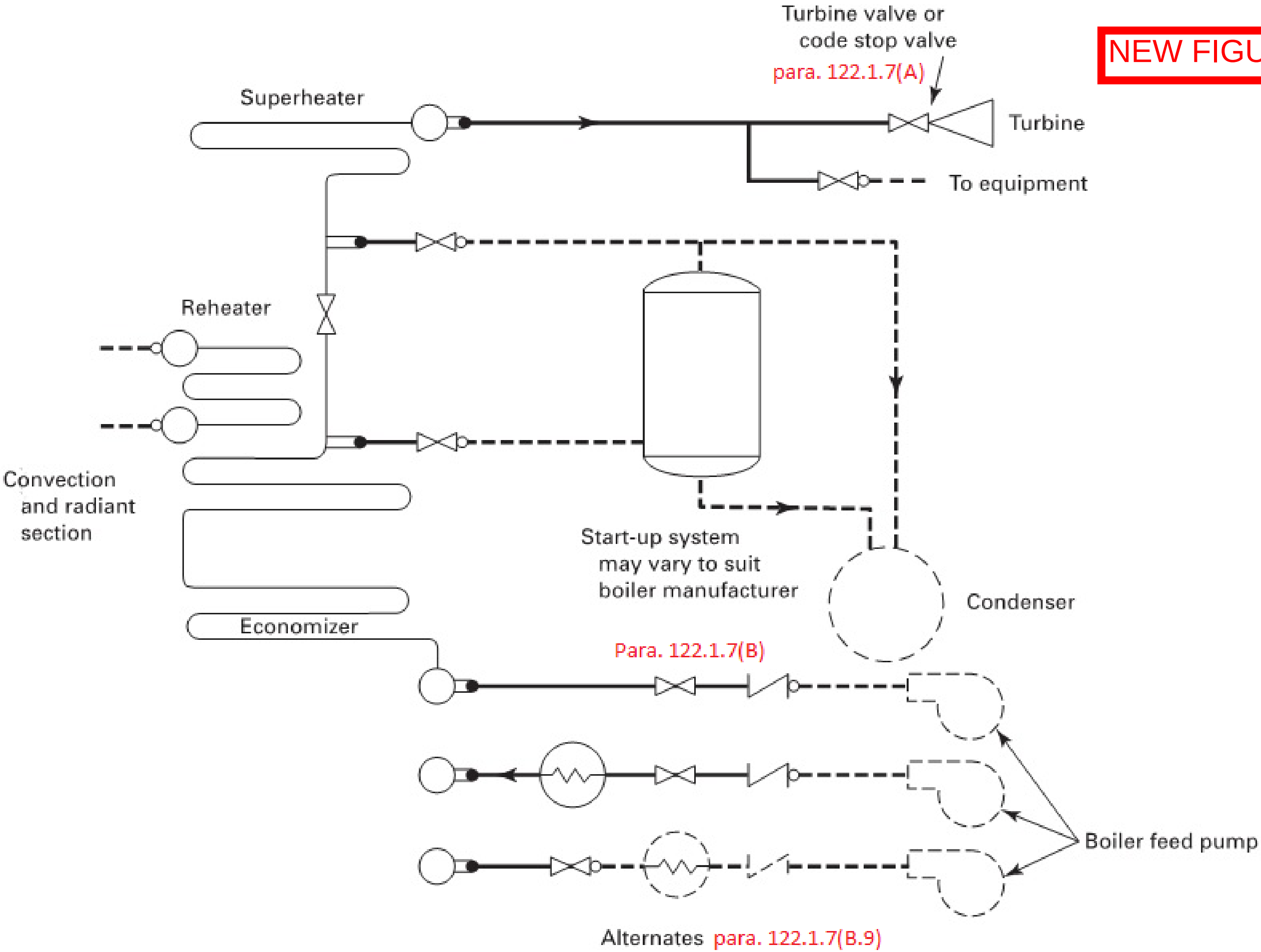
Administrative Jurisdiction and Technical Responsibility

——— Boiler Proper — The ASME Boiler and Pressure Vessel Code (ASME BPVC) has total administrative jurisdiction and technical responsibility. Refer to ASME BPVC Section I Preamble.

•——— Boiler External Piping and Joint (BEP) — The ASME BPVC has total administrative jurisdiction (mandatory certification by stamping the Certification Mark with the appropriate Designator, ASME Data Forms, and Authorized Inspection) of BEP. The ASME Section Committee B31.1 has been assigned technical responsibility. Refer to ASME BPVC Section I Preamble, fifth, sixth, and seventh paragraphs and ASME B31.1 Scope, para. 100.1.2(A). Applicable ASME B31.1 Editions and Addenda are referenced in ASME BPVC Section I, PG-58.3.

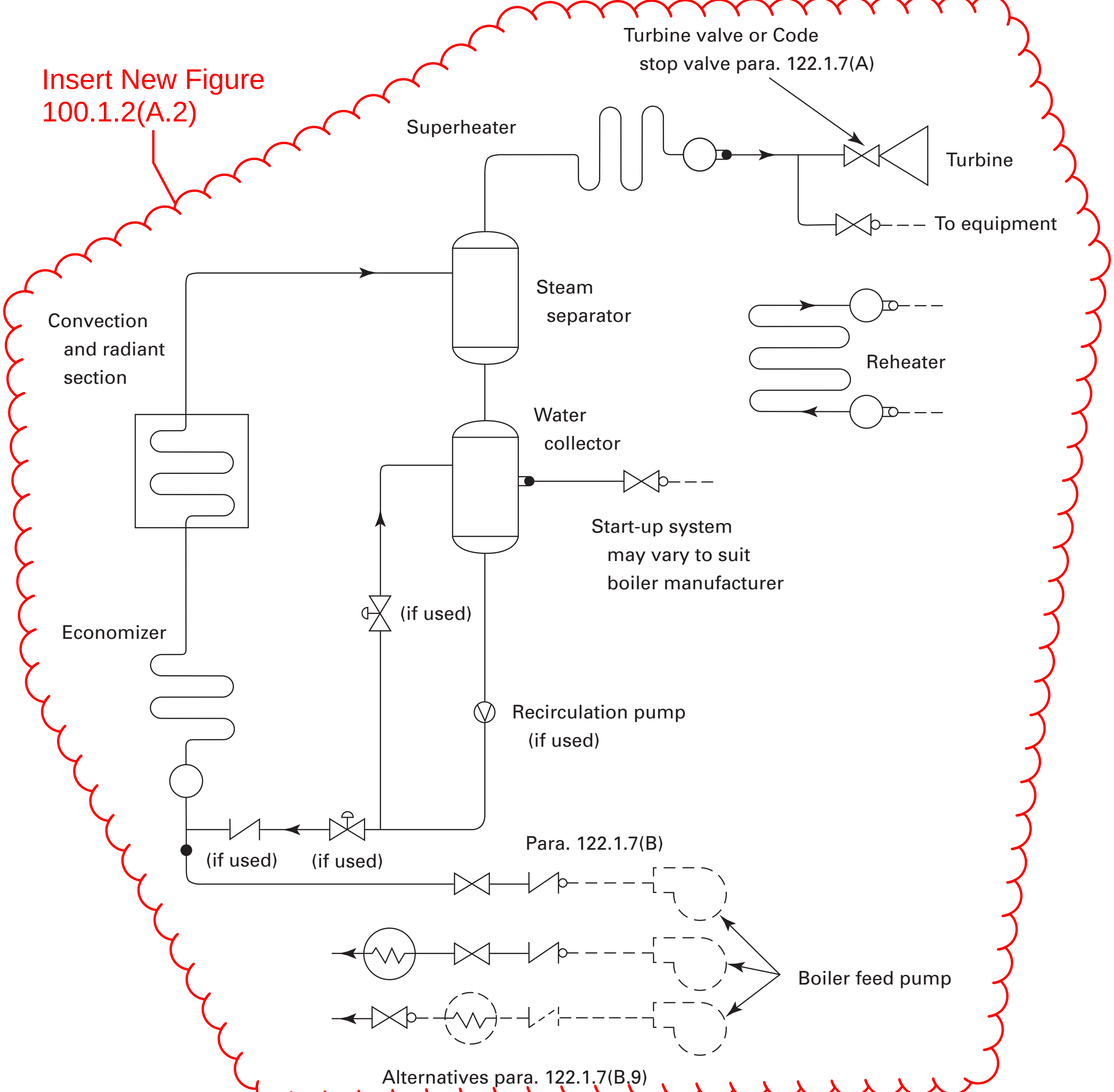
o- - - - Nonboiler External Piping and Joint (NBEP) — The ASME Code Committee for Pressure Piping, B31, has total administrative and technical responsibility.

NEW FIGURE 100.1.2(A.1)



or

Fig. 100.1.2(A.2) Code Jurisdictional Limits for Piping — An Example of Steam Separator Type Forced Flow Steam Generators With No Fixed Steam ~~and~~ Water Line



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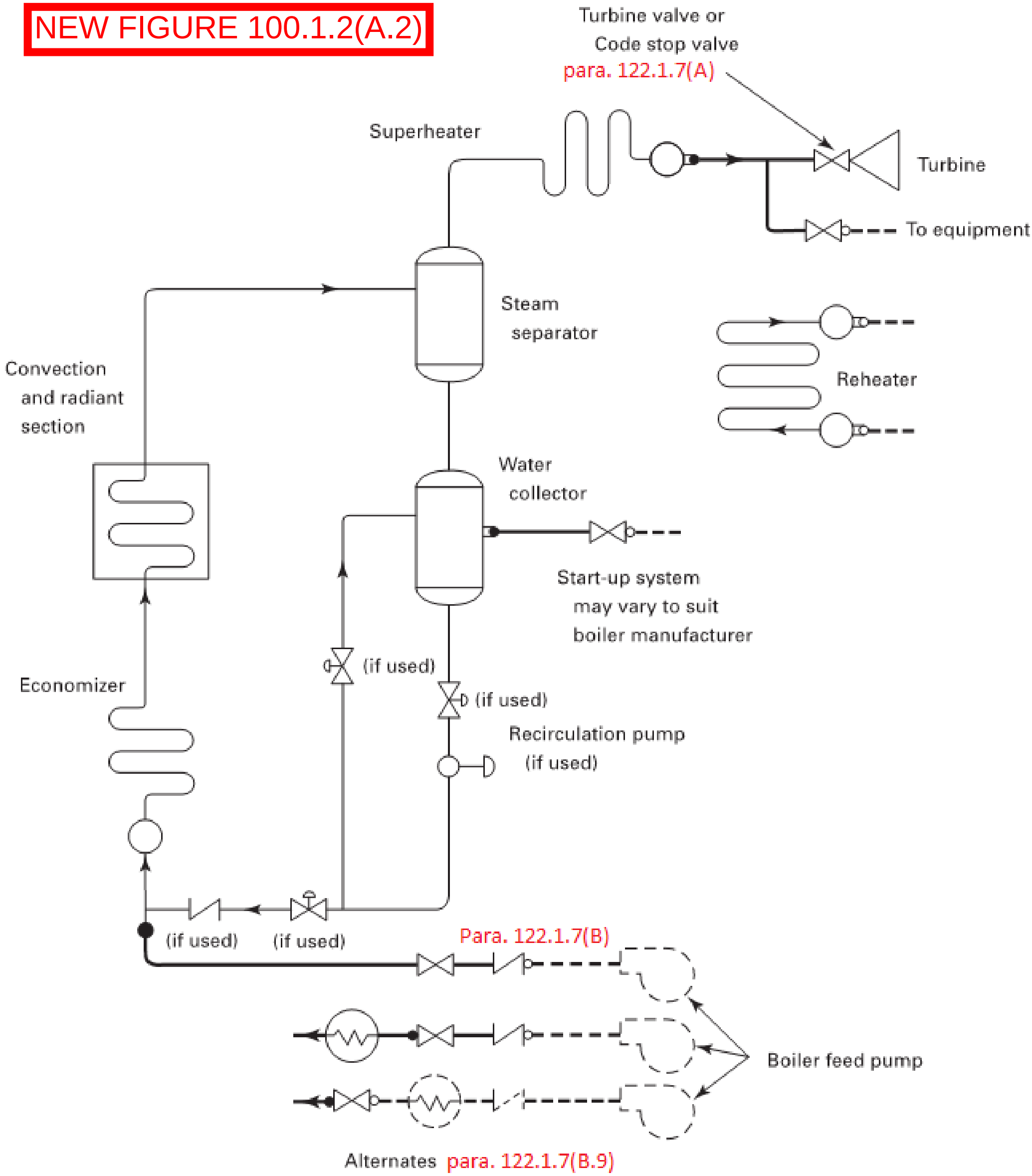
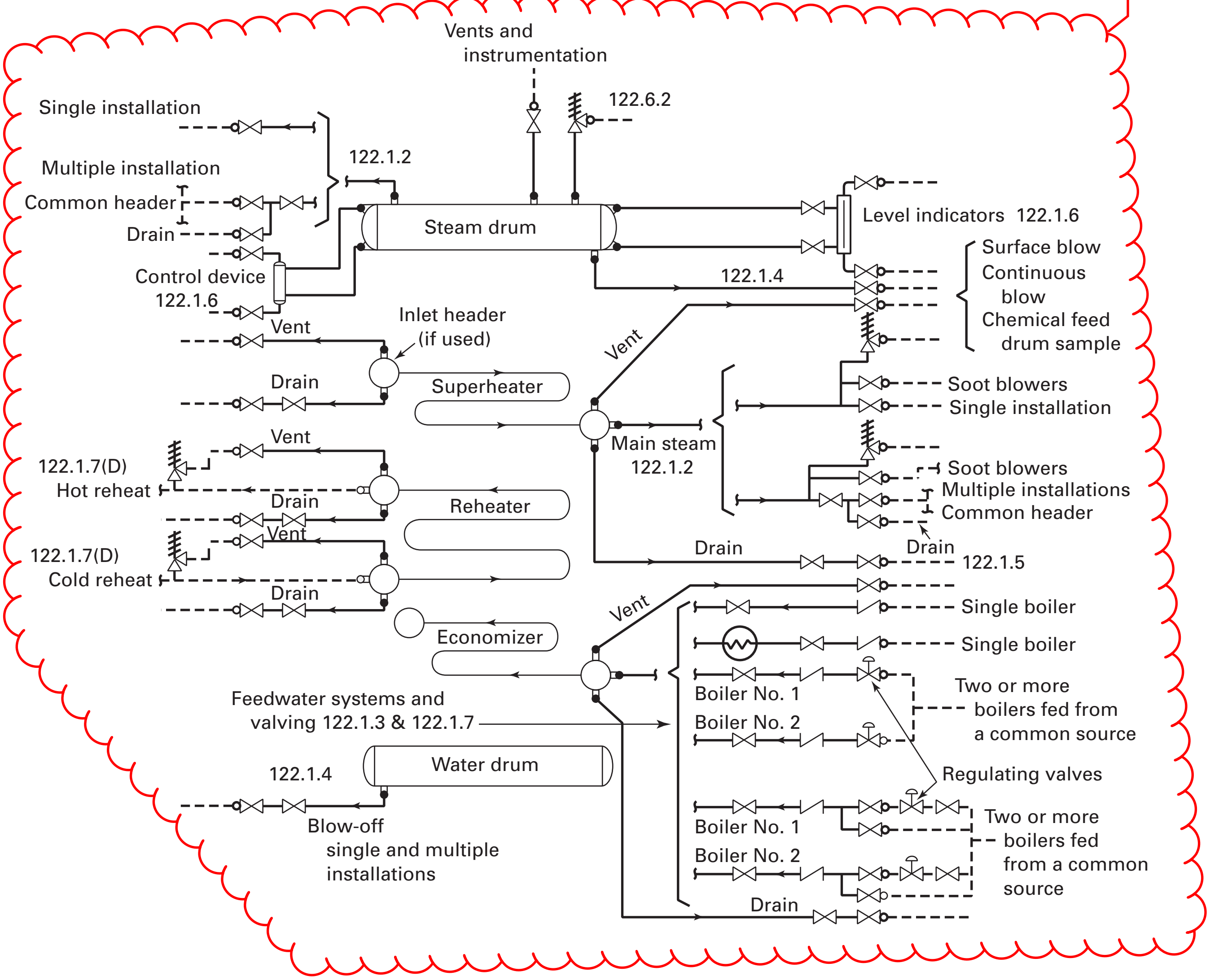
NEW FIGURE 100.1.2(A.2)



Insert New Figure
100.1.2(B.1)

(16) **Fig. 100.1.2(B.1) Code Jurisdictional Limits for Piping — Drum-Type Boilers**



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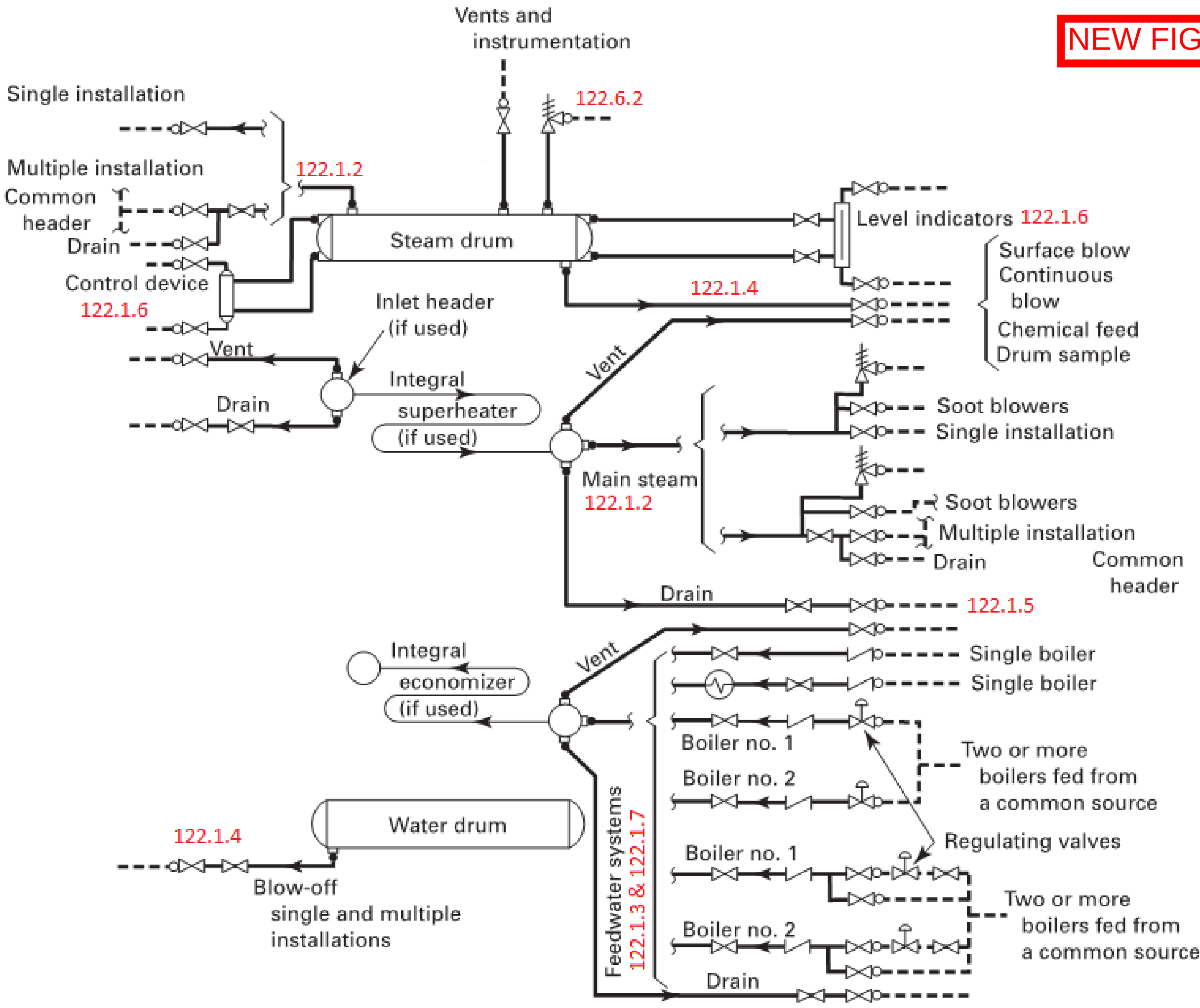
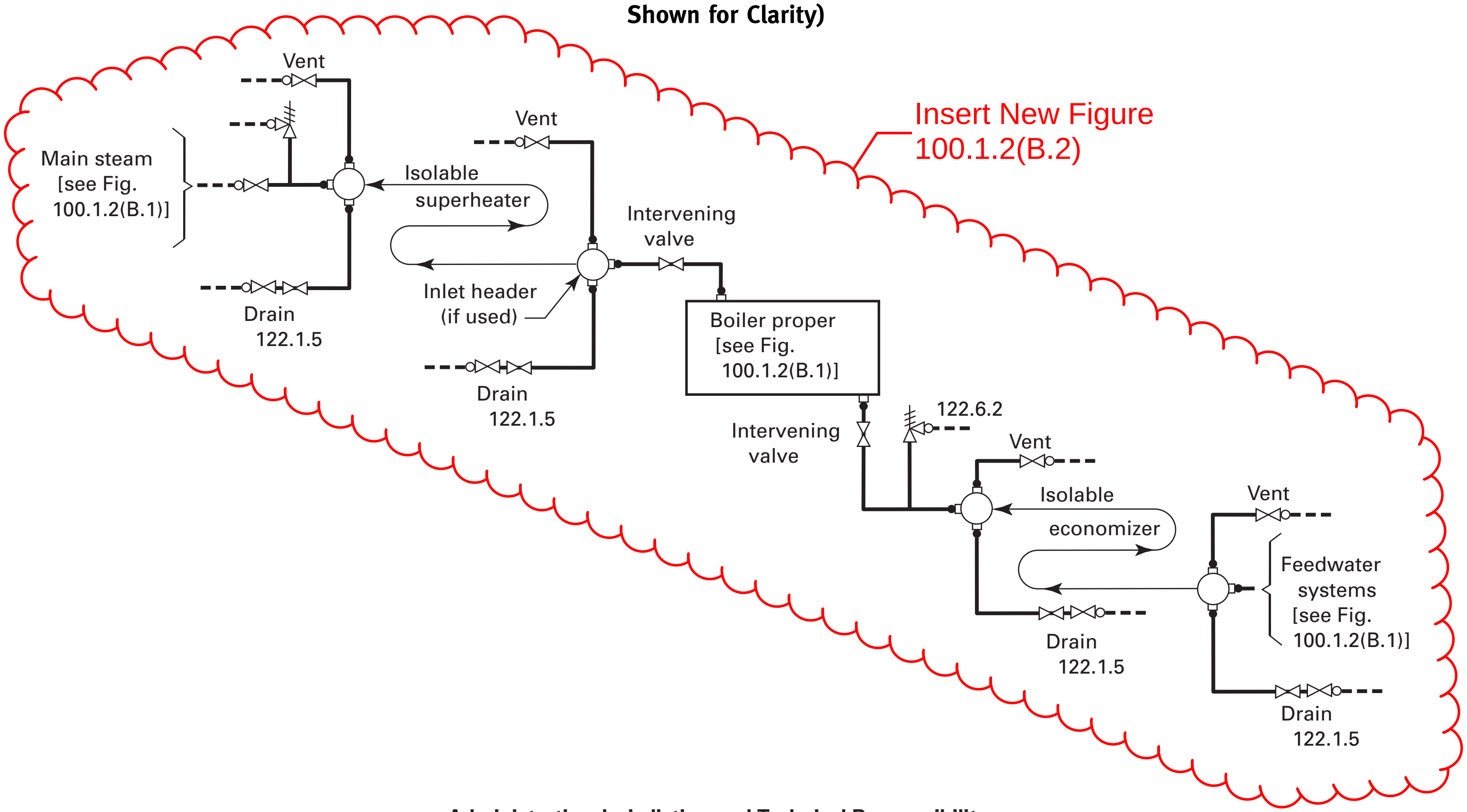
Nonboiler External Piping and Joint (NBEP) — The ASME Code Committee for Pressure Piping, B31, has total administrative jurisdiction and technical responsibility.

NEW FIGURE 100.1.2(B.1)



(16) **Fig. 100.1.2(B.2) Code Jurisdictional Limits for Piping — Isolable Economizers Located in Feedwater Piping and Isolable Superheaters in Main Steam Piping (Boiler Pressure Relief Valves, Blowoff, and Miscellaneous Piping for Boiler Proper Not Shown for Clarity)**



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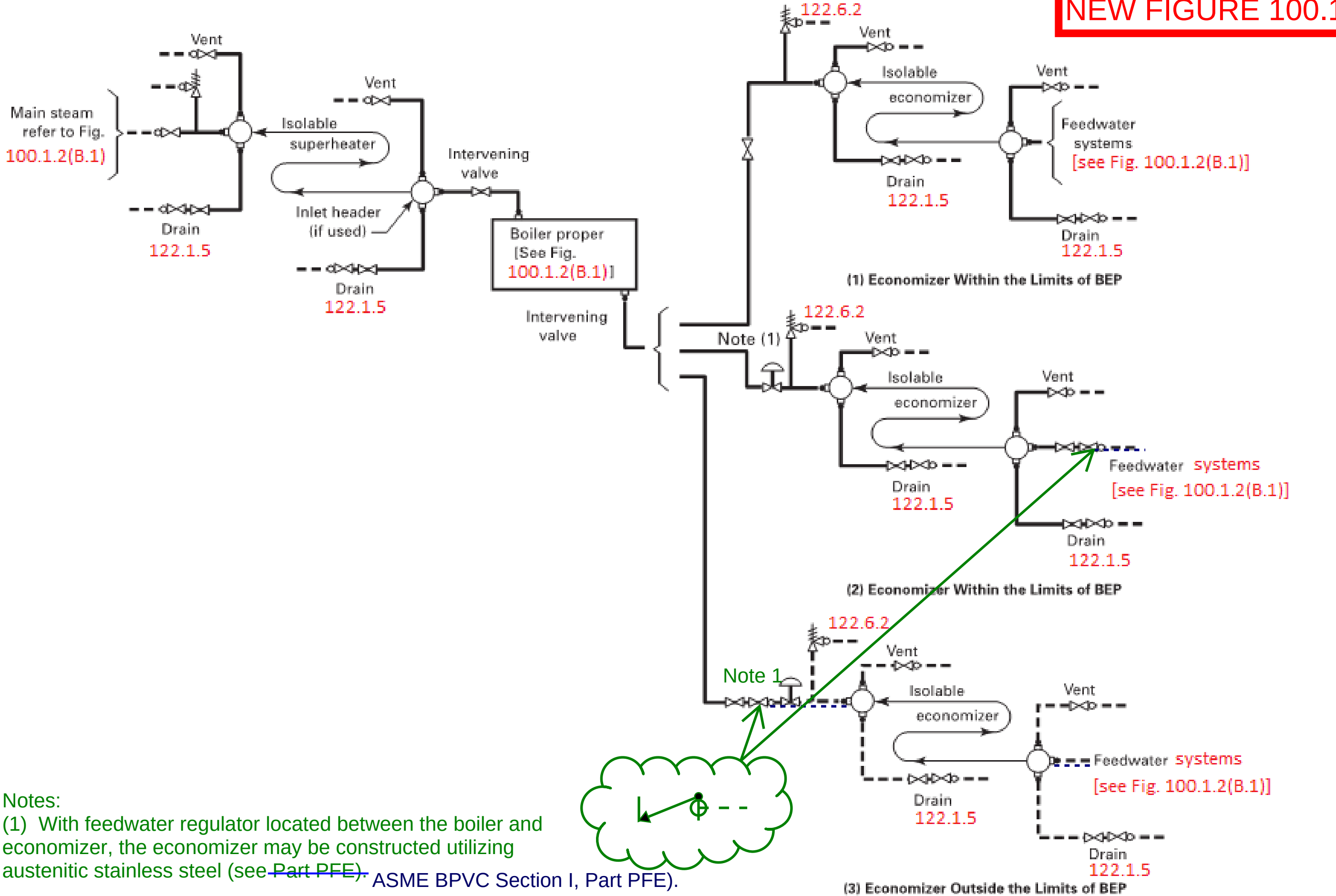
○- - - - Nonboiler External Piping and Joint (NBEP) — The ASME Code Committee for Pressure Piping, B31, has total administrative jurisdiction and technical responsibility.

NEW FIGURE 100.1.2(B.2)



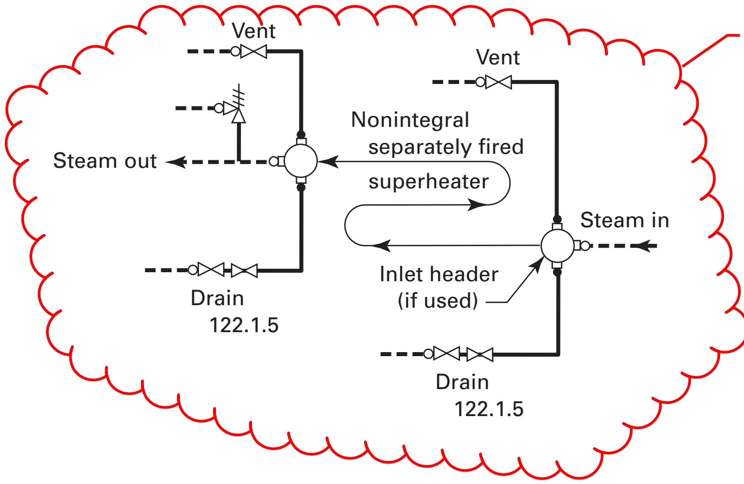
Notes:

(1) With feedwater regulator located between the boiler and economizer, the economizer may be constructed utilizing austenitic stainless steel (see ~~Part PFE).~~ ASME BPVC Section I, Part PFE).

Reheaters and

(16) **Fig. 100.1.2(B.3) Code Jurisdictional Limits for Piping — Nonintegral Separately Fired Superheaters**

Insert New Figure 100.1.2(B.3)



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○- - - - Nonboiler External Piping and Joint (NBEP) — The ASME Code Committee for Pressure Piping, B31, has total administrative jurisdiction and technical responsibility.

, ASME CA-1, Conformity Assessment Requirements, and ASME QAI-1 Qualifications for Authorized Inspectors

ASME Boiler and Pressure Vessel Code shall apply. These requirements are shown in Mandatory Appendix J of this Code.

The valve or valves required by para. 122.1 are part of the boiler external piping, but do not require ASME Boiler and Pressure Vessel Code, Section I inspection and stamping except for safety, safety relief, and relief valves; see para. 107.8.2. Refer to PG-11.

Pipe connections meeting all other requirements of this Code but not exceeding NPS ½ (DN 15) may be welded to pipe or boiler headers without inspection and stamping required by Section I of the ASME Boiler and Pressure Vessel Code.

(B) Nonboiler external piping includes all the piping covered by this Code except for that portion defined above as boiler external piping.

100.1.3 This Code does not apply to the following:

(A) economizers, heaters, pressure vessels, and components covered by Sections of the ASME Boiler and Pressure Vessel Code.

(B) building heating and distribution steam and condensate piping designed for 15 psig [100 kPa (gage)] or less, or hot water heating systems designed for 30 psig [200 kPa (gage)] or less.

(C) piping for hydraulic or pneumatic tools and their components downstream of the first block or stop valve off the system distribution header.

(D) piping for marine or other installations under Federal control.

(E) towers, building frames, tanks, mechanical equipment, instruments, and foundations.

(F) piping included as part of a shop-assembled packaged equipment assembly within a B31.1 Code piping installation when such equipment piping is constructed to another B31 Code Section (e.g., B31.3 or B31.9) with the owner's approval. See para. 100.2 for a definition of packaged equipment.

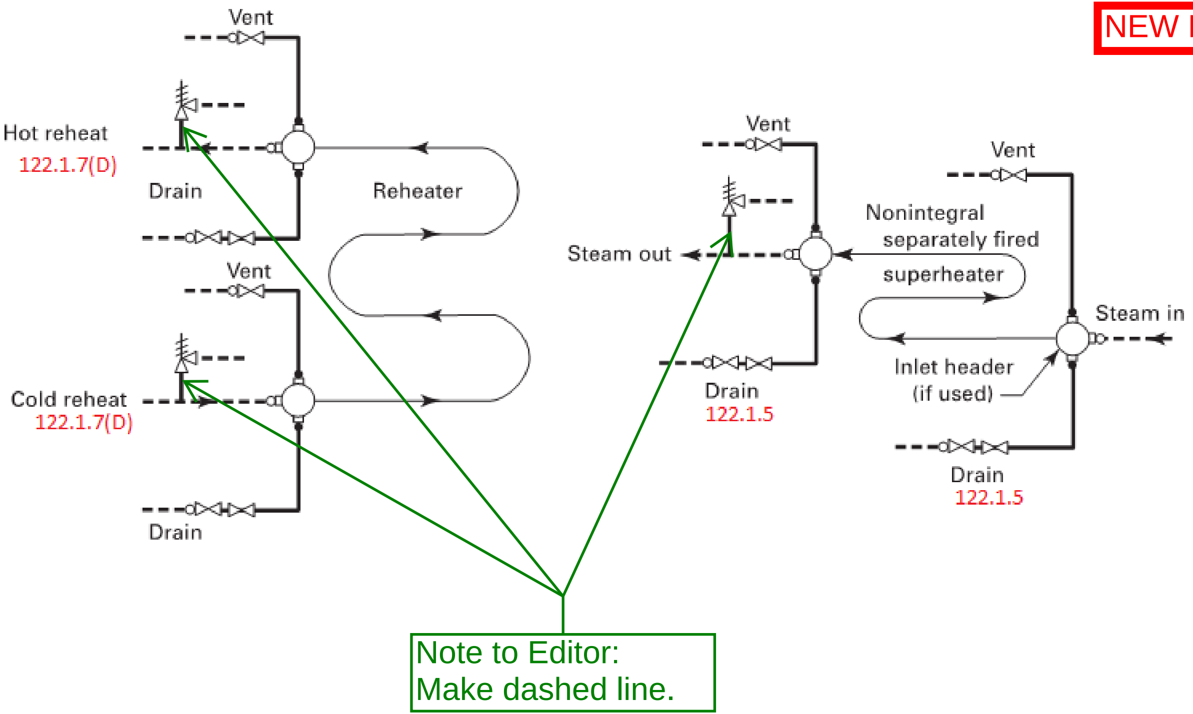
100.1.4 This Code does not provide procedures for flushing, cleaning, start-up, operating, or maintenance. (16)

100.2 Definitions (16)

Some commonly used terms relating to piping are defined below. Terms related to welding generally agree with AWS A3.0. Some welding terms are defined with

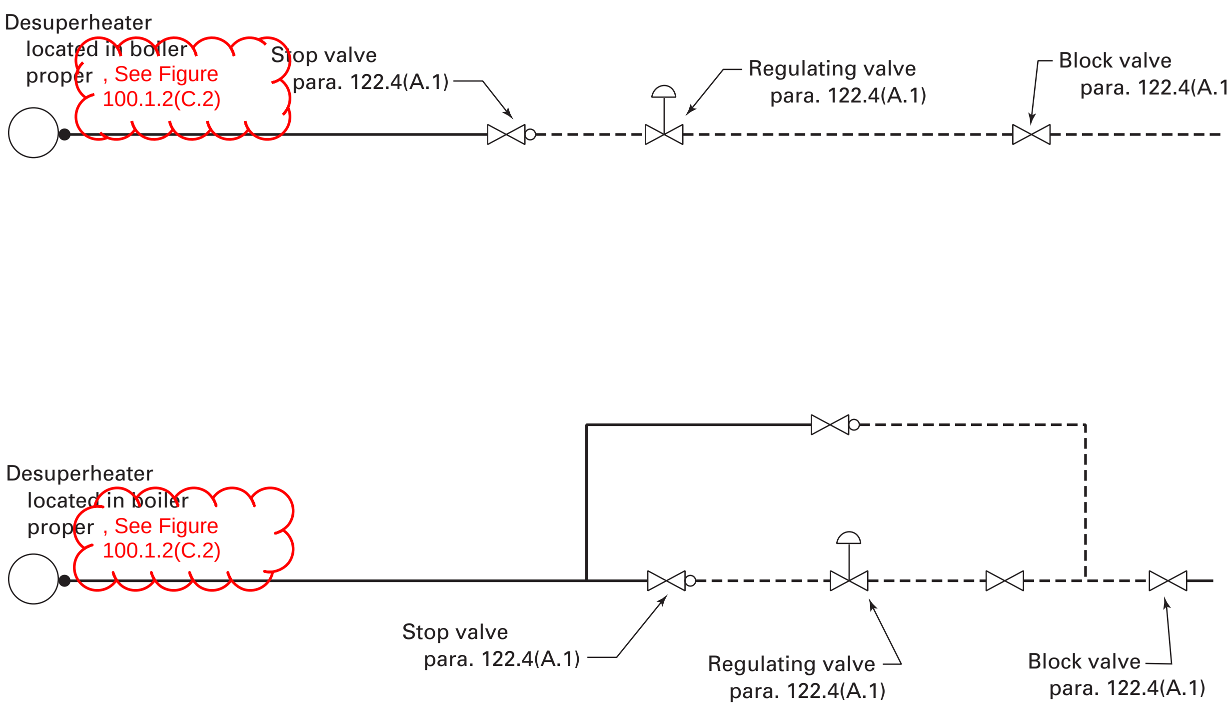
Code users are advised, however, that the cleaning and purging of flammable gas systems may be subject to the requirements of NFPA Standard 56.

NEW FIGURE 100.1.2(B.3)



C.1

Fig. 100.1.2(C) Code Jurisdictional Limits for Piping — Spray-Type Desuperheater



Administrative Jurisdiction and Technical Responsibility

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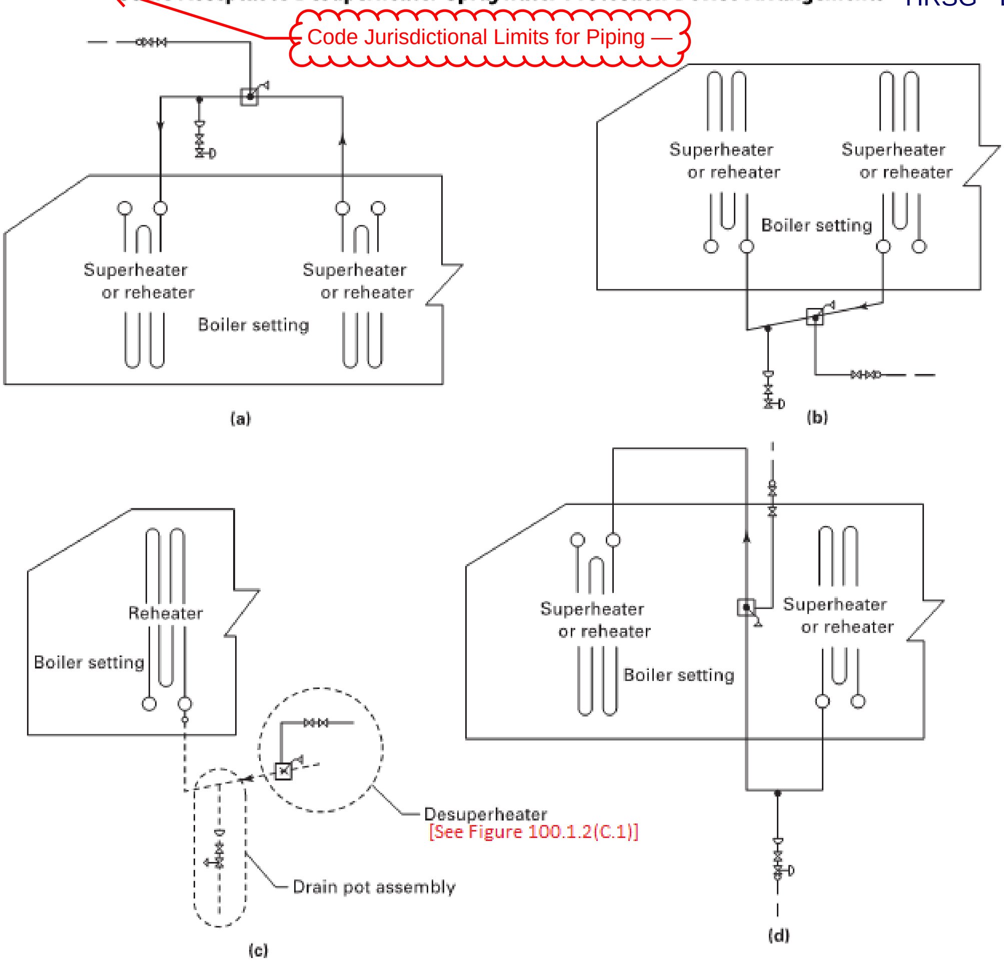
○- - - - Nonboiler External Piping and Joint (NBEP) — The ASME Code Committee for Pressure Piping, B31, has total administrative and technical responsibility.

NOTE TO EDITOR: The next page contains a new Figure 100.1.2(C.2) which needs to be inserted after this page.

Figure 100.1.2(C.2)

~~Some Acceptable Desuperheater Spraywater Protection Device Arrangements~~ HRSG - Desuperheater Protection Devices



Administrative Jurisdiction and Technical Responsibilities

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○- - - - Nonboiler External Piping and Joint (NBEP) — The ASME Code Committee for Pressure Piping, B31, has total administrative and technical responsibility.

austenitizing: see heat treatments.

specified reference to piping. For welding terms used in this Code, but not shown here, definitions of AWS A3.0 apply.

alteration: a change in any item described in the original design that affects the pressure-containing capability of the pressure-retaining component.

anchor: a rigid restraint providing substantially full fixation, permitting neither translatory nor rotational displacement of the pipe.

annealing: see *heat treatments.*

arc welding: a group of welding processes wherein coalescence is produced by heating with an electric 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, caulking, brazing, soldering, cementing, or threading into their installed location as specified by the engineering design.

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

backing ring: backing in the form of a ring that can be used in the welding of piping.

ball joint: a component that permits universal rotational movement in a piping system.

base metal: the metal to be welded, brazed, soldered, or cut.

branch connection: the attachment of a branch pipe to the run of a main pipe with or without the use of fittings.

braze welding: a method of welding whereby a groove, fillet, plug, or slot weld is made using a nonferrous filler metal having a melting point below that of the base metals, but above 840°F (450°C). The filler metal is not distributed in the joint by capillary action. (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 840°F (450°C) but lower than that of the base metals joined. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

butt joint: a joint between two members lying approximately in the same plane.

capacitor discharge welding (CDW): stud arc welding process in which DC arc power is produced by a rapid discharge of stored electrical energy with pressure applied during or immediately following the electrical discharge. The process uses an electrostatic storage system as a power source in which the weld energy is stored in capacitors.

cold spring: the intentional movement of piping during assembly to produce a desired initial displacement and reaction.

component: component as used in this Code is defined as consisting of but not limited to items such as pipe, piping subassemblies, parts, valves, strainers, relief devices, fittings, pipe supports and hangers, etc.

specially designed component: a component designed in accordance with para. 104.7.2.

standard component: a component manufactured in accordance with one or more of the standards listed in Table 126.1.

covered piping systems (CPS): piping systems on which condition assessments are to be conducted. As a minimum for electric power generating stations, the CPS systems are to include NPS 4 (DN 100) and larger of the main steam, hot reheat steam, cold reheat steam, and boiler feedwater piping systems. In addition to the above, CPS also includes NPS 4 (DN 100) and larger piping in other systems that operate above 750°F (400°C) or above 1,025 psi (7 100 kPa). ~~The Operating Company may add other piping systems to the scope of covered piping systems.~~

creep strength enhanced ferritic steel: steel in which the microstructure, consisting of lower transformation products such as martensite and bainite, is stabilized by controlled precipitation of temper-resistant carbides, carbonitrides, and/or nitrides.

defect: a flaw (imperfection or unintentional discontinuity) of such size, shape, orientation, location, or properties as to be rejectable.

discontinuity: a lack of continuity or cohesion; an interruption in the normal physical structure of material or a product.

employer: the owner, manufacturer, fabricator, contractor, assembler, or installer responsible for the welding, brazing, and NDE performed by his organization including procedure and performance qualifications.

engineering design: the detailed design developed from process requirements and conforming to Code requirements, including all necessary drawings and specifications, governing a piping installation.

equipment connection: an integral part of such equipment as pressure vessels, heat exchangers, pumps, etc., designed for attachment of pipe or piping components.

erection: the complete installation of a piping system, including any field assembly, fabrication, testing, and inspection of the system.

examination: denotes the procedures for all nondestructive examination. Refer to para. 136.3 and the definition for visual examination.

expansion joint: a flexible piping component that absorbs thermal and/or terminal movement.

Insert Text: *austenitizing:* forming austenite by heating ~~a steel object~~ steel above the transformation range.

Insert Text: "for that material"

Insert Text: "(PWHT)"

fabrication: primarily, the joining of piping components … d- … ns … ay … de

Insert Text: PWHT often refers to a general heat treatment applied to provide tempering, stress relieving, or a controlled rate of cooling to prevent formation of a hard or brittle microstructure.

failure: a physical condition that renders a system or … d function(s)

Insert Text: *subcritical heat treatment:* a general heat treating process where ~~a metal or alloy~~ ferritic or martensitic steel is heated to a temperature below the temperature at which austenite begins to form.

… d evaluating … (s) and cause … g, soldering,

fillet weld: a weld of approximately triangular cross section … at right angles … corner joint, or … l of more than … ists in the pres- … continuity that is detectable by a nondestructive examination.

Insert Text: *tempering:* reheating a quench hardened or normalized steel to a temperature below the temperature at which austenite begins to form, and then cooling at any desired rate.

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

failure: a physical condition that renders a system or component unable to perform its intended function(s), meet design and performance requirements or is a hazard to personnel safety.

gas purge: a process to purge air from the flammable gas supply piping, typically conducted at a low pressure and velocity.

gas welding: a group of welding processes wherein coalescence is produced by heating with a gas flame or … application of pressure, and … filler metal.

Edit to heading has been removed.

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

heat affected zone: portion of the base metal that has not been melted, but whose mechanical … structure have been altered by the … cutting.

Insert Text: "for that material"

heat treatments

annealing, full: heating a metal or alloy to a temperature above the ~~critical~~ temperature range and holding above the range for a proper period of time, followed by cooling to below that range. (A softening treatment is often carried out just below the ~~critical~~ range, which is referred to as a subcritical anneal.)

Delete Text:

Insert Text: ~~(or~~ transformation~~)~~

Insert Text: transformation

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.

postweld heat treatment: any heat treatment subsequent to welding.

preheating: the application of heat to a base metal immediately prior to a welding or cutting operation.

stress-relieving: 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.

imperfection: a condition of being imperfect; a departure of a quality characteristic from its intended condition.

indication: the response or evidence from the application of a nondestructive examination.

inert gas metal arc welding: an arc welding process wherein coalescence is produced by heating with an electric arc between a metal electrode and the work. Shielding is obtained fr… or argon. Pressure ma… metal may or may not …

Insert Text: below the ~~critical (or transformation)~~ temperature range for that material

inspection: denotes th… Authorized Inspector, … that all required examinations and testing have been completed, and to ensure that all the documentation for material, fabrication, and examination conforms to the applicable requirements of this Code and the engineering design.

integrally reinforced branch outlet fitting: a branch outlet fitting that is welded directly to a run pipe, where the branch fitting and the deposited weld metal used to attach the fitting to the run pipe are designed by the fitting manufacturer to provide all the reinforcement required by this Code without the addition of separate saddles or pads. The attachment of the branch pipe to the fitting is by butt welding, socket welding, threading, or by a flanged connection. Integrally reinforced branch outlet fittings include those fittings conforming to MSS SP-97.

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

joint penetration: the minimum depth of a groove weld extends from its face into a joint, exclusive of reinforcement.

…w energy capacitor discharge welding: a resistance welding process wherein coalescence is produced by the rapid discha… …ric energy from a low voltage electrostatic storage system.

Delete Text:

manual welding: welding wherein the entire welding operation is performed a…

maximum allowable stress: … may be used in the desig… and design temperature.

Note to Editor: The three definitions being added under the *heat treatments group* should be slightly indented (e.g., see *stress-relieving).*

reinforcement of weld (internal): weld metal on the interior face of a groove weld which extends past the root opening of the joint.

(E) double submerged arc welded pipe: pipe having a longitudinal butt joint produced by the submerged arc process, with at least two passes, one of which is on the inside of the pipe.

(F) seamless pipe: pipe produced by one or more of the following processes:

(F.1) rolled pipe: pipe produced from a forged billet that is pierced by a conical mandrel between two diametrically opposed rolls. The pierced shell is subsequently rolled and expanded over mandrels of increasingly larger diameter. Where closer dimensional tolerances are desired, the rolled pipe is cold or hot drawn through dies, and machined.

One variation of this process produces the hollow shell by extrusion of the forged billet over a mandrel in a vertical, hydraulic piercing press.

(F.2) forged and bored pipe: pipe produced by boring or trepanning of a forged billet.

(F.3) extruded pipe: pipe produced from hollow or solid round forgings, usually in a hydraulic extrusion press. In this process the forging is contained in a cylindrical die. Initially a punch at the end of the extrusion plunger pierces the forging. The extrusion plunger then forces the contained billet between the cylindrical die and the punch to form the pipe, the latter acting as a mandrel.

(F.4) centrifugally cast pipe: pipe formed from the solidification of molten metal in a rotating mold. Both metal and sand molds are used. After casting, the pipe is machined, to sound metal, on the internal and external diameters to the surface roughness and dimensional requirements of the applicable material specification.

One variation of this process utilizes autofrettage (hydraulic expansion) and heat treatment, above the recrystallization temperature of the material, to produce a wrought structure.

(F.5) statically cast pipe: pipe formed by the solidification of molten metal in a sand mold.

pipe supporting elements: pipe supporting elements consist of hangers, supports, and structural attachments.

hangers and supports: hangers and supports include elements that 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.

structural attachments: structural attachments include elements that are welded, bolted, or clamped to the pipe, such as clips, lugs, rings, clamps, clevises, straps, and skirts.

porosity: cavity-type discontinuities formed by gas entrapment during metal solidification.

postweld heat treatment: see *heat treatments.*

preheating: see *heat treatments.*

pressure: an application of force per unit area; fluid pressure (an application of internal or external fluid force per unit area on the pressure boundary of piping components).

Procedure Qualification Record (PQR): a record of the welding data used to weld a test coupon. The PQR is a record of variables recorded during the welding of the test coupons. It also contains the test results of the tested specimens. Recorded variables normally fall within a small range of the actual variables that will be used in production welding.

qualified (personnel): individuals who have demonstrated and documented abilities gained through training and/or experience that enable them to perform a required function to the satisfaction of the Operating Company.

readily accessible: for visual examination, readily accessible inside surfaces are defined as those inside surfaces that can be examined without the aid of optical devices. (This definition does not prohibit the use of optical devices for a visual examination; however, the selection of the device should be a matter of mutual agreement between the owner and the fabricator or erector.)

Reid vapor pressure: the vapor pressure of a flammable or combustible liquid as determined by ASTM Standard Test Method D323 Vapor Pressure of Petroleum Products (Reid Method).

(external)

reinforcement of weld: weld metal on the face of a groove weld in excess of the metal necessary for the specified weld size.

repair: ~~the work necessary to restore pressure retaining items~~ to a safe and satisfactory operating condition.

restraint: any device that prevents, resists, or limits movement of a piping system.

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

root penetration: the depth a groove weld extends into the root opening of a joint measured on the centerline of the root cross section.

seal weld: a weld used on a pipe joint primarily to obtain fluid tightness as opposed to mechanical strength.

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

shall: "shall" or "shall not" is used to indicate that a provision or prohibition is mandatory.

shielded metal arc welding: an arc welding process wherein coalescence is produced by heating with an electric 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.

the work necessary to restore a system or component to meet the applicable Code requirements and to a safe and satisfactory operating condition.

should: "should" or "it is recommended" is used to indicate that a provision is not mandatory but recommended as good practice.

size of weld

fillet weld: for equal leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.

groove weld: the joint penetration (depth of chamfering plus the root penetration when specified).

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 temperature and by using a nonferrous alloy fusible at temperatures below 840°F (450°C) 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 action. In general, solders are lead–tin alloys and may contain antimony, bismuth, silver, and other elements.

steel: an alloy of iron and carbon with no more than 2% carbon by weight. Other alloying elements may include manganese, sulfur, phosphorus, silicon, aluminum, chromium, copper, nickel, molybdenum, vanadium, and others depending upon the type of steel. For acceptable material specifications for steel, refer to Chapter III, Materials.

stresses

sustained stress: a stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium between external and internal forces and moments. The basic characteristic of a sustained stress is that it is not self-limiting. If a sustained stress exceeds the yield strength of the material through the entire thickness, the prevention of failure is entirely dependent on the strain-hardening properties of the material. A thermal stress is not classified as a sustained stress. Further, the sustained stresses calculated in this Code are "effective" stresses and are generally lower than those predicted by theory or measured in strain-gage tests.

displacement stress: a stress developed by the self-constraint of the structure. It must satisfy an imposed strain pattern rather than being in equilibrium with an external load. The basic characteristic of a displacement stress is that it is self-limiting. Local yielding and minor distortions can satisfy the displacement or expansion conditions that cause the stress to occur. Failure from one application of the stress is not to be expected. Further, the displacement stresses calculated in this Code are "effective" stresses and are generally lower than those predicted by theory or measured in strain-gage tests.[1]

peak stress: the highest stress in the region under consideration. The basic characteristic of a peak stress is that it causes no significant distortion and is objectionable only as a possible source of a fatigue crack initiation or a brittle fracture. This Code does not utilize peak stress as a design basis, but rather uses effective stress values for sustained stress and for displacement stress; the peak stress effect is combined with the displacement stress effect in the displacement stress range calculation.

stress-relieving: see *heat treatments.*

subcritical heat treatment: see heat treatments.

submerged arc welding: an arc welding process wherein coalescence is produced by heating with an electric arc or arcs between a 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 is obtained from the electrode and sometimes from a supplementary welding rod.

supplementary steel: steel members that are installed between existing members for the purpose of installing supports for piping or piping equipment.

swivel joint: a component that permits single-plane rotational movement in a piping system.

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

tempering: see heat treatments.

throat of a fillet weld

actual: the shortest distance from the root of a fillet weld to its face.

theoretical: the distance from the beginning of the root of the joint perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the fillet weld cross section.

toe of weld: the junction between the face of the weld and the base metal.

tube: refer to *pipe and tube.*

tungsten electrode: a nonfiller metal electrode used in arc welding, consisting of a tungsten wire.

undercut: ~~a groove melted into the base metal adjacent to the toe of a weld and not filled with weld metal.~~ a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

visual examination: the observation of whatever portions of components, joints, and other piping elements that are exposed to such observation either before, during, or after manufacture, fabrication, assembly, erection,

[1] Normally, the most significant displacement stress is encountered in the thermal expansion stress range from ambient to the normal operating condition. This stress range is also the stress range usually considered in a flexibility analysis. However, if other significant stress ranges occur, whether they are displacement stress ranges (such as from other thermal expansion or contraction events, or differential support point movements) or sustained stress ranges (such as from cyclic pressure, steam hammer, or earthquake inertia forces), paras. 102.3.2(B) and 104.8.3 may be used to evaluate their effect on fatigue life.

The design of metallic bellows expansion joints shall be in accordance with Appendix P.

used to define or refine the design wind forces. Where local jurisdictional rules covering the design of building structures are in effect and specify wind loadings for piping, these values shall be considered the minimum design values. Wind need not be considered as acting concurrently with earthquakes.

101.5.3 Earthquake. The effect of earthquakes shall be considered in the design of piping, piping supports, and restraints. The analysis considerations and loads may be as described in ASCE/SEI 7. Authoritative local seismological data may also be used to define or refine the design earthquake forces. Where local jurisdictional rules covering the design of building structures are in effect and specify seismic loadings for piping, these values shall be considered the minimum design values. ASME B31E, Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems, may be used as an alternate method of seismic qualification or for guidance in seismic design. Earthquakes need not be considered as acting concurrently with wind.

101.5.4 Vibration. Piping shall be arranged and supported with consideration of vibration [see paras. 120.1(C) and 121.7.5].

101.6 Weight Effects

The following weight effects combined with loads and forces from other causes shall be taken into account in the design of piping. Piping shall be carried on adjustable hangers or properly leveled rigid hangers or supports, and suitable springs, sway bracing, vibration dampeners, etc., shall be provided where necessary.

101.6.1 Live Load. The live load consists of the weight of the fluid transported. Snow and ice loads shall be considered in localities where such conditions exist.

101.6.2 Dead Load. The dead load consists of the weight of the piping components, insulation, protective lining and coating, and other superimposed permanent loads.

101.6.3 Test or Cleaning Fluid Load. The test or cleaning fluid load consists of the weight of the test or cleaning fluid.

101.7 Thermal Expansion and Contraction Loads

101.7.1 General. The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction, and from the effects of expansion joints.

Thermal expansion and contraction shall be provided for preferably by pipe bends, elbows, offsets, or changes in direction of the pipeline.

Hangers and supports shall permit expansion and contraction of the piping between anchors.

101.7.2 Expansion, Swivel, or Ball Joints, and Flexible Metal Hose Assemblies. (16) Joints of the corrugated bellows, slip, sleeve, ball, or swivel types and flexible metal hose assemblies may be used if their materials conform to this Code, their structural and working parts are of ample proportions, and their design prevents the complete disengagement of working parts while in service. In determining expansion joint design criteria, the designer shall give due consideration to conditions of service, including, but not limited to, temperature, pressure, externally imposed displacements, corrosion/erosion, fatigue, and flow velocity.

102 DESIGN CRITERIA

102.1 General

These criteria cover pressure–temperature ratings for standard and specially designed components, allowable stresses, stress limits, and various allowances to be used in the design of piping and piping components.

102.2 Pressure–Temperature Ratings for Piping Components

102.2.1 Components Having Specific Ratings. Pressure–temperature ratings for certain piping components have been established and are contained in some of the standards listed in Table 126.1.

Where piping components have established pressure–temperature ratings that do not extend to the upper material temperature limits permitted by this Code, the pressure–temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Code, but such extensions are subject to restrictions, if any, imposed by the standards.

Standard components may not be used at conditions of pressure and temperature that exceed the limits imposed by this Code.

102.2.2 Components Not Having Specific Ratings. Some of the Standards listed in Table 126.1, such as those for buttwelding fittings, specify that components shall be furnished in nominal thicknesses. Unless limited elsewhere in this Code, such components shall be rated for the same allowable pressures as seamless pipe of the same nominal thickness, as determined in paras. 103 and 104 for material having the same allowable stress.

Piping components, such as pipe, for which allowable stresses have been developed in accordance with para. 102.3, but that do not have established pressure ratings, shall be rated by rules for pressure design in para. 104, modified as applicable by other provisions of this Code.

Should it be desired to use methods of manufacture or design of components not covered by this Code or not listed in referenced standards, it is intended that the manufacturer shall comply with the requirements

See para. 104.1.2 for the other nomenclature used above.
W = 1 for seamless pipe or for seam welded pipe operating below the creep range and for parts of the bend that do not contain a weld.

Table 102.4.5 Bend Thinning Allowance

Radius of Bends	Minimum Thickness Recommended Prior to Bending
6 pipe diameters or greater	$1.06t_m$
5 pipe diameters	$1.08t_m$
4 pipe diameters	$1.14t_m$
3 pipe diameters	$1.25t_m$

GENERAL NOTES:
(a) Interpolation is permissible for bending to intermediate radii.
(b) t_m is determined by eq. (7) or (8) of para. 104.1.2(A).
(c) Pipe diameter is the nominal diameter as tabulated in ASME B36.10M, Tables 1, and ASME B36.19M, Table 1. For piping with a diameter not listed in these Tables, and also for tubing, the nominal diameter corresponds with the outside diameter.

allowable stress values given in Mandatory Appendix A. The factors in Table 102.4.3 apply to both straight seam and spiral seam welded pipe.

102.4.4 Mechanical Strength. Where necessary for mechanical strength to prevent damage, collapse, excessive sag, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe should be increased; or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods. The requirements of para. 104.1.2(C) shall also apply.

102.4.5 Bending. The minimum wall thickness at any point on the bend shall conform to (A) or (B) below.

(A) The minimum wall thickness at any point in a completed bend shall not be less than required by eq. (7) or (8) of para. 104.1.2(A).

(A.1) Table 102.4.5 is a guide to the designer who must specify wall thickness for ordering pipe. In general, it has been the experience that when good shop practices are employed, the minimum thicknesses of straight pipe shown in Table 102.4.5 should be sufficient for bending and still meet the minimum thickness requirements of para. 104.1.2(A).

(A.2) The bend thinning allowance in Table 102.4.5 may be provided in all parts of the cross section of the pipe circumference without any detrimental effects being produced.

(B) The minimum required thickness, t_m, of a bend, after bending, in its finished form, shall be determined in accordance with eq. (3) or (4)

$$t_m = \frac{PD_o}{2(SE/I + Py)} + A \qquad (3)$$

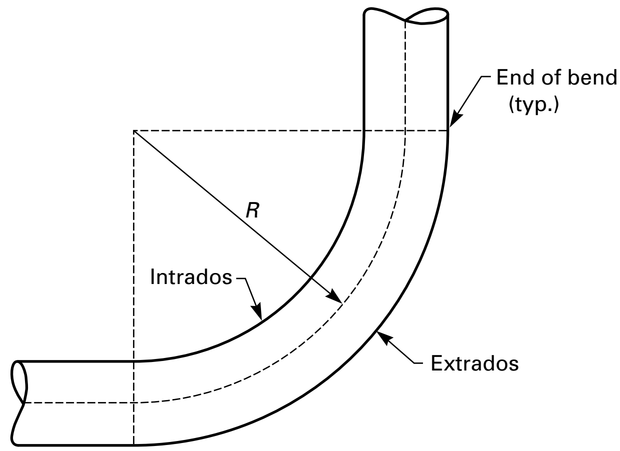
SEW

or

$$t_m = \frac{Pd + 2SEA/I + 2yPA}{2(SE/I + Py - P)} \qquad (4)$$

SEW SEW

Fig. 102.4.5 Nomenclature for Pipe Bends



where at the intrados (inside of bend)

$$I = \frac{4(R/D_o) - 1}{4(R/D_o) - 2} \qquad (5)$$

and at the extrados (outside of bend)

$$I = \frac{4(R/D_o) + 1}{4(R/D_o) + 2} \qquad (6)$$

and at the sidewall on the bend centerline

$$I = 1.0$$

where
R = bend radius of pipe bend

Thickness variations from the intrados to the extrados and at the ends of the bend shall be gradual. The thickness requirements apply at the center of the bend arc, at the intrados, extrados, and bend centerline (see Fig. 102.4.5). The minimum thickness at the ends of the bends shall not be less than the requirements of para. 104.1.2 for straight pipe. For bends to conform to this paragraph, all thickness requirements must be met.

102.4.6 Casting Quality Factors **(16)**

(A) General. Except for gray iron castings, the use of a casting quality factor is required for all cast components that use the allowable stress values of Mandatory Appendix A as the design basis. The factor, 0.80 for castings and 0.85 for centrifugally cast pipe, is included in the allowable stress values given in Mandatory Appendix A.

This required factor does not apply to component standards listed in Table 126.1, if such standards define allowable pressure–temperature ratings or provide the allowable stresses to be used as the design basis for the component.

Table 102.4.6(B.2.2) Maximum Severity Level for Casting Thickness Greater Than $4\frac{1}{2}$ in. (114 mm)

Discontinuity Category Designation	Severity Level
A, B, and Types 1, 2, and 3 of C	2
D, E, and F	None acceptable

Vessel Code. Radiographs shall conform to the requirements of ASTM E280.

The maximum acceptable severity level for a 1.0 quality factor shall be as listed in Table 102.4.6(B.2.2). MSS SP-54 may be used for guidance. Where appropriate, radiographic examination (RT) of castings may be supplemented or replaced with ultrasonic examination (UT), provided it is performed in accordance with MSS SP-94.

(B.2.3) Any discontinuities in excess of the maximum permitted in (B.2.1) and (B.2.2) above shall be removed and may be repaired by welding after the base metal has been magnetic particle or dye penetrant inspected to ensure complete removal of discontinuities. [Refer to para. 127.4.11(A).]

(B.2.4) All weld repairs of depth exceeding 1 in. (25 mm) or 20% of the section thickness, whichever is the lesser, shall be inspected by volumetric examination (RT or UT) in accordance with (B.2.2) above and by magnetic particle or dye penetrant inspection of the finished weld surface. All weld repairs of depth less than 20% of the section thickness, or 1 in. (25 mm), whichever is the lesser, and all weld repairs of section that cannot be effectively radiographed shall be examined by magnetic particle or dye penetrant inspection of the first layer, of each $\frac{1}{4}$ in. (6 mm) thickness of deposited weld metal, and of the finished weld surface. Magnetic particle or dye penetrant testing of the finished weld surface shall be done after postweld heat treatment.

(C) For cast iron and nonferrous materials, no increase of the casting quality factor is allowed except when special methods of examination, prescribed by the material specification, are followed. If such increase is specifically permitted by the material specification, a factor not exceeding 1.0 may be applied.

102.4.7 Weld Strength Reduction Factors. At elevated temperatures, seam welds on longitudinal-welded or spiral-welded pipe can have lower creep strength than the base material. This reduction is a factor in determining the minimum wall thickness for longitudinal-welded or spiral-welded pipe (i.e., not seamless), whether fabricated in accordance with a material specification or fabricated in accordance with the rules of this Code. The weld strength reduction factor, *W*, is given in Table 102.4.7. The designer is responsible to assess application of weld strength reduction factor requirements for welds other than longitudinal and spiral, as applicable (e.g., circumferential welds).

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

103 CRITERIA FOR PRESSURE DESIGN OF PIPING COMPONENTS

The design of piping components shall consider the effects of pressure and temperature, in accordance with paras. 104.1 through 104.7, including the consideration of allowances permitted by paras. 102.2.4 and 102.4. In addition, the mechanical strength of the piping system shall be determined adequate in accordance with para. 104.8 under other applicable loadings, including but not limited to those loadings defined in para. 101.

104 PRESSURE DESIGN OF COMPONENTS

104.1 Straight Pipe

104.1.1 Straight Pipe Under Internal Pressure. Straight pipe under internal pressure shall have a minimum wall thickness calculated per para. 104.1.2 ~~if the pipe is of seamless construction or is designed for sustained operation below the creep range. Straight pipe under internal pressure shall have a minimum wall thickness calculated per para. 104.1.4 if the pipe is of longitudinal-welded or spiral-welded construction designed for sustained operation within the creep range~~. ~~(See para. 123.4 for definition of the creep range.)~~

104.1.2 Straight Pipe Under Internal Pressure — Seamless, Longitudinal Welded, or Spiral Welded and Operating Below the Creep Range (16)

(A) Minimum Wall Thickness. The minimum thickness of pipe wall required for design pressures and for temperatures not exceeding those for the various materials listed in the Allowable Stress Tables, including allowances for mechanical strength, shall not be less than that determined by eq. (7) or (8), as follows:

$$t_m = \frac{PD_o}{2(SE + Py)} + A \qquad (7)^3$$

$$t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)} \qquad (8)^3$$

Design pressure shall not exceed

$$P = \frac{2SE(t_m - A)}{D_o - 2y(t_m - A)} \qquad (9)^3$$

[3] *SF* shall be used in place of *SE* where casting quality factors are intended. See definition of *SE*. Units of *P* and *SE* must be identical. Mandatory Appendix A values must be converted to kPa when the design pressure is in kPa.

W

$$P = \frac{2SE(t_m - A)}{d - 2y(t_m - A) + 2t_m} \qquad (10)[3]$$

where the nomenclature used above is

(A.1) t_m = minimum required wall thickness, in. (mm)

(A.1.1) If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness t_m is determined by eq. (7) or (8), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from thickness schedules such as contained in ASME B36.10M or from manufacturers' schedules for other than standard thickness.

(A.1.2) To compensate for thinning in bends, refer to para. 102.4.5.

(A.1.3) For cast piping components, refer to para. 102.4.6.

(A.1.4) Where ends are subject to forming or machining for jointing, the wall thickness of the pipe, tube, or component after such forming or machining shall not be less than t_m minus the amount provided for removal by para. 104.1.2 (A.6.1).

(A.2) P = internal design pressure, psig [kPa (gage)]

NOTE: When computing the design pressure for a pipe of a definite minimum wall thickness by eq. (9) or (10), the value of P obtained by these formulas may be rounded out to the next higher unit of 10. For cast iron pipe, see para. 104.1.2(B).

(A.3) D_o = outside diameter of pipe, in. (mm). For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of t_m. When calculating the allowable working pressure of pipe on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.

(A.4) d = inside diameter of pipe, in. (mm). For design calculations, the inside diameter of pipe is the maximum possible value allowable under the purchase specification. When calculating the allowable working pressure of pipe on hand or in stock, the actual measured inside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.

(A.5) SE or SF = maximum allowable stress in material due to internal pressure and joint efficiency (or casting quality factor) at the design temperature, psi (MPa). The value of SE or SF shall not exceed that given in Mandatory Appendix A, for the respective material and design temperature. These values include the weld joint efficiency, E, or the casting factor, F.

(A.6) A = additional thickness, in. (mm)

(A.6.1) To compensate for material removed in threading, grooving, etc., required to make a mechanical joint, refer to para. 102.4.2.

(A.6.2) To provide for mechanical strength of the pipe, refer to para. 102.4.4 (not intended to provide for extreme conditions of misapplied external loads or for mechanical abuse).

(A.6.3) To provide for corrosion and/or erosion, refer to para. 102.4.1.

(A.7) y = coefficient having values as given in Table 104.1.2(A)

(A.8) W = weld strength reduction factor (see para. 102.4.7)
W = 1 for seamless pipe or for seam welded pipe operating below the creep range

(B) Thickness of gray and ductile iron fittings conveying liquids may be determined from ANSI/AWWA C110/A21.10 or ANSI/AWWA C153/A21.53. The thickness of ductile iron pipe may be determined by ANSI/AWWA C115/A21.15 or ANSI/AWWA C150/A21.50. These thicknesses include allowances for foundry tolerances and water hammer.

(C) While the thickness determined from eq. (7) or (8) is theoretically ample for both bursting pressure and material removed in threading, the following minimum requirements are mandatory to furnish added mechanical strength:

(C.1) Where steel pipe is threaded and used for steam service at pressure above 250 psi (1 750 kPa) or for water service above 100 psi (700 kPa) with water temperature above 220°F (105°C), the pipe shall be seamless having the minimum ultimate tensile strength of 48,000 psi (330 MPa) and a weight at least equal to Schedule 80 of ASME B36.10M.

(C.2) Where threaded brass or copper pipe is used for the services described in (C.1) above, it shall comply with pressure and temperature classifications permitted for these materials by other paragraphs of this Code and shall have a wall thickness at least equal to that specified above for steel pipe of corresponding size.

(16)

Table 104.1.2(A) Values of *y*

Material	Temperature, °F (°C) 900 (482) and Below	950 (510)	1,000 (538)	1,050 (566)	1,100 (593)	1,150 (621)	1,200 (649)	1,250 (677) and Above
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
Nickel alloy UNS No. N06690	0.4	0.4	0.4	0.4	0.5	0.7	0.7	. . .
Nickel alloys UNS Nos. N06617, N08800, N08810, N08825	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
Cast iron	0.0	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Other metals [Note (1)]	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

GENERAL NOTES:

(a) The value of y may be interpolated between the 50°F (27.8°C) incremental values shown in the Table.

(b) For pipe with a D_o/t_m ratio less than 6, the value of y for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below shall be taken as

$$y = \frac{d}{d + D_o}$$

NOTE:

(1) Metals listed in Mandatory Appendix A that are not covered by the categories of materials listed above.

(C.3) Plain end nonferrous pipe or tube shall have minimum wall thicknesses as follows:

(C.3.1) For nominal sizes smaller than NPS ¾ (DN 20), the thickness shall not be less than that specified for Type K of ASTM B88.

(C.3.2) For nominal sizes NPS ¾ (DN 20) and larger, the wall thickness shall not be less than 0.049 in. (1.25 mm). The wall thickness shall be further increased, as required, in accordance with para. 102.4.

104.1.3 Straight Pipe Under External Pressure. For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in UG-28, UG-29, and UG-30 of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code shall be followed.

104.1.4 Longitudinal-Welded or Spiral-Welded Pipe Operating in the Creep Range. The minimum thickness of pipe wall required for design pressures and for temperature not exceeding that for the various materials listed in the Allowable Stress Tables shall not be less than that determined by eq. (11) or (12) as follows:

$$t_m = \frac{PD_o}{2(SEW + Py)} + A \quad (11)$$

$$t_m = \frac{Pd + 2SEWA + 2yPA}{2(SEW + Py - P)} \quad (12)$$

Design pressure shall not exceed

$$P = \frac{2SEW(t_m - A)}{D_o - 2y(t_m - A)}$$

$$P = \frac{2SEW(t_m - A)}{d - 2y(t_m - A) + 2t_m}$$

where the nomenclature used above is given in para. 104.1.2 and

E = weld joint efficiency factor (as given in Table 102.4.3 and referenced in Mandatory Appendix A tables)

SE = maximum allowable stress in material due to internal pressure and joint efficiency at the design temperature, psi (MPa). The value of SE shall not exceed that given in Mandatory Appendix A, for the respective material and design temperature. These values include the weld joint efficiency factor, E.

W = weld strength reduction factor (see para. 102.4.7)

Also see requirements in para. 123.4 and Table 102.4.3.

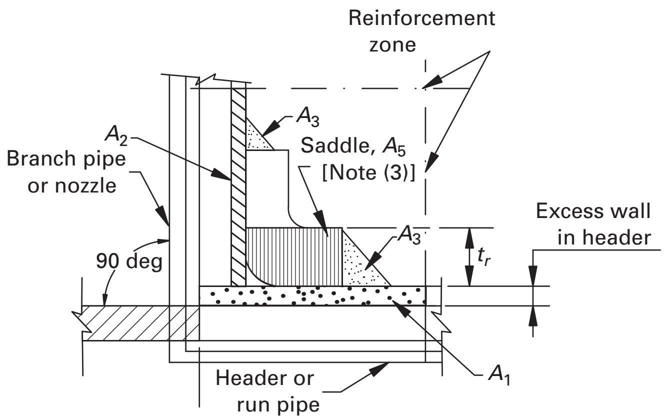
104.2 Curved Segments of Pipe

104.2.1 Pipe Bends. Pipe bends shall be subject to the following limitations:

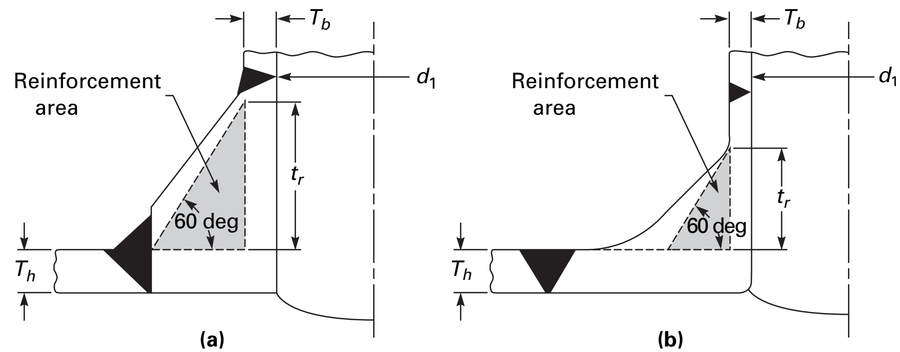
(A) The minimum wall thickness shall meet the requirements of para. 102.4.5 and the fabrication requirements of para. 129.

(B) Limits on flattening and buckling at bends may be specified by design, depending upon the service, the material, and the stress level involved. Where limits on flattening and buckling are not specified by design, the requirements of para. 129.1 shall be met.

Fig. 104.3.1(D) Reinforcement of Branch Connections (Cont'd)



Detail for Example A



Example B

(dt should be replaced with d1)

GENERAL NOTES:

(a) This Figure illustrates the nomenclature of para. 104.3.1(D).

(b) Required reinforcement area $= A_7 = A_6\ (2 - \sin\ \alpha) = (t_{mh} - A) d_t\ (2 - \sin\ \alpha)$.

(c) Available reinforcement areas $= A_1 + A_2 + A_3 + A_4 + A_5$ (as applicable).

(d) Available reinforcement areas ≥ required reinforcement area.

NOTES:

(1) When a ring or pad is added as reinforcement (Example A), the value of reinforcement area may be taken in the same manner in which excess header metal is considered, provided the weld completely fuses the branch pipe, header pipe, and ring or pad. Typical acceptable methods of welding that meet the above requirement are shown in Fig. 127.4.8(D), sketches (c) and (d).

(2) Width to height of rings and pads shall be reasonably proportioned, preferably on a ratio as close to 4:1 as the available horizontal space within the limits of the reinforcing zone along the run and the outside diameter of the branch will permit, but in no case may the ratio be less than 1:1.

(3) Reinforcement saddles are limited to use on 90 deg branches (Example A Detail).

The loads described in paragraph 101.5 may be considered as occasional loads, if the time limitations of the term k are met.

(SI Units)

$$S_L = \frac{PD_o}{(1\,000)4t_n} + \frac{0.75iM_A}{Z} \leq 1.0\ S_h$$

where

i = stress intensification factor (see Mandatory Appendix D). The product 0.75i shall never be taken as less than 1.0.

M_A = resultant moment loading on cross section due to weight and other sustained loads, in.-lb (mm-N) (see para. 104.8.4)

S_h = basic material allowable stress at maximum (hot) temperature [see para. 102.3.2(B)]

S_L = sum of the longitudinal stresses due to pressure, weight, and other sustained loads

Z = section modulus, in.^{3} (mm^3) (see para. 104.8.4)

104.8.2 Stress Due to Occasional Loads. The effects of pressure, weight, other sustained loads, and occasional loads ~~including earthquake~~ shall meet the requirements of eq. (16).

(U.S. Customary Units)

P_o →

$$\frac{PD_o}{4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kS_h \qquad (16)$$

(SI Units)

P_o →

$$\frac{PD_o}{(1\,000)4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kS_h$$

Terms same as para. 104.8.1, except

k = 1.15 for occasional loads acting for no more than 8 hr at any one time and no more than 800 hr/yr [see para. 102.3.3(A)]

= 1.2 for occasional loads acting for no more than 1 hr at any one time and no more than 80 hr/yr [see para. 102.3.3(A)]

M_B = resultant moment loading on the cross section due to occasional loads, such as thrusts from relief/safety valve loads, from pressure and flow transients, and earthquake, in.-lb (mm-N) [see paras. 102.3.3(A) and 104.8.4]

(16) **104.8.3 Stress Due to Displacement Load Ranges.** The effects of thermal expansion and other cyclic loads shall meet the requirements of eq. (17).

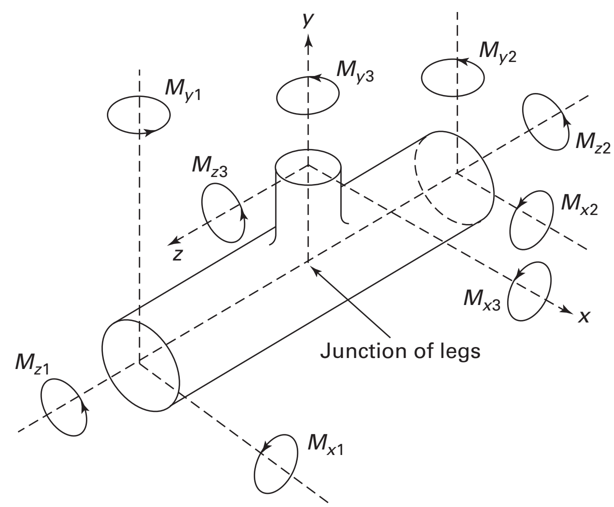
$$S_E = \frac{iM_C}{Z} \leq S_A \qquad (17)$$

Terms same as para. 104.8.1, except

M_C = resultant moment loading range on the cross section due to the reference displacement load range. For flexibility analyses, the resultant moment due to the ambient to normal operating load range and eq. (1A) are typically used, in.-lb (mm-N) [see paras. 102.3.2(B), 104.8.4, and 119.7].

P_o = Pressure coincident with the occasional load being evaluated, psi (kPa)

Fig. 104.8.4 Cross Section Resultant Moment Loading



104.8.4 Moments and Section Modulus

(A) For eqs. (15), (16), and (17), the resultant moments for straight through components, curved pipe, or welding elbows may be calculated as follows:

$$M_j = (M_{xj}^2 + M_{yj}^2 + M_{zj}^2)^{1/2}$$

where

j = A, B, or C as defined in paras. 104.8.1, 104.8.2, and 104.8.3

Z = section modulus of piping, in.^{3} (mm^3)

(B) For full outlet branch connections, calculate the resultant moment of each leg separately in accordance with (A) above. Use Z, section modulus, in eqs. (15), (16), and (17) as applicable to branch or run pipe. Moments are taken at the junction point of the legs. See Fig. 104.8.4.

(C) For reduced outlets, calculate the resultant moment of each leg separately in accordance with (A) above. Moments are to be taken at the junction point of the legs, unless the designer can demonstrate the validity of a less conservative method. See Fig. 104.8.4. For the reduced outlet branch, except for branch connections covered by Mandatory Appendix D, Fig. D-1, ↖ Table D-1 Note 15 or

$$M_A, M_B, M_C = \sqrt{M_{x3}^2 + M_{y3}^2 + M_{z3}^2}$$

and

Z = $\pi r_b^2 t_e$ (effective section modulus)

r_b = branch mean cross-sectional radius, in. (mm)

t_e = effective branch wall thickness, in. (mm)

= lesser of t_{nh} or it_{nb} in eq. (17), or lesser of t_{nh} or $0.75it_{nb}$, where $0.75i \geq 1.0$, in eqs. (15) and (16)

For the reduced outlet branch connections covered by Fig. D-1,

$$M_A, M_B, M_C = \sqrt{M_{x3}^2 + M_{y3}^2 + M_{z3}^2}$$

and

$$Z = \pi r'_m{}^2 T_b$$

If L_1 in Fig. D-1, illustrations (a), (b), and (c) equals or exceeds $0.5\sqrt{r_i T_b}$, then r'_m can be taken as the radius to the center of T_b when calculating the section modulus and the stress intensification factor. For such a case, the transition between branch pipe and nozzle must be evaluated separately from the branch connection.

For the main run outlets,

$$M_A, M_B, M_C = \sqrt{M_{x1}^2 + M_{y1}^2 + M_{z1}^2}$$

$$= \sqrt{M_{x2}^2 + M_{y2}^2 + M_{z2}^2}$$

and

Z = section modulus of pipe, in.^{3} (mm^3)

PART 3
SELECTION AND LIMITATIONS OF PIPING COMPONENTS

105 PIPE

105.1 General

Pipe conforming to the standards and specifications listed in Mandatory Appendix A shall be used within the range of temperatures for which allowable stresses are given within the limitations specified herein.

105.2 Metallic Pipe

105.2.1 Ferrous Pipe

(A) Furnace butt welded steel pipe shall not be used for flammable, combustible, or toxic fluids.

(B) Ductile iron pipe may be used for design pressures within the ratings established by the standards and specifications listed in Tables 126.1 and A-5 and Notes thereto, and the limitations herein and in para. 124.6. Ductile iron pipe shall not be used for flammable, combustible, or toxic fluids. Temperature limits for the use of ductile iron pipe are often determined by the type of elastomeric gasket used in the pipe joints, or the lining material used on the internal surface of the pipe. It is the reponsibility of the Designer to determine whether these components are suitable for use in the particular application being considered. See para. 106.1(E).

105.2.2 Nonferrous Pipe

(A) Copper and brass pipe for water and steam service may be used for design pressures up to 250 psi (1 750 kPa) and for design temperatures to 406°F (208°C).

(B) Copper and brass pipe for air may be used in accordance with the allowable stresses given in the Allowable Stress Tables.

(C) Copper tubing may be used for dead-end instrument service with the limitations stated in para. 122.3.2(D).

(D) Copper, copper alloy, or aluminum alloy pipe or tube may be used under the conditions stated in para. 124.7. Copper, copper alloy, or aluminum pipe or tube shall not be used for flammable, combustible, or toxic fluids except as permitted in paras. 122.7 and 122.8.

105.3 Nonmetallic Pipe

(A) Rules and service limitations for plastic and elastomer-based piping materials, with or without fabric or fibrous material added for pressure reinforcement, are given in Mandatory Appendix N. These materials include thermoplastics and reinforced thermosetting resins.

(B) Metallic piping lined with nonmetals may be used for fluids that would corrode or be contaminated by unprotected metal. See para. 122.9 and Mandatory Appendix N.

(C) Reinforced concrete pipe may be used in accordance with the specifications listed in Table 126.1 for water service up to 150°F (65°C).

(D) A flexible nonmetallic pipe or tube assembly may be used in applications where

(D.1) satisfactory service experience exists

(D.2) the pressure and temperature conditions are within the manufacturer's recommendations

(D.3) the conditions described in paras. 104.7, 124.7, and 124.9 are met

106 FITTINGS, BENDS, AND INTERSECTIONS

106.1 Fittings

shouldered,

(A) Threaded, flanged, grooved and ~~shouldered~~ socket-welding, buttwelding, compression, push-on, mechanical gland, and solder-joint fittings made in accordance with the applicable standards in Table 126.1 may be used in power piping systems within the material, size, pressure, and temperature limitations of those standards, and within any further limitations specified in this Code. Material for fittings in flammable, combustible, or toxic fluid systems shall in addition conform to the requirements of paras. 122.7 and 122.8.

(B) Fittings not covered by the Standards listed in Table 126.1 may be used if they conform to para. 104.7.

(C) Cast buttwelding steel fittings not covered by the dimensional standards listed in Table 126.1 may be used up to the manufacturer's pressure and temperature ratings, provided they are radiographed in accordance with MSS SP-54. Fittings with discontinuities in excess of those permitted by MSS SP-54 shall be rejected. The

Chapter III
Materials

123 GENERAL REQUIREMENTS

Chapter III contains limitations and required qualifications for materials based on their inherent properties. Use of these materials in piping systems is also subject to requirements and limitations in other parts of this Code.

123.1 Materials and Specifications

123.1.1 Listed Materials. Material meeting the following requirements shall be considered listed and acceptable material:

(A) Materials for which allowable stress values are listed in Mandatory Appendix A or that have been approved by the procedure established by (C) below.

(B) A material conforming to a specification for which [illegible] not listed in Mandatory [illegible] provided its use is not specifi[illegible]ode Section and it satisfies one [illegible]ents:

[Insert text from first sentence of Appendix VI, as indicated above]

(B.1) It is referenced in a standard listed in Table 126.1. Such a material shall be used only within the scope of and in [illegible]ed by the referencing standard

Start New Section: *(C.1)*

(B.2) It is referenced in other parts of this Code Section and shall be used only within the scope of and in the product form [illegible]

Insert text: ", the user need,"

(C) Where it is desired to use materials that are not currently acceptable under the rules of this Code Section, written application shall be made to the Committee fully describing the proposed material and the contemplated use. Such material shall not be considered listed and not used as a listed material until it has been approved by the Committee and allowable stress values have been assigned. Details of information that should be included in such applications are given in ~~Nonmandatory Appendix VI. See para. 123.1.2~~.

(D) Materials conforming to ASME SA or SB specifications may be used interchangeably with material specified to the listed ASTM A or B specifications of the same number, except where the requirements of para. 123.2.2 apply.

(E) The tabulated stress values in Mandatory Appendix A that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.

Add New Section: *(C.2)* [insert text from Appendix VI, as indicated above]

[illegible]**terials.** Materials other than [illegible]ements of para. 123.1.1 shall be considered unlisted materials. Such unlisted materials may only be used for nonboiler external piping provided they satisfy all of the following requirements:

(A) Unlisted materials are certified by the material manufacturer to satisfy the requirements of a specification listed in any Code Section of the ASME B31 Code for Pressure Piping, the ASME Boiler and Pressure Vessel Code, Section II, Part D, or to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control.

(B) The allowable stresses of the unlisted materials shall be determined in accordance with the rules of para. 102.3.1(C).

(C) Unlisted materials shall be qualified for service within a stated range of minimum and maximum temperatures based upon data associated with successful experience, tests, or analysis; or a combination thereof. See para. 124.1.2 for minimum service temperature qualifications.

(D) The designer shall document the owner's acceptance for use of unlisted material.

(E) All other requirements of this Code are satisfied.

123.1.3 Unknown Materials. Materials of unknown specification shall not be used for pressure-containing piping components.

Replace Deleted Text with: "ASME Boiler and Pressure Vessel Code (ASME BPVC) Section II, Part D, Mandatory Appendix 5.

[illegible] the [illegible]cope [illegible]y be [illegible]other requirements of the specification, and no other similar limitation is given in the rules for construction.

123.1.6 Marking of Materials or Products. Materials or products marked as meeting the requirements for more than one grade, type, or alloy of a material specification or multiple specifications, are acceptable provided

(A) one of the markings includes the material specification, grade, class, and type or alloy of the material permitted by this Code and the material meets all the requirements of that specification

(B) the appropriate allowable stress for the specified grade, type, or alloy of a material specification from Mandatory Appendix A is used

(C) all other requirements of this Code are satisfied for the material permitted

123.1.7 Materials Manufactured to Other Specification Editions. Materials may meet the requirements of material specification editions other than the editions listed in Mandatory Appendix F provided

(A) the materials are the same specification, grade, type, class, or alloy, and heat-treated condition, as applicable.

(B) the material tensile and yield strengths shall be compared and any differences shall be evaluated. If the material has a lower strength than required by the edition of the specification in Mandatory Appendix F, the effect of the reduction on the allowable stress and the design shall be reconciled.

123.2 Piping Components

123.2.1 General. Materials that do not comply with the rules of para. 123.1 may be used for flared, flareless, and compression type tubing fittings, provided that the requirements of para. 115 are met.

123.2.2 Boiler External Piping

(A) Materials for boiler external piping, as defined in para. 100.1.2(A), shall be specified in accordance with ASME SA, SB, or SFA specifications. Material produced under an ASTM specification may be used, provided that the requirements of the ASTM specification are identical or more stringent than the ASME specification for the Grade, Class, or Type produced. The material manufacturer or component manufacturer shall certify, with evidence acceptable to the Authorized Inspector, that the ASME specification requirements have been met. Materials produced to ASME or ASTM material specifications are not limited as to country of origin.

(B) Materials that are not fully identified shall comply with PG-10 of Section I of the ASME Boiler and Pressure Vessel Code.

(C) In addition to materials listed in Mandatory Appendix A without Note (1), materials that are listed in Section I of the ASME Boiler and Pressure Vessel Code may be used in boiler external piping. When such Section I materials are used, the allowable stresses shall be those listed in Section II, Part D, Subpart 1, Tables 1A and 1B applicable to Section I. For these Section I materials, the applicable requirements in Table 1A, Table 1B, and Section I paras. PG-5 through PG-13, PW-5, PWT-5, PMB-5, and PEB-5 shall be met.

123.3 Pipe-Supporting Elements

Materials used for pipe-supporting elements shall be suitable for the service and shall comply with the requirements of para. 121.2(C), para. 121.7.2(C), para. 121.7.2(D), para. 123.1, or MSS SP-58. When utilizing MSS SP-58, the allowable stresses for unlisted materials shall be established in accordance with the rules of para. 102.3.1(C) of ASME B31.1 in lieu of para. 4.4 of MSS SP-58.

123.4 Longitudinal-Welded or Spiral-Welded Pipe With Filler Metal Added

(A) For the purposes of para. 104.1.1, the start of the creep range is the highest temperature where the nonitalicized stress values end in Mandatory Appendix A.

(B) All welds in longitudinal-welded or spiral-welded pipe operating in the creep range shall receive and pass a 100% volumetric examination (RT or UT) per the applicable material specification or in accordance with para. 136.4.5 or 136.4.6 and Table 136.4, or the joint efficiency factor (used as a multiplier to the weld strength reduction factor) from Table 102.4.7 shall be used.

124 LIMITATIONS ON MATERIALS

124.1 Temperature Limitations

124.1.1 Upper Temperature Limits. The materials listed in the Allowable Stress Tables A-1 through A-10, Mandatory Appendix A, shall not be used at design temperatures above those for which stress values are given except as permitted by para. 122.6.2(G).

124.1.2 Lower Temperature Limits

(A) The designer shall give consideration to the possibility of brittle fracture at low service temperature.

(B) The requirements of ASME B31T, Standard Toughness Requirements for Piping, shall be met.

(B.1) For materials listed in B31T, see Nonmandatory Appendix VIII for guidelines to determine if low-temperature service requirements apply.

(B.2) For materials not listed in B31T, the designer shall establish the T-number group using the guidelines provided in B31T Nonmandatory Appendix B, and the requirements of B31T for that T-number group shall be met. To confirm the T-number group assignment, impact tests shall be run on three heats of the material. The test shall be in accordance with the requirements of section 4 of B31T and the test temperature shall be at or below the "Material Minimum Temperature Without Impacts" listed for the T-number group in Table 3.1-1 of B31T.

124.2 Steel

(A) Upon prolonged exposure to temperatures above 800°F (427°C), the carbide phase of plain carbon steel, [carbon-molybdenum steel,] plain nickel alloy steel, carbon–manganese alloy steel, manganese–vanadium alloy steel, and carbon–silicon steel may be converted to graphite.

(B) Upon prolonged exposure to temperatures above 875°F (468°C), the carbide phase of alloy steels, such as ~~carbon–molybdenum,~~ manganese–molybdenum–vanadium, manganese–chromium–vanadium, and chromium–vanadium, may be converted to graphite.

(C) Carbon or alloy steel having carbon content of more than 0.35% shall not be used in welded construction or be shaped by oxygen cutting process or other thermal cutting processes.

(D) Where low alloy 2¼% chromium steels are used at temperatures above 850°F (454°C), the carbon content of the base material and weld filler metal shall be 0.05% or higher.

(E) Carbon and low alloy steels may be susceptible to flow-accelerated corrosion (FAC, also referred to as flow-assisted corrosion) under certain conditions, which might include rapid or turbulent single- or two-phase flow, low pH, low oxygen concentration, and temperatures in the range of approximately 200oF (93oC) to 500oF (260oC). Materials containing at least 0.1% chromium are considered to be less susceptible to FAC, and these steels will exhibit increasing resistance to FAC as chromium content is increased. Additional information regarding FAC is provided in Appendix IV.

124.4 Cast Gray Iron

The low ductility of cast gray iron may result in sudden failure if shock loading (pressure, temperature, or mechanical) should occur. Possible shock loadings and consequences of failure must be considered before specifying the use of such material. Cast iron components may be used within the nonshock pressure–temperature ratings established by the standards and specifications herein and in para. 105.2.1(B). Castings to ASME SA-278 and ASTM A278 shall have maximum limits of 250 psig [1 725 kPa (gage)] and 450°F (232°C).

The following referenced paragraphs prohibit or restrict the use of gray cast iron for certain applications or to certain pressure–temperature ratings:

Pipe supports	121.7.2(C)
BEP blowoff	122.1.4(A.3)
BEP blowdown	122.1.4(B.3)
BEP valves and fittings	122.1.7
Blowoff valves	122.1.7(C.5) and (C.6)
Non-BEP blowoff	122.2(A.1)
Non-BEP blowdown	122.2(A.2)
Flammable or combustible liquids	122.7.2(A) and (B), 122.7.4
Flammable gases	122.8.1(B) and (C)
Toxic gases or liquids	122.8.2(B) and (D)

124.5 Malleable Iron

Certain types of malleable iron have low ductility characteristics and may be subject to brittle fracture. Malleable iron may be used for design conditions not to exceed 350 psig [2 415 kPa (gage)] or 450°F (232°C).

The following referenced paragraphs prohibit or restrict the use of malleable iron for certain applications or to certain pressure–temperature ratings:

Pipe supports	121.7.2(D)
BEP blowoff	122.1.4(A.3)
BEP blowdown	122.1.4(B.3)
Non-BEP blowoff	122.2(A.1)
Non-BEP blowdown	122.2(A.2)
Flammable or combustible liquids	122.7.2(A) and (B), 122.7.4
Flammable gases	122.8.1(B) and (C)
Toxic gases or liquids	122.8.2(B) and (D)

124.6 Ductile (Nodular) Iron

Ductile iron components complying with ANSI/AWWA C110/A21.10, C115/A21.15, C151/A21.51, or C153/A21.53 may be used for water and other nontoxic, nonflammable service, with pressure limits as specified in those standards and temperature limits as specified in para. 106(E). These components may not be used for boiler external piping.

(C) The following referenced paragraphs prohibit or restrict the use of ductile iron for certain applications or to certain pressure–temperature ratings:

BEP blowoff	122.1.4(A.3)
BEP blowdown	122.1.4(B.3)
BEP blowoff valves	122.1.7(C.5) and (C.6)
Non-BEP blowoff	122.2(A.1)
Non-BEP blowdown	122.2(A.2)
Flammable or combustible liquids	122.7.2(A) and (B), 122.7.4
Flammable gases	122.8.1(B) and (C)
Toxic gases or liquids	122.8.2(B) and (D)
Pipe supports	123.3

124.7 Nonferrous Metals

Nonferrous metals may be used in piping systems under the following conditions:

(A) The melting points of copper, copper alloys, aluminum, and aluminum alloys must be considered particularly where there is a fire hazard.

(B) The Designer shall consider the possibility of galvanic corrosion when combinations of dissimilar metals, such as copper, aluminum, and their alloys, are used in conjunction with each other or with steel or other metals in the presence of an electrolyte.

(C) Threaded Connections. A suitable thread compound shall be used in making up threaded joints in aluminum pipe to prevent seizing that might cause leakage and perhaps prevent disassembly. Pipe in the annealed temper should not be threaded.

124.8 Cladding and Lining Materials

Materials with cladding or lining may be used provided that

(A) the base material is an approved Code material. The allowable stress used shall be that of the base metal at the design temperature.

(B) the cladding or lining is a material that in the judgment of the user is suitable for the intended service, and the cladding/lining and its method of application do not detract from the serviceability of the base material.

(C) bending procedures are such that damaging or detrimental thinning of the cladding material is prevented.

(D) welding and the inspection of welds is in accordance with the provisions of Chapters V and VI of this Code.

(E) the thickness of the cladding is not credited for structural strength in the piping design.

124.9 Nonmetallic Pipe

This Code recognizes the existence of a wide variety of nonmetallic piping materials that may be used in corrosive (either internal or external) or other specialized applications. Extreme care must be taken in their selection, as their design properties vary greatly and depend upon the material, type, and grade. Particular consideration shall be given to

(A) possible destruction where fire hazard is involved

(B) possible decrease in tensile strength at slight increase in temperature

(C) effects of toxicity

(D) requirements for providing adequate support for flexible pipe

Rules and service limitations for plastic and elastomer-based piping materials, including thermoplastics and reinforced thermosetting resins, are given in Mandatory Appendix N.

124.10 Deterioration of Materials in Service

It is the responsibility of the engineer to select materials suitable for the intended application. Some guideline for selection of protective coatings for metallic piping are provided in Nonmandatory Appendix IV.

124.11 Gaskets

Limitations on gasket materials are covered in para. 108.4.

124.12 Bolting

Limitations on bolting materials are covered in para. 108.5.

125 CREEP STRENGTH ENHANCED FERRITIC MATERIALS

125.1 Requirements for ASTM A217 Grade C12A Castings

125.1.1 Required Examinations. The casting shall be examined in accordance with the requirements of para. 102.4.6(B).

Alternatively, castings for valves may be examined in accordance with the requirements of ASME B16.34 for special class valves.

125.1.2 Heat Treatment Requirements

(A) The material shall be austenitized within the temperature range of 1,900°F to 1,975°F (1 040°C to 1 080°C), followed by air or accelerated cooling[1] to a temperature of 200°F (95°C) or below, followed by tempering within a range of 1,350°F to 1,470°F (730°C to 800°C). However, if a major weld repair, as defined in ASTM A217, Section 9.4, is made after the austenitizing and tempering heat treatment, then a new austenitizing and tempering heat treatment in accordance with the requirements of this subparagraph shall be carried out.

(B) When heat treating single castings, compliance with the specified temperature range shall be verified by thermocouples placed directly on the casting. For castings that are heat treated in batches, compliance with the specified temperature range shall be verified by thermocouples placed on selected castings in each heat treatment batch. The number and location of thermocouples to be placed on each casting, or on each heat treatment batch of castings, for verification of heat treatment shall be as agreed between the purchaser and the producer. A record of the final austenitizing and tempering heat treatment, and any subsequent subcritical heat treatment, to include both the number and location of thermocouples applied to each casting, or to each heat treatment batch of castings, shall be prepared and made available to the purchaser. In addition, all heat treatment temperatures and cycle times for the final austenitizing and tempering heat treatment, and any subsequent subcritical heat treatment, shall be shown on the certification report.

(C) The hardness of the cast material after the final heat treatment (including PWHT) shall be Brinell hardness number 185 to 248 or Rockwell B90 to C25. Hardness testing shall be in accordance with Supplementary Requirement S13 of ASTM A217.

125.1.3 Weld Repair Requirements

(A) Weld repairs to castings shall be made with one of the following welding processes and consumables:

(A.1) SMAW, SFA-5.5/SFA-5.5M E90XX-B9

(A.2) SAW, SFA-5.23/SFA-5.23M EB9 + neutral flux

(A.3) GTAW, SFA-5.28/SFA-5.28M ER90S-B9

(A.4) FCAW, SFA-5.29/SFA-5.29M E91T1-B9

In addition, the Ni + Mn content of all welding consumables shall not exceed 1.0%.

(B) Weld repairs to castings as part of material manufacture shall be made with welding procedures and welders qualified in accordance with ASME BPVC Section IX.

(C) All weld repairs shall be recorded with respect to their location on the casting. For all major weld repairs, as defined in ASTM A217, Section 9.4, the record shall include a description of the length, width, and depth of the repair. Supplementary Requirement S12 of ASTM A703 shall apply. For weld repairs performed as part of material manufacture, the documentation shall

[1] To facilitate complete transformation to martensite after the austenitizing, cooling should be as uniform as possible.

(16)

Table 126.1 Specifications and Standards

Designator	Title
	AISC Publication
. . .	Manual of Steel Construction Allowable Stress Design
	ASCE Standard
ASCE/SEI 7	~~Minimum Design Loads for Buildings and Other Structures~~ Minimum Design Loads and Associated Criteria for Buildings and Other Structures
	ASTM Ferrous Material Specifications
Bolts, Nuts, and Studs	
A193/A193M	Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service
A194/A194M	Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service
A307	Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength
A320/A320M	Alloy-Steel Bolting Materials for Low-Temperature Service
A354	Quenched and Tempered Alloy Steel Bolts, Studs and Other Externally-Threaded Fasteners
A437/A437M	Stainless and Alloy-Steel Turbine-Type Bolting Material Specially Heat Treated for High Temperature Service
A449	Hex Cap Screws, Bolts, and Studs, Steel, Heat Treated
A453 / A453M	High-Temperature Bolting Materials, With Expansion Coefficients Comparable to Austenitic Steels
Castings	
A47/A47M	Ferritic Malleable Iron Castings
A48/A48M	Gray Iron Castings
A126	Gray Iron Castings for Valves, Flanges, and Pipe Fittings
A197/A197M	Cupola Malleable Iron
A216/A216M	Steel Castings, Carbon Suitable for Fusion Welding for High Temperature Service
A217/A217M	Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts Suitable for High-Temperature Service
A278/A278M	Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C)
A351/A351M	Steel Castings, Austenitic, for High-Temperature Service
A389/A389M	Steel Castings, Alloy, Specially Heat-Treated for Pressure-Containing Parts Suitable for High-Temperature Service
A395/A395M	Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures
A536	Ductile Iron Castings
Forgings	
A105/A105M	Carbon Steel Forgings for Piping Applications
A181/A181M	Carbon Steel Forgings for General Purpose Piping
A182/A182M	Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
A336/A336M	Alloy Steel Forgings for Pressure and High-Temperature Parts
A350/A350M	Carbon and Low-Alloy Steel Forgings Requiring Notch Toughness Testing for Piping
A965/A965M	Steel Forgings, Austenitic, for Pressure and High Temperature Parts
Cast Pipe	
A377	Standard Index of Specifications for Ductile Iron Pressure Pipe
A426/A426M	Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service
A451/A451M	Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service
Seamless Pipe and Tube	
A106/A106M	Seamless Carbon Steel Pipe for High-Temperature Service
A179/A179M	Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes
A192/A192M	Seamless Carbon Steel Boiler Tubes for High-Pressure Service
A210/A210M	Seamless Medium-Carbon Steel Boiler and Superheater Tubes
A213/A213M	Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
A335/A335M	Seamless Ferritic Alloy Steel Pipe for High-Temperature Service
A369/A369M	Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service
A376/A376M	Seamless Austenitic Steel Pipe for High-Temperature Central-Station Service

A1091/A1091M Steel Castings, Creep-Strength Enhanced Ferritic Alloy, for Pressure-Containing Parts, Suitable for High Temperature Service

Table 126.1 Specifications and Standards (Cont'd)

Designator	Title
	MSS Standard Practices (Cont'd)
SP-93	Quality Standard for Steel Castings and Forgings for Valves, Flanges, and Fittings and Other Piping Components — Liquid Penetrant Examination Method
SP-94	Quality Standard for Ferritic and Martensitic Steel Castings for Valves, Flanges, and Fittings and Other Piping Components — Ultrasonic Examination Method
SP-95	Swage(d) Nipples and Bull Plugs
SP-97	Integrally Reinforced Forged Branch Outlet Fittings — Socket Welding, Threaded and Buttwelding Ends
SP-105	Instrument Valves for Code Applications
SP-106	Cast Copper Alloy Flanges and Flanged Fittings: Class 125, 150, and 300
	ASME Codes & Standards
. . .	ASME Boiler and Pressure Vessel Code
B1.1	Unified Inch Screw Threads
B1.13M	Metric Screw Threads — M Profile
B1.20.1	Pipe Threads, General Purpose (Inch)
B1.20.3	Dryseal Pipe Threads (Inch)
B16.1	Cast Iron Pipe Flanges and Flanged Fittings — 25, 125, 250 & 800 Classes
B16.3	Malleable Iron Threaded Fittings
B16.4	Gray Iron Threaded Fittings
B16.5	Pipe Flanges and Flanged Fittings
B16.9	Factory-Made Wrought Buttwelding Fittings
B16.10	Face-to-Face and End-to-End Dimensions of Valves
B16.11	Forged Fittings, Socket-Welding and Threaded
B16.14	Ferrous Pipe Plugs, Bushings, and Locknuts With Pipe Threads
B16.15	Cast Bronze Threaded Fittings, Classes 125 and 250
B16.18	Cast Copper Alloy Solder-Joint Pressure Fittings
B16.20	Metallic Gaskets for Pipe Flanges — Ring Joint, Spiral Wound, and Jacketed
B16.21	Nonmetallic Flat Gaskets for Pipe Flanges
B16.22	Wrought Copper and Copper Alloy Solder Joint Pressure Fittings
B16.24	Cast Copper Alloy Pipe Flanges and Flanged Fittings — Class 150, 300, 400, 600, 900, 1500, and 2500
B16.25	Butt Welding Ends
B16.26	Cast Copper Alloy Fittings for Flared Copper Tubes
B16.34	Valves — Flanged, Threaded, and Welding End
B16.42	Ductile Iron Pipe Flanges and Flanged Fittings — Classes 150 and 300
B16.47	Large Diameter Steel Flanges
B16.48	Steel Line Blanks
B16.50	Wrought Copper and Copper Alloy Braze-Joint Pressure Fittings
B18.2.1	Square and Hex Bolts and Screws — Inch Series
B18.2.2	Square and Hex Nuts (Inch Series)
B18.2.3.5M	Metric Hex Bolts
B18.2.3.6M	Metric Heavy Hex Bolts
B18.2.4.6M	Hex Nuts, Heavy, Metric
B18.21.1	Lock Washers (Inch Series)
B18.22M	Washers, Metric Plain
B18.22.1 [Note (2)]	Plain Washers
B31.3	Process Piping
B31.4	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
B31.8	Gas Transmission and Distribution Piping Systems
B31E	Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems
B31J	~~Standard Test Method for Determining Stress Intensification Factors (*i*-Factors) for Metallic Piping Components~~ Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors) and their Determination for Metallic Piping Components
B31T	Standard Toughness Requirements for Piping
B36.10M	Welded and Seamless Wrought Steel Pipe
B36.19M	Stainless Steel Pipe
TDP-1	Recommended Practices for the Prevention of Water Damage to Steam Turbines Used for Electric Power Generation — Fossil Fueled Plants

Table 126.1 Specifications and Standards (Cont'd)

Designator	Title
	AWS Specifications
A3.0	Standard Welding Terms and Definitions
D10.10	Recommended Practices for Local Heating of Welds in Piping and Tubing
QC1	Standard for AWS Certification of Welding Inspectors
	AWWA and ANSI/AWWA Standards
C110/A21.10	Ductile-Iron and Gray-Iron Fittings, 3 in. Through 48 in. (76 mm Through 1200 mm), for Water and Other Liquids
C111/A21.11	Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings
C115/A21.15	Flanged Ductile-Iron Pipe With Threaded Flanges
C150/A21.50	Thickness Design of Ductile-Iron Pipe
C151/A21.51	Ductile-Iron Pipe, Centrifugally Cast, for Water
C153/A21.53	Ductile-Iron Compact Fittings, 3 in. Through 24 in. (76 mm Through 610 mm) and 54 in. Through 64 in. (1,400 mm Through 1,600 mm), for Water Service
C200	Steel Water Pipe—6 in. (150 mm) and Larger
C207	Steel Pipe Flanges for Waterworks Service—Sizes 4 in. Through 144 in. (100 mm Through 3,600 mm)
C208	Dimensions for Fabricated Steel Water Pipe Fittings
C300	Reinforced Concrete Pressure Pipe, Steel-Cylinder Type, for Water and Other Liquids (Includes Addendum C300a-93.)
C301	Prestressed Concrete Pressure Pipe, Steel-Cylinder Type, for Water and Other Liquids
C302	Reinforced Concrete Pressure Pipe, Noncylinder Type, for Water and Other Liquids
C304	Design of Prestressed Concrete Cylinder Pipe
C500	Metal-Seated Gate Valves for Water Supply Service
C504 [Note (1)]	Rubber Seated Butterfly Valves
C509	Resilient-Seated Gate Valves for Water Supply Service
C600	Installation of Ductile-Iron Water Mains and Their Appurtenances
C606	Grooved and Shouldered Joints
	National Fire Codes
NFPA 85	Boiler and Combustion Systems Hazards Code
NFPA 1963	Standard for Fire Hose Connections
	PFI Standards
ES-16	Access Holes and Plugs for Radiographic Inspection of Pipe Welds
ES-24	Pipe Bending Methods, Tolerances, Process and Material Requirements
	FCI Standard
79-1-09	Proof of Pressure Ratings for Pressure Regulators

Expansion Joint Manufacturers Association, Inc.
Standards of the Expansion Joint Manufacturers Association, Inc.

GENERAL NOTES:

(a) For boiler external piping application, see para. 123.2.2.

(b) For all other piping, materials conforming to an ASME SA or SB specification may be used interchangeably with material specified to an ASTM A or B specification of the same number listed in Table 126.1.

(c) The approved year of issue of the specifications and standards is not given in this Table. This information is given in Mandatory Appendix F of this Code.

(d) The addresses and phone numbers of organizations whose specifications and standards are listed in this Table are given at the end of Mandatory Appendix F.

NOTES:

(1) See para. 107.1(D) for valve stem retention requirements.

(2) ANSI B18.22.1 is nonmetric.

Table 127.4.2 Reinforcement of Girth and Longitudinal Butt Welds

Thickness of Base Metal, in. (mm)	Maximum Thickness of Reinforcement for Design Temperature					
	> 750°F (400°C)		≤ ~~350°F–~~750°F (~~175°C~~–400°C)		~~< 350°F (175°C)~~	
	in.	mm	in.	mm	~~in.~~	~~mm~~
Up to 1/8 (3.0), incl.	1/16	2.0	3/32	2.5	~~3/16~~	~~5.0~~
Over 1/8 to 3/16 (3.0 to 5.0), incl.	1/16	2.0	1/8	3.0	~~3/16~~	~~5.0~~
Over 3/16 to 1/2 (5.0 to 13.0), incl.	1/16	2.0	5/32	4.0	~~3/16~~	~~5.0~~
Over 1/2 to 1 (13.0 to 25.0), incl.	3/32	2.5	3/16	5.0	~~3/16~~	~~5.0~~
Over 1 to 2 (25.0 to 50.0), incl.	1/8	3.0	1/4	6.0	~~1/4~~	~~6.0~~
Over 2 (50.0)	5/32	4.0	The greater of 1/4 in. (6 mm) or 1/8 times the width of the weld in inches (millimeters).			

GENERAL NOTES:

double sided groove welds

(a) For ~~double welded butt joints~~, this limitation on reinforcement given above shall apply separately to both inside and outside surfaces of the joint.

(b) ~~For single welded butt joints, the reinforcement limits given above shall apply to the outside surface of the joint only.~~

(c) The thickness of weld reinforcement shall be based on the thickness of the thinner of the materials being joined.

(d) The weld reinforcement thicknesses shall be determined from the higher of the abutting surfaces involved.

(e) Weld reinforcement may be removed if so desired.

(b): For single sided groove welds with backing strips or bars that remain in place, the limitation on reinforcement given above shall apply to the outside surface. For single sided groove welds without backing strips or bars that remain in place, the limits shall apply to the outside surface; and they also apply to the inside surface when the inside surface is readily available.

Table 129.3.1 Approximate Lower Critical Temperatures

Material	Approximate Lower Critical Temperature, °F (°C) [Note (1)]
Carbon steel (P-No. 1)	1,340 (725)
Carbon–molybdenum steel (P-No. 3)	1,350 (730)
1Cr–½Mo (P-No. 4, Gr. No. 1)	1,375 (745)
1¼Cr–½Mo (P-No. 4, Gr. No. 1)	1,430 (775)
2¼Cr–1Mo, 3Cr–1Mo (P-No. 5A)	1,480 (805)
5Cr–½Mo (P-No. 5B, Gr. No. 1)	1,505 (820)
9Cr	1,475 (800)
9Cr–1Mo–V, 9Cr–2W (P-No. 15E)	1,470 (800)

NOTE:
(1) These values are intended for guidance only. The user may apply values obtained for the specific material in lieu of these values.

records that identify the braze joints(s) made by the brazer or brazing operator.

129 BENDING AND FORMING

129.1 Bending

Pipe may be bent by any hot or cold method and to any radius that will result in a bend surface free of cracks. Such bends shall meet the design requirements of para. 102.4.5 with regard to minimum wall thickness. Where limits on flattening and buckling are not specified by design, as delineated in para. 104.2.1, manufacturing limits of PFI ES-24 shall be met. When defaulting to PFI ES-24, mutual agreement between purchaser and fabricator beyond the stated manufacturing limits shall not be allowed without the approval of the designer.

The use of bends designed as creased or corrugated is not prohibited.

129.2 Forming

Piping components may be formed (swedging, lapping, or upsetting of pipe ends, extrusion of necks, etc.) by any suitable hot or cold working method, provided such processes result in formed surfaces that are uniform and free of cracks or other defects, as determined by method of inspection specified in the design.

129.3 Heat Treatment of Bends and Formed Components

129.3.1 Except for creep strength enhanced ferritic steels (P-No. 15E), hot bending or hot forming is performed at a temperature equal to or above T_{crit} − 100°F (56°C), where T_{crit} is the lower critical temperature of the material. Cold bending or cold forming is performed at a temperature below T_{crit} − 100°F (56°C). (See Table 129.3.1 for lower critical temperatures.) For creep strength enhanced ferritic steels (P-No. 15E), hot bending or hot forming is performed at a temperature equal to or above 1,300°F (705°C). Cold bending or cold forming is performed at a temperature below 1,300°F (705°C).

129.3.2 A postbending or postforming heat treatment at the time and temperature cycles listed for postweld heat treatment in Table 132 is required on all carbon steel (P-No. 1) materials with a nominal wall thickness in excess of 0.75 in. (19.0 mm) unless the bending or forming operations are performed and completed at temperatures of 1,650°F (900°C) or greater.

129.3.3 A postforming or postbending heat treatment as defined below is required for all ferritic alloy (16)
steel (excluding P-No. 1 and P-No. 15E) materials with a nominal pipe size 4 in. (DN 100) and larger or with a nominal thickness of 0.50 in. (12.7 mm) or greater.

(A) If hot bending or hot forming is performed, the material shall receive a full anneal, normalization and temper, or tempering heat treatment as specified by the designer.

(B) If cold bending or cold forming is performed, a heat treatment is required at the time and temperature cycle listed for the material in Table 132.

129.3.3.1 Creep strength enhanced ferritic ~~steel~~ steels (16)
(P-No. 15E) ~~materials~~ subject to forming or bending shall be heat treated in accordance with the following rules. When the material is cold formed or cold bent, cold forming strains shall be calculated in accordance with para. 129.3.4.1 or para. 129.3.4.2.

(A) If hot bending or hot forming is performed, and for all cold swages, flares, or upsets, normalizing and tempering of the material is required in accordance with the requirements in the base material specification.

(B) If cold bending or cold forming is performed, the material shall be heat treated as listed in Table 129.3.3.1.

129.3.3.2 For materials with less than or equal to 5% strain or design temperatures less than 1,000°F (540°C), heat treatment is neither required nor prohibited.

129.3.4 Postbending or postforming heat treatment of austenitic materials and nickel alloys shall be performed as follows:

129.3.4.1 Cold-formed areas of components manufactured of austenitic ~~alloys~~ and nickel alloys shall be heat treated after forming if they exceed both the design temperatures and forming strains shown in Table 129.3.4.1. Forming strains shall be calculated as follows:

(A) For cylinders formed from plate

$$\% \text{ strain} = 50t_n/R_f(1 - R_f/R_g)$$

(B) For spherical or dished heads formed from plate

$$\% \text{ strain} = 75t_n/R_f(1 - R_f/R_g)$$

or Creep Strength Enhanced Ferritic Steels

Table 129.3.3.1 Post Cold-Forming Strain Limits and Heat-Treatment Requirements (16)

		Limitations in Lower Temperature Range					Limitations in Higher Temperature Range			
		For Design Temperature								
		Exceeding		But Less Than or Equal to			For Design Temperature Exceeding			Required Heat Treatment When Design Temperature and Forming Strain Limits Are Exceeded
Grade	UNS Number	°F	°C	°F	°C	And Forming Strains	°F	°C	And Forming Strains	
91	K90901	1,000	540	1,115	600	>25%	1,115	600	>20%	Normalize and temper [Note (1)]
		1,000	540	1,115	600	>5% to ≤25%	1,115	600	>5% to ≤20%	Postbend heat treatment [Notes (2), (3), and (4)]

GENERAL NOTE: The limits shown are for pipe and tube formed from plates, spherical or dished heads formed from plate, and tube and pipe bends. The forming strain limits tabulated in this Table shall be divided by two if para. 129.3.4.2 is applied.

NOTES:

(1) Normalization and tempering shall be performed in accordance with the requirements in the base material specification, and shall not be performed locally. The material shall either be heat treated in its entirety, or the cold-strained area (including the transition to the unstrained portion) shall be cut away from the balance of the tube or component and heat treated separately or replaced.

(2) Postbend heat treatments shall be performed at 1,350°F to 1,425°F (730°C to 775°C) for 1 hr/in. (1 h/25 mm) or 30 min minimum. Alternatively, a normalization and temper in accordance with the requirements in the base material specification may be performed.

(3) For materials with greater than 5% strain but less than or equal to 25% strain, with design temperatures less than or equal to 1,115°F (600°C), if a portion of the component is heated above the heat-treatment temperature allowed above, one of the following actions shall be performed:

(a) The component in its entirety must be renormalized and tempered.

(b) For BEP piping only, the allowable stress shall be that for Grade 9 material (i.e., SA-213 T9, SA-335 P9, or equivalent product specification) at the design temperature, provided that the portion of the component that was heated to a temperature exceeding the maximum holding temperature is subjected to a final heat treatment within the temperature range and for the time required in Note (2) above. The use of this provision shall be noted on the Manufacturer's Data Report.

(4) If a longitudinal weld is made to a portion of the material that is cold strained, that portion shall be normalized and tempered prior to or following welding. This normalizing and tempering shall not be performed locally.

(C) For tube and pipe bends

$$\% \text{ strain} = 100 r_{od}/R$$

where

R = centerline radius of bend

R_f = mean radius after forming

R_g = original mean radius (equal to infinity for a flat plate)

r_{od} = nominal outside radius of pipe or tube

t_n = nominal thickness of the plate, pipe, or tube before forming

129.3.4.2 When forming strains cannot be calculated as shown in para. 129.3.4.1, the manufacturer shall have the responsibility to determine the maximum forming strain.

129.3.4.3 For flares, swages, or upsets, heat treatment in accordance with Table 129.3.4.1 shall apply, regardless of the amount of strain, unless the finishing forming temperature is equal to or greater than the minimum heat treatment temperature for a given grade or UNS number material, provided the requirements of para. 129.3.4.5 are met.

129.3.4.4 Heat treatment, in accordance with Table 129.3.4.1, shall not be required if the finishing forming temperature is equal to or greater than the minimum heat treatment temperature for a given grade or UNS number material, provided the requirements of para. 129.3.4.5 are met.

129.3.4.5 The piping components being heat treated shall be held at the temperatures given in Table 129.3.4.1 for 20 min/in. (20 min/25 mm) of thickness, or for 10 min, whichever is greater. (16)

129.3.4.6 Postbending or postforming heat treatment of materials not identified in Table 129.3.4.1 is neither required nor prohibited. If a postbending or postforming heat treatment is to be performed, the designer shall fully describe the procedure to be used.

129.3.5 For ASTM A335 P36 and ASTM A182 F36, after either cold bending to strains in excess of 5% or any hot bending of this material, the full length of the component shall be heat treated in accordance with the requirements specified in the material specification.

129.3.6 Postbending or postforming heat treatment of other materials is neither required nor prohibited. If a postbending or postforming heat treatment is to be performed, the designer shall fully describe the procedure to be used.

for Austenitic Materials and Nickel Alloys

(16)

Table 129.3.4.1
Post Cold-Forming Strain Limits and Heat-Treatment Requirements

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

GENERAL NOTE: The limits shown are for pipe and tube formed from plates, spherical or dished heads formed from plate, and pipe and tube bends. When the forming strains cannot be calculated as shown in para. 129.3.4.1, the forming strain limits shall be half those tabulated in this Table (see para. 129.3.4.2).

NOTES:

(1) Rate of cooling from heat-treatment temperature not subject to specific control limits.

(2) While minimum heat-treatment temperatures are specified, it is recommended that the heat-treatment temperature range be limited to 150°F (85°C) above that minimum and 250°F (140°C) for 347, 347H, 348, and 348H.

(3) For simple bends of tubes or pipes whose outside diameter is less than 3.5 in. (89 mm), this limit is 20%.

Table 131.4.1 Preheat Temperatures

Base Metal P-No. [Note (1)]	Base Metal Group	Greater Material Thickness		Additional Limits	Required Minimum Temperature	
		in.	mm		°F	°C
1	Carbon steel	≤1	≤25	~~%C > 0.30 [Note (2)]~~ None	50	10
		>1	>25	%C ≤ 0.30 [Note (2)]	50	10
		>1	>25	%C > 0.30 [Note (2)]	200	95
3	Alloy steel Cr ≤ ½%	≤½	≤13	SMTS ≤ 65 ksi (450 MPa)	50	10
		>½	>13	SMTS ≤ 65 ksi (450 MPa)	200	95
		All	All	SMTS > 65 ksi (450 MPa)	200	95
4	Alloy steel ½% < Cr ≤ 2%	All	All	None	250	120
5A	Alloy steel	All	All	SMTS ≤ 60 ksi (414 MPa)	300	150
				SMTS > 60 ksi (414 MPa)	400	200
5B	Alloy steel	All	All	SMTS ≤ 60 ksi (414 MPa)	300	150
		All	All	SMTS > 60 ksi (414 MPa)	400	200
		>½	>13	%Cr > 6.0 [Note (2)]	400	200
6	Martensitic stainless steel	All	All	None	400 [Note (3)]	200 [Note (3)]
9A	Nickel alloy steel	All	All	None	250	120
9B	Nickel alloy steel	All	All	None	300	150
10I	27Cr steel	All	All	None	300 [Note (4)]	150 [Note (4)]
15E	9Cr–1Mo–V CSEF steel	All	All	None	400	200
All other materials		. . .	. . .	None	50	10

GENERAL NOTE: SMTS = specified minimum tensile strength.

NOTES:

(1) P-Nos. and Group nos. from ASME BPV Code, Section IX, QW/QB-422.

(2) Composition may be based on ladle or product analysis or per specification limits.

(3) Maximum interpass temperature 600°F (315°C).

(4) Maintain interpass temperature between 300°F and 450°F (150°C and 230°C).

listed below. Except as otherwise provided in paras. 127.4.9, 132.2, and 132.3, all welds in materials included in the P-Numbers listed in Table 132 shall be given a postweld heat treatment within the temperature range specified in Table 132. (The range specified in Table 132 may be modified by Table 132.1 for the lower limit and para. 132.2 for the upper limit.) The materials in Table 132 are listed in accordance with the material P-Numbers and Group numbers of ASME BPVC, Section IX, Table QW/QB-422. (Note that the P-Nos. are also listed in Mandatory Appendix A.) Welds of materials not included in Table 132 shall be heat treated in accordance with the WPS. Austenitizing PWHTs may be performed but are required to be addressed within the qualified WPS.

132.1.2 Pressure part welds and attachment welds using ferritic filler metals that have a specified chromium content of more than 3% shall receive a postweld heat treatment. The postweld heat treatment time and temperature range used shall be that shown in Table 132 for a base metal of similar composition.

132.1.3 For ASTM A335 P36 and ASTM A182 F36, postweld heat treatment is mandatory under all conditions. Postweld heat treatment shall be in accordance with Table 132.1.3.

132.2 Mandatory PWHT Requirements

Heat treatment may be accomplished by a suitable heating method that will provide the desired heating

Table 132 Postweld Heat Treatment

P-No. and Group No. (ASME BPV Code, Section IX, QW/QB-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Control Thickness [Note (2)]	
		≤2 in. (50 mm)	>2 in. (50 mm)
P-No. 1, Groups 1–3	1,100 to 1,200 (595 to 650)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)
P-No. 3, Groups 1 and 2	1,100 to 1,200 (595 to 650)		
P-No. 4, Groups 1 and 2	1,200 to 1,300 (650 to 705)		
P-No. 5A, Group 1	1,250 to 1,400 (675 to 760)		
P-No. 5B, Group 1	1,250 to 1,400 (675 to 760)		
P-No. 6, Groups 1–3	1,400 to 1,475 (760 to 800)		
P-No. 7, Groups 1 and 2 [Note (3)]	1,350 to 1,425 (730 to 775)		
P-No. 8, Groups 1–4	PWHT not required unless required by WPS		
P-No. 9A, Group 1	1,100 to 1,200 (595 to 650)		
P-No. 9B, Group 1	1,100 to 1,175 (595 to 630)		
P-No. 10H, Group 1	PWHT not required unless required by WPS. If done, see Note (4).		
P-No. 10I, Group 1 [Note (3)]	1,350 to 1,500 (730 to 815)		
P-No. 15E, Group 1 [Note (5)]	~~1,350 to 1,425 (730 to 775)~~ [1300 to 1425 (705 to 775)] [Notes (6), (7)]	1 hr/in. (25 mm), 30 min minimum	1 hr/in. (25 mm) up to 5 in. (125 mm) plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)
All other materials	PWHT as required by WPS	Per WPS	Per WPS

GENERAL NOTE: The exemptions for mandatory PWHT are defined in Table 132.2.

NOTES:

(1) The holding temperature range is further defined in paras. 132.1.1 and 132.2.

(2) The control thickness is defined in para. 132.4.1.

(3) Cooling rate shall not be greater than 100°F (55°C) per hour in the range above 1,200°F (650°C), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.

(4) If PWHT is performed after bending, forming, or welding, it shall be within the following temperature ranges for the specific alloy, followed by rapid cooling:

Alloys S31803 and S32205 — 1,870°F to 2,010°F (1 020°C to 1 100°C)
Alloy S32550 — 1,900°F to 2,050°F (1 040°C to 1 120°C)
Alloy S32750 — 1,880°F to 2,060°F (1 025°C to 1 125°C)
All others — 1,800°F to 1,900°F (980°C to 1 040°C)

(5) See para. 125.1.2(C) for hardness requirements for ASTM A217 Grade C12A [and A1091 Grade C91] castings after PWHT.

(6) The minimum PWHT holding temperature may be ~~1,325°F (720°C)~~ [1250F (675C)] for nominal material thicknesses (see para. 132.4.3) ≤½ in. (13 mm).

(7) The Ni+Mn content of the filler metal shall not exceed 1.2% unless specified by the designer, in which case the maximum temperature to be reached during PWHT shall be the A_1 (lower transformation or lower critical temperature) of the filler metal, as determined by analysis and calculation or by test, but not exceeding 1,470°F (800°C). If the 1,470°F (800°C) was not exceeded but the A_1 of the filler metal was exceeded or if the composition of the filler metal is unknown, the weld must be removed and replaced. It shall then be rewelded with compliant filler metal and subjected to a compliant PWHT. If the 1,470°F (800°C) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation.

Table 132.1 Alternate Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels, P-Nos. 1 and 3

Decrease in Specified Minimum Temperature, °F (°C)	Minimum Holding Time at Decreased Temperature, hr [Note (1)]
50 (30)	2
100 (55)	4
150 (85) [Note (2)]	10
200 (110) [Note (2)]	20

NOTES:
(1) Times shown apply to thicknesses ≤1 in. (25 mm). Add 15 min/in. (25 mm) of thickness for control thicknesses >1 in. (25 mm) (see para. 132.4).
(2) A decrease >100°F (55°C) below the minimum specified temperature is allowable only for P-No. 1, Groups 1 and 2 materials.

Table 132.1.3 Postweld Heat Treatment of P36/F36

Class	Holding Temperature, °F (°C)	Holding Time
1	1,100–1,200 (595–650)	2 in. (50 mm) and less thickness: 1 hr/in. (25 mm), 15 min minimum Over 2 in. (50 mm): add 15 min for each additional 1 in. (25 mm) of thickness
2	1,000–1,150 (540–620)	1 hr/in. (25 mm), ½ hr minimum

and cooling rates, the required metal temperature, temperature uniformity, and temperature control.

(A) The upper limit of the PWHT temperature range in Table 132 is a recommended value that may be exceeded provided the actual temperature does not exceed the lower critical temperature of either material (see Table 129.3.1).

(B) When parts of two different P-Numbers are joined by welding, the postweld heat treatment shall be that specified for the material requiring the higher PWHT temperature. When a nonpressure part is welded to a pressure part and PWHT is required for either part, the maximum PWHT temperature shall not exceed the maximum temperature acceptable for the pressure retaining part.

(C) Caution is necessary to preclude metallurgical damage to some materials or welds not intended or qualified to withstand the PWHT temperatures required. The use of material transition joint designs may be required.

(D) The designer may require PWHT even if not mandatory per Table 132 or Table 132.2.

132.3 Exemptions to Mandatory PWHT Requirements

132.3.1 Postweld heat treatment is not required for the following conditions unless required by the qualified WPS or the designer:

(A) welds in nonferrous materials

(B) welds exempted in Table 132 or Table 132.2

(C) welds subject to temperatures above the lower critical temperature (see Table 129.3.1) during fabrication provided the WPS has been qualified with PWHT (see para. 132.1) at the temperature range to be reached during fabrication

132.3.2 The postweld heat treatment exemptions of Table 132.2 may be based on the actual chemical composition as determined by a ladle or product analysis in accordance with the material specification in lieu of the specified or maximum specified chemical composition limits.

132.3.3 Thermocouples may be temporarily attached directly to pressure-containing parts using the capacitor discharge method of welding in accordance with the requirements of para. 127.4.9(A).

132.4 Definition of Thicknesses ~~Governing~~ Controlling PWHT

132.4.1 The term *control thicknesses* as used in Table 132, Table 132.2, and Notes is the lesser thickness of (A) or (B) as follows:

(A) the thickness of the weld

(B) the thicker of the materials being joined at the weld or the thickness of the pressure-containing material if the weld is attaching a nonpressure-containing material to a pressure-containing material

132.4.2 Thickness of the weld, which is a factor in determining the control thickness, is defined as follows: (16)

(A) groove welds (girth and longitudinal) — the thicker of the two abutting ends after weld preparation, including I.D. machining

Chapter VI
Inspection, Examination, and Testing

Authorized Inspection

136 INSPECTION AND EXAMINATION

136.1 Inspection

136.1.1 General. Inspection is the responsibility of the owner and may be performed by employees of the owner or a party authorized by the owner, except for the inspections required by para. 136.2.

136.1.2 Verification of Compliance. Prior to initial operation, a piping installation shall be inspected to ensure that the piping has been constructed in accordance with the design, material, fabrication, assembly, examination, and testing requirements of this Code.

(A) For boiler external piping (BEP), the Authorized Inspector shall verify, in accordance with PG-90 of Section I of the Boiler and Pressure Vessel Code, compliance with the requirements of this Code when a Code stamp for BEP is to be applied. The quality control system requirements of Nonmandatory Appendix A, A-301 and A-302, of Section I of the ASME Boiler and Pressure Vessel Code and Mandatory Appendix J of this Code shall apply.

(B) For nonboiler external piping (NBEP), the owner shall ensure that the design and construction documents and the requirements of this Code have been complied with in accordance with the owner's requirements.

136.1.3 Rights of Inspectors. Inspectors shall have access to any place where work concerned with the piping is being performed. This includes manufacture, fabrication, heat treatment, assembly, erection, examination, and testing of the piping. They shall have the right to audit any examination, to inspect the piping using any appropriate examination method required by the engineering design or this Code, and to review all certifications and records necessary to satisfy the owner's responsibility as stated in para. 136.1.1.

(16) **136.1.4 Qualifications of the Owner's Inspector**

(A) The Owner's Inspector shall be designated to perform inspections on behalf of the owner and shall be an employee of the owner, an engineering or scientific organization, or a recognized insurance or inspection company acting as the owner's agent. The Owner's Inspector shall not represent nor be an employee of the piping manufacturer, fabricator, or erector unless the owner is also the manufacturer, fabricator, or erector.

(B) The Owner's Inspector shall meet one of the following requirements:

(B.1) have at least 10 yr of experience in the design, manufacture, erection, fabrication, inspection, or examination of piping systems. Each year of satisfactorily completed work toward an accredited engineering or engineering technology degree shall be considered equivalent to 1 yr of experience, up to 5 yr total.

(B.2) have a professional engineering registration or nationally recognized equivalent with a minimum of 5 yr of experience in the design, manufacturing, erection, fabrication, inspection, or examination of piping systems.

(B.3) be a certified Welding Inspector or a Senior Certified Welding Inspector as defined in AWS QC1, or a nationally recognized equivalent, with a minimum of 5 yr of experience in the design, manufacturing, erection, fabrication, inspection, or examination of piping systems.

(B.4) be an Authorized Piping Inspector as defined in API 570, Piping Inspection Code: In-Service Inspection, Rating, Repair, and Alteration of Piping Systems, with a minimum of 5 yr of experience in the design, manufacturing, erection, fabrication, inspection, or examination of piping systems.

(C) In delegating the performance of inspections, the owner is responsible for determining that a person to whom an inspection function is delegated is qualified to perform that function.

136.2 Inspection and Qualification of Authorized Inspector for Boiler External Piping

Authorized Inspection

136.2.1 Piping for which inspection and stamping is required as determined in accordance with para. 100.1.2(A) shall be inspected during construction and after completion and at the option of the Authorized Inspector at such stages of the work as he/she may designate. For specific requirements see the applicable parts of Section I of the ASME Boiler and Pressure Vessel Code, PG-104 through PG-113. Each manufacturer, fabricator, or assembler is required to arrange for the services of Authorized Inspectors.

Authorized Inspection

136.2.1.1 The inspections required by this Section shall be performed by an Inspector employed by an ASME accredited Authorized Inspection Agency.

136.2.2 Certification by use of the ASME Certification Mark and Designators, and Data Reports, ASME CA-1 Conformity Assessment Requirements

where required, shall be as per ~~PG-104, PG-105, PG-109, PG-110, PG-111, and PG-112 of Section I of the ASME Boiler and Pressure Vessel Code~~.

136.3 Examination

136.3.1 General. Examination denotes the functions performed by the manufacturer, fabricator, erector, or a party authorized by the owner that include nondestructive examinations (NDE), such as visual, radiography, ultrasonic, eddy current, liquid penetrant, and magnetic particle methods. The degree of examination and the acceptance standards beyond the requirements of this Code shall be a matter of prior agreement between the manufacturer, fabricator, or erector and the owner.

(16) **136.3.2 Qualification of NDE Personnel.** Personnel who perform nondestructive examination of welds shall be qualified and certified for each examination method in accordance with a program established by the employer of the personnel being certified, which shall be based on the following minimum requirements:

(A) instruction in the fundamentals of the nondestructive examination method.

(B) on-the-job training to familiarize the NDE personnel with the appearance and interpretation of indications of weld defects. The length of time for such training shall be sufficient to ensure adequate assimilation of the knowledge required.

(C) an eye examination performed at least once each year to determine optical capability of NDE personnel to perform the required examinations.

(D) upon completion of (A) and (B) above, the NDE personnel shall be given a~~n oral or~~ written examination and performance examination by the employer to determine if the NDE personnel are qualified to perform the required examinations and interpretation of results.

(E) certified NDE personnel whose work has not included performance of a specific examination method for a period of 1 yr or more shall be recertified by successfully completing the examination of (D) above and also passing the visual examination of (C) above. Substantial changes in procedures or equipment shall require recertification of the NDE personnel.

, T-120(e) or (f),

As an alternative to the preceding program, the requirements of the ASME Boiler and Pressure Vessel Code, Section V, Article 1 may be used for the qualification of NDE personnel. Personnel qualified to AWS QC1 may be used for the visual examination of welds provided they meet the annual eye examination requirement of (C) above and the J1 visual acuity requirement of Section V, Article 9.

136.4 Examination Methods of Welds

136.4.1 Nondestructive Examination. Nondestructive examinations shall be performed in accordance with the requirements of this Chapter. The types and extent of mandatory examinations for pressure welds and welds to pressure retaining components are specified in Table 136.4. For welds other than those covered by Table 136.4, only visual examination is required. Welds requiring nondestructive examination shall comply with the applicable acceptance standards for indications as specified in paras. 136.4.2 through 136.4.6. As a guide, the detection capabilities for the examination method are shown in Table 136.4.1. Welds not requiring examination (i.e., RT, UT, MT, or PT) by this Code or the engineering design shall be judged acceptable if they meet the examination requirements of para. 136.4.2 and the pressure test requirements specified in para. 137. NDE for P-Nos. 3, 4, 5A, 5B, and 15E material welds shall be performed after postweld heat treatment unless directed otherwise by engineering design. Required NDE for welds in all other materials may be performed before or after postweld heat treatment.

136.4.2 Visual Examination. Visual examination as defined in para. 100.2 shall be performed in accordance with the requirements described in Section V, Article 9, of the ASME Boiler and Pressure Vessel Code. Visual examinations may be conducted, as necessary, during the fabrication and erection of piping components to provide verification that the design and WPS requirements are being met. In addition, visual examination shall be performed to verify that all completed welds in pipe and piping components comply with the acceptance standards specified in (A) below or with the limitations on imperfections specified in the material specification under which the pipe or component was furnished. (16)

(A) Acceptance Standards. The following indications are unacceptable:

(A.1) cracks — external surface.

(A.2) undercut on the surface that is greater than $\frac{1}{32}$ in. (1.0 mm) deep, or encroaches on the minimum required section thickness.

(A.3) undercut on the surface of longitudinal butt welds.

(A.4) weld reinforcement greater than specified in Table 127.4.2.

(A.5) lack of fusion on surface.

(A.6) incomplete penetration (applies only when inside surface is readily accessible).

(A.7) any other linear indications greater than $\frac{3}{16}$ in. (5.0 mm) long.

(A.8) surface porosity with rounded indications having dimensions greater than $\frac{3}{16}$ in. (5.0 mm) or four or more rounded indications separated by $\frac{1}{16}$ in. (2.0 mm) or less edge to edge in any direction. Rounded indications are indications that are circular or elliptical with their length less than three times their width.

136.4.3 Magnetic Particle Examination. Whenever required by this Chapter (see Table 136.4), magnetic particle examination shall be performed in accordance (16)

(C) As an alternative to *(B.1)* and *(B.2)* above, the fracture mechanics ultrasonic acceptance criteria in Mandatory Appendix R may be used providing all of the requirements of Mandatory Appendix R are met.

(B.2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (5.0 mm)

(B.3) four or more rounded indications in a line separated by $\frac{1}{16}$ in. (2.0 mm) or less edge to edge

(B.4) ten or more rounded indications in any 6 in.^{2} (3 870 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) with the area taken in the most unfavorable location relative to the indications being evaluated

(16) **136.4.5 Radiography.** When required by this Chapter (see Table 136.4), radiographic examination shall be performed in accordance with the requirements of Section V, Article 2, of the ASME Boiler and Pressure Vessel Code, except that the requirements of T-274 are to be used as a guide but not for the rejection of radiographs unless the geometrical unsharpness exceeds 0.07 in. (2.0 mm).

(A) Acceptance Standards. Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(A.1) any type of crack or zone of incomplete fusion or penetration

(A.2) any other elongated indication that has a length greater than

(A.2.1) $\frac{1}{4}$ in. (6.0 mm) for t up to $\frac{3}{4}$ in. (19.0 mm), inclusive

(A.2.2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19.0 mm) to $2\frac{1}{4}$ in. (57.0 mm), inclusive

(A.2.3) $\frac{3}{4}$ in. (19.0 mm) for t over $2\frac{1}{4}$ in. (57.0 mm) where t is the thickness of the thinner portion of the weld

NOTE: t referred to in (A.2.1), (A.2.2), and (A.2.3) above pertains to the thickness of the weld being examined; if a weld joins two members having different thickness at the weld, t is the thinner of these two thicknesses.

(A.3) any group of indications in line that have an aggregate length greater than t in a length of $12t$, except where the distance between the successive indications exceeds $6L$ where L is the longest indication in the group

(A.4) porosity in excess of that shown as acceptable in Nonmandatory Appendix A, A-250 of Section I of the ASME Boiler and Pressure Vessel Code

(A.5) root concavity when there is an abrupt change in density, as indicated on the radiograph

(16) **136.4.6 Ultrasonic Examination.** When required by this Chapter (see Table 136.4), ultrasonic examination (UT) shall be performed in accordance with the requirements of Section V, Article 4, of the ASME Boiler and Pressure Vessel Code and the additional requirements below.

(A) The following criteria shall also be met when performing ultrasonic examinations:

(A.1) The equipment used to perform the examination shall be capable of recording the UT data to facilitate the analysis by a third party and for the repeatability of subsequent examinations, should they be required. Where physical obstructions prevent the use of systems capable of recording the UT data, manual UT may be used with the approval of the owner.

(A.2) NDE personnel performing and evaluating UT examinations shall be qualified and certified in accordance with their employer's written practice and the requirements of para. 136.3.2 of this Code. Personnel, procedures, and equipment used to collect and analyze UT data shall have demonstrated their ability to perform an acceptable examination using test blocks approved by the owner.

(B) Acceptance Standards. Welds that are shown by ultrasonic examination to have discontinuities that produce an indication greater than 20% of the reference level shall be investigated to the extent that ultrasonic examination personnel can determine their shape, identity, and location so that they may evaluate each discontinuity for acceptance in accordance with (B.1) and (B.2) below.

(B.1) Discontinuities evaluated as being cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

(B.2) Other discontinuities are unacceptable if the indication exceeds the reference level and their length exceeds the following:

(B.2.1) $\frac{1}{4}$ in. (6.0 mm) for t up to $\frac{3}{4}$ in. (19.0 mm).

(B.2.2) $\frac{1}{3}t$ for t from $\frac{3}{4}$ in. (19.0 mm) to $2\frac{1}{4}$ in. (57.0 mm).

(B.2.3) $\frac{3}{4}$ in. (19.0 mm) for t over $2\frac{1}{4}$ in. (57.0 mm) where t is the thickness of the weld being examined. If the weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

137 PRESSURE TESTS

137.1 General Requirements

137.1.1 Subassemblies. When conducted in accordance with the requirements of this Code, the pressure testing of piping systems to ensure leak tightness shall be acceptable for the determination of any leaks in piping subassemblies.

137.1.2 Temperature of Test Medium. The temperature of the test medium shall be that of the available source unless otherwise specified by the owner. The test pressure shall not be applied until the system and the pressurizing medium are approximately at the same temperature. When conducting pressure tests at low metal temperatures, the possibility of brittle fracture shall be considered.

137.1.3 Personnel Protection. Suitable precautions in the event of piping system rupture shall be taken to eliminate hazards to personnel in the proximity of lines being tested.

137.1.4 Maximum Stress During Test. At no time during the pressure test shall any part of the piping

Table A-1 Carbon Steel (Cont'd)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding											
100	200	300	400	500	600	650	700	750	800	Grade	Spec. No.
										Wrought Fittings (Seamless and Welded)	
17.1	17.1	17.1	17.1	17.1	17.1	17.1	*15.6*	*13.0*	*10.8*	WPB	A234
20.0	20.0	20.0	20.0	20.0	20.0	19.8	*18.3*	*14.8*	*12.0*	WPC	
										Castings	
13.7	13.7	13.7	13.7	13.0	12.2	11.8	11.4	*10.4*	*8.6*	WCA	A216
16.0	16.0	16.0	16.0	15.7	14.7	14.2	13.8	*11.8*	*9.6*	WCB	
16.0	16.0	16.0	16.0	16.0	16.0	15.8	*14.6*	*11.8*	*9.6*	WCC	
										Bars and Shapes	
16.6	16.6	16.6	16.6	16.6	16.6	16.6	*15.6*	*13.0*	*10.8*	. . .	A36
18.6	18.6	18.6	18.6	18.6	18.6	18.6	*16.9*	*13.9*	*11.4*	. . .	A992

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR CONSTRUCTION OF PRESSURE RETAINING PARTS OF BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) Upon prolonged exposure to temperatures above 800°F (427°C), the carbide phase of carbon steel may be converted to graphite.

(3) The allowable stress values given are for pipe fabricated from plate not exceeding $2\frac{1}{2}$ in. in thickness.

(4) This material shall not be used for flammable fluids. Refer to para. 105.2.1(A).

(5) Tensile value in parentheses is expected minimum.

(6) The 0.80 material quality factor for casting may be increased in accordance with para. 102.4.6.

(7) The stress values for structural quality plate include a material quality factor of 0.92. The allowable stresses for A283 Grade D and A36 plate have been limited to 12.7 ksi.

(8) These stress values are permitted only if killed or semikilled steels are used.

(9) A254 is copper brazed (not welded) steel pipe.

(10) For saturated steam at 250 psi (406°F), the values given for 400°F may be used.

(11) The allowable stress values listed in MSS SP-58 for this material may be used for pipe supporting elements designed in accordance with MSS SP-58.

(12) These values apply to material less than or equal to 1 in. thick.

(13) These values apply to material greater than 1 in. thick.

(14) This material is not listed in the ASME Boiler and Pressure Vessel Code, Section IX. However, weld procedures shall be qualified in accordance with the P-Number shown. See para. 127.5.1.

(15) This material shall not be used in nominal wall thicknesses exceeding $\frac{3}{4}$ in.

(16) These allowable stress values are for pipe made using a butt-welded joint process. Pipe made by other processes shall not be used.

Table A-2 Low and Intermediate Alloy Steel (Cont'd)

Spec. No.	Grade	Type or Class	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube (Cont'd)								
A369	FP12	. . .	1Cr–$\frac{1}{2}$Mo	4	. . .	60	32	1.00
	FP21	. . .	3Cr–1Mo	5A	. . .	60	30	1.00
	FP22	. . .	2$\frac{1}{4}$Cr–1Mo	5A	(5)	60	30	1.00
A714	V	. . .	2Ni–1Cu	9A	(1)	65	46	1.00
Centrifugally Cast Pipe								
A426	CP1	. . .	C–$\frac{1}{2}$Mo	3	(1)(2)(3)(4)(7)	65	35	0.85
	CP2	. . .	$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	3	(1)(3)(4)(7)	60	30	0.85
	CP5	. . .	5Cr–$\frac{1}{2}$Mo	5B	(1)(3)(4)(7)	90	60	0.85
	CP5b	. . .	5Cr–$\frac{1}{2}$Mo–Si	5B	(1)(3)(4)(7)	60	30	0.85
A426	CP9	. . .	9Cr–1Mo	5B	(1)(3)(4)(7)	90	60	0.85
	CP11	. . .	1$\frac{1}{4}$Cr–$\frac{1}{2}$Mo	4	(1)(3)(4)(7)	70	40	0.85
A426	CP12	. . .	1Cr–$\frac{1}{2}$Mo	4	(1)(3)(4)(7)	60	30	0.85
	CP21	. . .	3Cr–1Mo	5A	(1)(3)(4)(7)	60	30	0.85
	CP22	. . .	2$\frac{1}{4}$Cr–1Mo	5A	(1)(3)(4)(5)(7)	70	40	0.85
Electric Resistance Welded Pipe								
A333	3	. . .	3$\frac{1}{2}$Ni	9B	(1)	65	35	0.85
	7	. . .	2$\frac{1}{2}$Ni	9A	(1)	65	35	0.85
	9	. . .	2Ni–1Cu	9A	(1)	63	46	0.85
A714	V	E	2Ni–Cu	9A	(1)	65	46	0.85
Electric Fusion Welded Pipe — Filler Metal Added								
A672	L65	20,23,30,33	C–$\frac{1}{2}$Mo	3	(1)	65	37	0.90
	L65	21,22,31,32	C–$\frac{1}{2}$Mo	3	(1)	65	37	1.00
A672	L70	20,23,30,33	C–$\frac{1}{2}$Mo	3	(1)	70	40	0.90
	L70	21,22,31,32	C–$\frac{1}{2}$Mo	3	(1)	70	40	1.00
A672	L75	20,23,30,33	C–$\frac{1}{2}$Mo	3	(1)	75	43	0.90
	L75	21,22,31,32	C–$\frac{1}{2}$Mo	3	(1)	75	43	1.00
A691	CM-65	20,23,30,33	C–$\frac{1}{2}$Mo	3	(1)	65	37	0.90
	CM-65	21,22,31,32	C–$\frac{1}{2}$Mo	3	(1)	65	37	1.00
A691	CM-70	20,23,30,33	C–$\frac{1}{2}$Mo	3	(1)	70	40	0.90
	CM-70	21,22,31,32	C–$\frac{1}{2}$Mo	3	(1)	70	40	1.00
A691	CM-75	20,23,30,33	C–$\frac{1}{2}$Mo	3	(1)	75	43	0.90
	CM-75	21,22,31,32	C–$\frac{1}{2}$Mo	3	(1)	75	43	1.00
A691	$\frac{1}{2}$CR	20,23	$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	3	(1)(8)	55	33	0.90
	$\frac{1}{2}$CR	21,22	$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	3	(1)(8)	55	33	1.00
	$\frac{1}{2}$CR	20,23,30,33,40,43	$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	3	(1)(9)	70	45	0.90
	$\frac{1}{2}$CR	21,22,31,32,41,42	$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	3	(1)(9)	70	45	1.00

Table A-2 Low and Intermediate Alloy Steel (Cont'd)

Spec. No.	Grade	Type or Class	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Castings								
A217	WC1	. . .	C–$\frac{1}{2}$Mo	3	(2)(3)(4)	65	35	0.80
	WC4	. . .	1Ni–$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	4	(3)(4)	70	40	0.80
	WC5	. . .	$\frac{3}{4}$Ni–1Mo–$\frac{3}{4}$Cr	4	(3)(4)	70	40	0.80
	WC6	. . .	1$\frac{1}{4}$Cr–$\frac{1}{2}$Mo	4	(3)(4)	70	40	0.80
A217	WC9	. . .	2$\frac{1}{4}$Cr–1Mo	5A	(3)(4)	70	40	0.80
	C5	. . .	5Cr–$\frac{1}{2}$Mo	5B	(3)(4)	90	60	0.80
	C12	. . .	9Cr–1Mo	5B	(3)(4)	90	60	0.80
	C12A	. . .	9Cr–1Mo–V	15E	(4)(14)	85	60	0.80

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers indicated in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given.

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.

(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) All the materials listed are classifed as ferritic [see Table 104.1.2(A)].

(i) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.

(j) See para. 124.1.2 for lower temperature limits.

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) Upon prolonged exposure to temperature above ~~875°F~~, the carbide phase of carbon-molybdenum steel may be converted to graphite.

(3) These allowable stress values apply to normalized and tempered material only.

(4) The material quality factors and allowable stress values for these materials may be increased in accordance with para. 102.4.6.

(5) For use at temperatures above 850°F, the carbon content of the base material and, where applicable, weld filler metal shall be 0.05% or higher. See para. 124.2(D).

(6) If A234 Grade WP-12 fittings are made from A387 Grade 12 Class 1 plate, the allowable stress values shall be reduced by the ratio of 55 divided by 60 in the temperature range −20°F through 850°F. At 900°F through 1,100°F, the values shown may be used.

(7) The mutual quality factor for centrifugally cast pipe (0.85) is based on all surfaces being machined, after heat treatment, to a surface finish of 250 μin. arithmetic average deviation or better.

(8) These allowable stress values are for pipe fabricated from ASTM A387 Class 1 plate in the annealed condition.

(9) These allowable stress values are for pipe fabricated from ASTM A387 Class 2 plate. 800°F (427°C)

(10) These allowable stress values apply to thickness less than 3 in.

(11) These allowable stress values apply to thickness 3 in. or greater.

(12) Separate weld procedure and performance qualifications shall apply for both classes of this material. The postweld heat treatment shall be in accordance with para. 132.1.3.

A1091	C91	1	9Cr-1Mo-V	15E	(4)(14)	85	60	0.80

Table A-2 Low and Intermediate Alloy Steel (Cont'd)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Grade	Spec. No.
																			Castings
14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.7	14.3	13.9	13.5	. . .	. . .	. . .	. . .	. . .	. . .	. . .	WC1	A217
16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.4	12.0	7.4	4.7	. . .	. . .	. . .	. . .	WC4	
16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.4	*13.0*	*8.8*	*5.5*	*3.7*	*2.2*	. . .	. . .	WC5	
16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.8	15.4	15.0	*11.0*	*7.4*	*5.0*	*3.4*	*2.2*	. . .	. . .	WC6	
16.0	16.0	15.8	15.5	15.4	15.4	15.3	15.0	14.8	14.3	13.8	*12.6*	*9.1*	*6.2*	*4.1*	*2.6*	. . .	. . .	WC9	A217
20.6	20.6	19.9	19.8	19.7	19.4	19.1	18.7	18.2	15.3	*11.4*	*8.7*	*6.4*	*4.6*	*3.4*	*2.3*	*1.4*	*0.8*	C5	
20.6	20.6	19.9	19.8	19.7	19.4	19.1	18.7	18.2	17.4	16.6	*13.1*	*8.8*	*5.9*	*4.0*	*2.6*	*1.8*	*1.2*	C12	
19.4	19.4	18.9	18.2	17.6	17.1	16.8	16.5	16.2	15.8	15.3	14.8	14.2	11.4	*9.1*	*7.0*	*5.2*	*3.4*	C12A	

NOTES (Cont'd):

(13) CAUTIONARY NOTE: Corrosion fatigue occurs by the combined actions of cyclic loading and a corrosive environment. In piping systems, corrosion fatigue is more likely to occur in portions of water systems with low strain rates (<1.0%/sec), higher temperatures [above 300°F (150°C)], and higher dissolved oxygen (>0.04 ppm), with a preference toward regions with increased local stresses. While the mechanisms of crack initiation and growth are complex and not fully understood, there is consensus that the two major factors are strain and waterside environment. Strain excursions of sufficient magnitude to fracture the protective oxide layer play a major role. In terms of the waterside environment, high levels of dissolved oxygen and pH excursions are known to be detrimental. Historically, the steels applied in these water-touched components have had the minimum specified yield strengths in the range of 27 ksi to 45 ksi (185 MPa to 310 MPa) and minimum specified tensile strengths in the range of 47 ksi to 80 ksi (325 MPa to 550 MPa). As these materials are supplanted by higher strength steels, some have concern that the higher design stresses and thinner wall thicknesses will render components more vulnerable to failures by corrosion fatigue. Thus, when employing such higher strength steels for water systems, it is desirable to use "best practices" in design by minimizing localized strain concentrations, in control of water chemistry and during lay-up by limiting dissolved oxygen and pH excursions, and in operation by conservative startup, shutdown, and turndown practices.

(14) For additional requirements for this material, see para. 125.1.

19.4 19.4 18.9 18.2 17.6 17.1 16.8 16.5 16.2 15.8 15.3 14.8 14.2 11.4 *9.1* *7.0* *5.2* *3.4* C91 A1091

A312	TP321	. . .	S32100	18Cr–10Ni–Ti	8	(10) (31)	70	25	1.00
	TP321	. . .	S32100	18Cr–10Ni–Ti	8	(9) (10) (31)	70	25	1.00
			S32109	18Cr–10Ni–Ti	8	(31)	70	25	1.00
	TP321H	. . .	S32109	18Cr–10Ni–Ti	8	(9) (31)	70	25	1.00

(16)

Table A-3 Stainless Steels (Cont'd)

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube (Cont'd)									
Austenitic (Cont'd)									
A312	TP304L	. . .	S30403	18Cr–8Ni	8	(1)	70	25	1.00
	TP304L	. . .	S30403	18Cr–8Ni	8	(1)(9)	70	25	1.00
	TP304N	. . .	S30451	18Cr–8Ni–N	8	(10)	80	35	1.00
	TP304N	. . .	S30451	18Cr–8Ni–N	8	(9)(10)	80	35	1.00
A312	. . .	. . .	S30815	21Cr–11Ni–N	8	(1)	87	45	1.00
	. . .	. . .	S30815	21Cr–11Ni–N	8	(1)(9)	87	45	1.00
A312	TP309H	. . .	S30909	23Cr–12Ni	8	(9)	75	30	1.00
	TP309H	. . .	S30909	23Cr–12Ni	8	. . .	75	30	1.00
	TP310H	. . .	S31009	25Cr–20Ni	8	(9)	75	30	1.00
	TP310H	. . .	S31009	25Cr–20Ni	8	. . .	75	30	1.00
A312	TP316	. . .	S31600	16Cr–12Ni–2Mo	8	(10)	75	30	1.00
	TP316	. . .	S31600	16Cr–12Ni–2Mo	8	(9)(10)	75	30	1.00
	TP316H	. . .	S31609	16Cr–12Ni–2Mo	8	. . .	75	30	1.00
	TP316H	. . .	S31609	16Cr–12Ni–2Mo	8	(9)	75	30	1.00
A312	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(29)	70	25	1.00
	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(9)(29)	70	25	1.00
	TP316N	. . .	S31651	16Cr–12Ni–2Mo–N	8	(10)	80	35	1.00
	TP316N	. . .	S31651	16Cr–12Ni–2Mo–N	8	(9)(10)	80	35	1.00
A312	TP317LMN	. . .	S31726	19Cr–15.5Ni–4Mo	8	(1)	80	35	1.00
	TP317LMN	. . .	S31726	19Cr–15.5Ni–4Mo	8	(1)(9)	80	35	1.00
	TP316Ti	. . .	S31635	16Cr–12Ni–2Mo–Ti	8	(10)	75	30	1.00
	TP316Ti	. . .	S31635	16Cr–12Ni–2Mo–Ti	8	(9)(10)	75	30	1.00
A312	TP317	. . .	S31700	18Cr–13Ni–3Mo	8	(1)(10)	75	30	1.00
	TP317	. . .	S31700	18Cr–13Ni–3Mo	8	(1)(9)(10)	75	30	1.00
	TP317L	. . .	S31703	18Cr–13Ni–3Mo	8	. . .	75	30	1.00
	TP317L	. . .	S31703	18Cr–13Ni–3Mo	8	(9)	75	30	1.00
A312	TP321	. . .	S32100	18Cr–10Ni–Ti	8	(10) (30)	75	30	1.00
	TP321	. . .	S32100	18Cr–10Ni–Ti	8	(9)(10) (30)	75	30	1.00
	TP321H	. . .	S32109	18Cr–10Ni–Ti	8	. . .	75	30	1.00
	TP321H	. . .	S32109	18Cr–10Ni–Ti	8	(9) (30)	75	30	1.00
A312	TP347	. . .	S34700	18Cr–10Ni–Cb	8	(10)	75	30	1.00
	TP347	. . .	S34700	18Cr–10Ni–Cb	8	(9)(10)	75	30	1.00
	TP347H	. . .	S34709	18Cr–10Ni–Cb	8	. . .	75	30	1.00
	TP347H	. . .	S34709	18Cr–10Ni–Cb	8	(9)	75	30	1.00
A312	TP348	. . .	S34800	18Cr–10Ni–Cb	8	(10)	75	30	1.00
	TP348	. . .	S34800	18Cr–10Ni–Cb	8	(9)(10)	75	30	1.00
	TP348H	. . .	S34809	18Cr–10Ni–Cb	8	. . .	75	30	1.00
	TP348H	. . .	S34809	18Cr–10Ni–Cb	8	(9)	75	30	1.00
A312	TPXM-15	. . .	S38100	18Cr–18Ni–2Si	8	(1)	75	30	1.00
	TPXM-15	. . .	S38100	18Cr–18Ni–2Si	8	(1)(9)	75	30	1.00
	TPXM-19	. . .	S20910	22Cr–13Ni–5Mn	8	(1)	100	55	1.00
	TPXM-19	. . .	S20910	22Cr–13Ni–5Mn	8	(1)(9)	100	55	1.00
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)	95	45	1.00
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)(9)	95	45	1.00

16.7	15.0	13.8	12.8	11.9	11.3	11.0	10.8	10.6	10.5	10.3	10.2	10.1	10.0	9.6	6.9	5.0	3.6	TP321	A312
16.7	16.7	16.7	16.7	16.1	15.2	14.9	14.6	14.3	14.1	13.9	13.8	13.6	13.5	9.6	6.9	5.0	3.6	TP321	
16.7	15.0	13.8	12.8	11.9	11.3	11.0	10.8	10.6	10.5	10.3	10.2	10.1	10.0	9.6	9.1	6.9	5.4	TP321H	
16.7	16.7	16.7	16.7	16.1	15.2	14.9	14.6	14.3	14.1	13.9	13.8	13.6	13.5	12.3	9.1	6.9	5.4	TP321H	

Table A-3 Stainless Steels (Cont'd)

(16)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type or Grade	Spec. No.
																		Seamless Pipe and Tube (Cont'd) Austenitic (Cont'd)	
16.7	14.3	12.8	11.7	10.9	10.4	10.2	10.0	9.8	9.7	...	...	...	...	...	...	...	...	TP304L	A312
16.7	16.7	16.7	15.8	14.7	14.0	13.7	13.5	13.3	13.0	...	...	...	...	...	...	...	...	TP304L	
22.9	19.1	16.7	15.1	14.0	13.3	13.0	12.8	12.5	12.3	12.1	11.8	11.6	11.3	11.0	9.8	7.7	6.1	TP304N	
22.9	22.9	21.7	20.3	18.9	17.9	17.5	17.2	16.9	16.6	16.3	16.0	15.6	15.2	12.4	9.8	7.7	6.1	TP304N	
24.9	24.7	22.0	19.9	18.5	17.7	17.4	17.2	17.0	16.8	16.6	16.4	16.2	14.9	11.6	9.0	6.9	5.2	...	A312
24.9	24.7	23.3	22.4	21.8	21.4	21.2	21.0	20.8	20.6	20.3	20.0	19.1	14.9	11.6	9.0	6.9	5.2	...	
20.0	20.0	20.0	20.0	19.4	18.8	18.5	18.2	18.0	17.7	17.5	17.2	16.9	13.8	10.3	7.6	5.5	4.0	TP309H	A312
20.0	17.5	16.1	15.1	14.4	13.9	13.7	13.5	13.3	13.1	12.9	12.7	12.5	12.3	10.3	7.6	5.5	4.0	TP309H	
20.0	20.0	20.0	19.9	19.3	18.5	18.2	17.9	17.7	17.4	17.2	16.9	16.7	13.8	10.3	7.6	5.5	4.0	TP310H	
20.0	17.6	16.1	15.1	14.3	13.7	13.5	13.3	13.1	12.9	12.7	12.5	12.3	12.1	10.3	7.6	5.5	4.0	TP310H	
20.0	17.3	15.6	14.3	13.3	12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	9.8	7.4	TP316	A312
20.0	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	TP316	
20.0	17.3	15.6	14.3	13.3	12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	9.8	7.4	TP316H	
20.0	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	TP316H	
16.7	14.2	12.7	11.7	10.9	10.4	10.2	10.0	9.8	9.6	9.4	9.2	9.0	8.8	8.6	8.4	8.3	6.4	TP316L	A312
16.7	16.7	16.7	15.7	14.8	14.0	13.7	13.5	13.2	12.9	12.7	12.4	12.1	11.9	11.6	11.4	8.8	6.4	TP316L	
22.9	20.7	19.0	17.6	16.5	15.6	15.2	14.9	14.5	14.2	13.9	13.7	13.4	13.2	12.9	12.3	9.8	7.4	TP316N	
22.9	22.9	22.0	21.5	21.2	21.0	20.5	20.0	19.6	19.2	18.8	18.5	18.1	17.8	15.8	12.3	9.8	7.4	TP316N	
22.9	20.0	17.9	16.3	15.3	14.6	...	...	...	...	...	...	...	...	...	...	...	...	TP317LMN	A312
22.9	21.8	20.9	20.5	20.3	19.7	...	...	...	...	...	...	...	...	...	...	...	...	TP317LMN	
20.0	17.7	15.8	14.3	13.2	12.4	12.2	12.0	11.9	11.8	11.7	11.6	11.5	11.4	11.2	11.0	9.8	7.4	TP316Ti	
20.0	20.0	20.0	19.4	17.8	16.8	16.5	16.2	16.0	15.9	15.8	15.7	15.5	15.3	15.1	12.3	9.8	7.4	TP316Ti	
20.0	17.3	15.6	14.3	13.3	12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	9.8	7.4	TP317	A312
20.0	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	TP317	
20.0	17.0	15.2	14.0	13.1	12.5	12.2	12.0	11.7	11.5	11.3	...	...	...	...	...	...	...	TP317L	
20.0	20.0	19.6	18.9	17.7	16.9	16.5	16.2	15.8	15.5	15.2	...	...	...	...	...	...	...	TP317L	
20.0	18.0	16.5	15.3	14.3	13.5	13.2	13.0	12.7	12.6	12.4	12.3	12.1	12.0	9.6	6.9	5.0	3.6	TP321	A312
20.0	20.0	19.1	18.7	18.7	18.3	17.9	17.5	17.2	16.9	16.7	16.5	16.4	16.2	9.6	6.9	5.0	3.6	TP321	
20.0	18.0	16.5	15.3	14.3	13.5	13.2	13.0	12.7	12.6	12.4	12.3	12.1	12.0	11.9	9.1	6.9	5.4	TP321H	
20.0	20.0	19.1	18.7	18.7	18.3	17.9	17.5	17.2	16.9	16.7	16.5	16.4	16.2	12.3	9.1	6.9	5.4	TP321H	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	12.1	9.1	6.1	4.4	TP347	A312
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	16.0	12.1	9.1	6.1	4.4	TP347	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	13.4	13.3	10.5	7.9	TP347H	
20.0	20.0	18.8	17.8	17.1	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	16.4	16.2	14.1	10.5	7.9	TP347H	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	12.1	9.1	6.1	4.4	TP348	A312
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	16.0	12.1	9.1	6.1	4.4	TP348	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	13.4	13.3	10.5	7.9	TP348H	
20.0	20.0	18.8	17.8	17.1	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	16.4	16.2	14.1	10.5	7.9	TP348H	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	...	...	...	...	TPXM-15	A312
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	10.6	10.4	...	...	...	...	TPXM-15	
28.6	28.4	26.9	26.0	25.5	25.0	24.6	24.2	23.9	23.5	23.3	23.0	22.7	22.5	22.2	...	...	...	TPXM-19	
28.6	28.4	26.9	26.0	25.5	25.1	24.9	24.7	24.5	24.2	23.9	23.6	23.2	22.8	22.3	...	...	...	TPXM-19	
27.1	27.1	25.8	24.6	23.7	23.2	23.1	23.0	22.9	...	...	...	...	...	...	...	...	...	...	
27.1	24.5	21.9	20.2	19.1	18.3	18.0	17.8	17.7	...	...	...	...	...	...	...	...	...	...	

Table A-3 Stainless Steels (Cont'd)

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Seamless Pipe and Tube (Cont'd)									
Austenitic (Cont'd)									
A376	TP304	. . .	S30400	18Cr–8Ni	8	(10)	75	30	1.00
	TP304	. . .	S30400	18Cr–8Ni	8	(9)(10)	75	30	1.00
	TP304H	. . .	S30409	18Cr–8Ni	8	. . .	75	30	1.00
	TP304H	. . .	S30409	18Cr–8Ni	8	(9)	75	30	1.00
	TP304N	. . .	S30451	18Cr–8Ni–N	8	(10)	80	35	1.00
	TP304N	. . .	S30451	18Cr–8Ni–N	8	(9)(10)	80	35	1.00
A376	TP316	. . .	S31600	16Cr–12Ni–2Mo	8	(10)	75	30	1.00
	TP316	. . .	S31600	16Cr–12Ni–2Mo	8	(9)(10)	75	30	1.00
	TP316H	. . .	S31609	16Cr–12Ni–2Mo	8	. . .	75	30	1.00
	TP316H	. . .	S31609	16Cr–12Ni–2Mo	8	(9)	75	30	1.00
	TP316N	. . .	S31651	16Cr–12Ni–2Mo–N	8	(10)	80	35	1.00
	TP316N	. . .	S31651	16Cr–12Ni–2Mo–N	8	(9)(10)	80	35	1.00
A376	TP321	. . .	S32100	18Cr–10Ni–Ti	8	(10)	75	30	1.00
	TP321	. . .	S32100	18Cr–10Ni–Ti	8	(9)(10)	75	30	1.00
	TP321H	. . .	S32109	18Cr–10Ni–Ti	8	. . .	75	30	1.00
	TP321H	. . .	S32109	18Cr–10Ni–Ti	8	(9)	75	30	1.00
A376	TP347	. . .	S34700	18Cr–10Ni–Cb	8	(10)	75	30	1.00
	TP347	. . .	S34700	18Cr–10Ni–Cb	8	(9)(10)	75	30	1.00
	TP347H	. . .	S34709	18Cr–10Ni–Cb	8	. . .	75	30	1.00
	TP347H	. . .	S34709	18Cr–10Ni–Cb	8	(9)	75	30	1.00
A376	TP348	. . .	S34800	18Cr–10Ni–Cb	8	(10)	75	30	1.00
	TP348	. . .	S34800	18Cr–10Ni–Cb	8	(9)(10)	75	30	1.00
A789	. . .	. . .	S32550	25.5Cr–5.5Ni–3.5Mo–2Cu	10H	(1)(25)(26)	110	80	1.00
A790	. . .	. . .	S32550	25.5Cr–5.5Ni–3.5Mo–2Cu	10H	(1)(25)(26)	110	80	1.00
Ferritic/Martensitic									
A268	TP405	. . .	S40500	12Cr–Al	7	(3)	60	30	1.00
	TP410	. . .	S41000	13Cr	6	. . .	60	30	1.00
	TP429	. . .	S42900	15Cr	6	(3)	60	35	1.00
	TP430	. . .	S43000	17Cr	7	(3)	60	35	1.00
	TPXM-27	. . .	S44627	26Cr–1Mo	10I	(1)(2)	65	40	1.00
	TP446-1	[illegible]	S44600	27Cr	10I	[illegible]	70	40	1.00
	TPXM-33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

New Lines Added (highlighted) in both A789 and A790 for UNS S32003.
Placed in order of strength in Ferritic/Austenitic Category.

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Ferritic/Austenitic									
A789	S31803	. . .	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	1.00
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	94	65	1.00
	2205	. . .	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	70	1.00
	S32003	...	S32003	21Cr-3.5Ni-1.75Mo-N	10H	(1)(23)(24)	100	70	1.00
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	101	77	1.00
	S32750	. . .	S32750	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	116	80	1.00
A790	S31803	. . .	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	1.00
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	94	65	1.00
	S32003	...	S32003	21Cr-3.5Ni-1.75Mo-N	10H	(1)(23)(24)	95	65	1.00
	2205	. . .	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	65	1.00
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	101	77	1.00
	S32750	. . .	S32750	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	116	80	1.00

Table A-3 Stainless Steels (Cont'd) (16)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																		Type or	Spec.
100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Grade	No.
Seamless Pipe and Tube (Cont'd) Austenitic (Cont'd)																			
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	TP304	A376
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	TP304	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	TP304H	
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	TP304H	
22.9	19.1	16.7	15.1	14.0	13.3	13.0	12.8	12.5	12.3	12.1	11.8	11.6	11.3	11.0	*9.8*	*7.7*	*6.1*	TP304N	
22.9	22.9	21.7	20.3	18.9	17.9	17.5	17.2	16.9	16.6	16.3	16.0	15.6	15.2	*12.4*	*9.8*	*7.7*	*6.1*	TP304N	
20.0	17.3	15.6	14.3	13.3	12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	*9.8*	*7.4*	TP316	A376
20.0	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	*12.4*	*9.8*	*7.4*	TP316	
20.0	17.3	15.6	14.3	13.3	12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	*9.8*	*7.4*	TP316H	
20.0	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	*12.4*	*9.8*	*7.4*	TP316H	
22.9	20.7	19.0	17.6	16.5	15.6	15.2	14.9	14.5	14.2	13.9	13.7	13.4	13.2	12.9	*12.3*	*9.8*	*7.4*	TP316N	
22.9	22.9	22.0	21.5	21.2	21.0	20.5	20.0	19.6	19.2	18.8	18.5	18.1	17.8	*15.8*	*12.3*	*9.8*	*7.4*	TP316N	
20.0	18.0	16.5	15.3	14.3	13.5	13.2	13.0	12.7	12.6	12.4	12.3	12.1	12.0	*9.6*	*6.9*	*5.0*	*3.6*	TP321	A376
20.0	20.0	19.1	18.7	18.7	18.3	17.9	17.5	17.2	16.9	16.7	16.5	16.4	*16.2*	*9.6*	*6.9*	*5.0*	*3.6*	TP321	
20.0	18.0	16.5	15.3	14.3	13.5	13.2	13.0	12.7	12.6	12.4	12.3	12.1	12.0	11.9	*9.1*	*6.9*	*5.4*	TP321H	
20.0	20.0	19.1	18.7	18.7	18.3	17.9	17.5	17.2	16.9	16.7	16.5	16.4	16.2	*12.3*	*9.1*	*6.9*	*5.4*	TP321H	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	*12.1*	*9.1*	*6.1*	*4.4*	TP347	A376
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	*16.0*	*12.1*	*9.1*	*6.1*	*4.4*	TP347	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	13.4	13.3	*10.5*	*7.9*	TP347H	
20.0	20.0	18.8	17.8	17.1	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	16.4	16.2	*14.1*	*10.5*	*7.9*	TP347H	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	*12.1*	*9.1*	*6.1*	*4.4*	TP348	A376
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	*16.0*	*12.1*	*9.1*	*6.1*	*4.4*	TP348	
31.4	31.3	29.5	28.6	28.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
31.4	31.3	29.5	28.6	28.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
Ferritic/Martensitic																			
17.1	17.1	16.8	16.5	16.3	15.9	15.6	15.2	...	...	...	...	...	...	...	...	...	...	TP405	A268
17.1	17.1	16.8	16.5	16.3	15.9	15.6	15.2	...	...	...	...	...	...	...	...	...	...	TP410	
17.1	17.1	16.8	16.5	16.3	15.9	15.6	15.2	...	...	...	...	...	...	...	...	...	...	TP429	
17.1	17.1	16.8	16.5	16.3	15.9	15.6	15.2	...	...	...	...	...	...	...	...	...	...	TP430	
18.6	18.6	18.3	18.1	18.1	18.1	18.1	...	...	...	...	...	...	...	...	...	...	...	TPXM-27	
20.0	20.0	19.3	18.8	18.4	17.9	17.7	...	...	...	...	...	...	...	...	...	...	...	TP446-1	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	...	TPXM-33	
Ferritic/Austenitic																			
25.7	25.7	24.8	23.9	23.3	23.1	...	...	...	...	...	...	...	...	...	...	...	...	S31803	A789
26.9	26.9	25.6	24.7	24.7	24.7	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
27.1	27.1	26.2	25.2	24.6	24.3	...	...	...	...	...	...	...	...	...	...	...	...	2205	
28.6	27.7	26.1	25.8	25.8	25.8	25.8	...	...	...	...	...	...	...	...	...	...	...	S32003	
28.9	28.9	27.5	26.5	26.5	26.5	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
33.1	33.0	31.2	30.1	29.6	29.4	...	...	...	...	...	...	...	...	...	...	...	...	S32750	
25.7	25.7	24.8	23.9	23.3	23.1	...	...	...	...	...	...	...	...	...	...	...	...	S31803	A790
26.9	26.9	25.6	24.7	24.7	24.7	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
27.1	26.3	24.8	24.5	24.5	24.5	24.5	...	...	...	...	...	...	...	...	...	...	...	S32003	
27.1	27.1	26.2	25.2	24.6	24.3	...	...	...	...	...	...	...	...	...	...	...	...	2205	
28.9	28.9	27.5	26.5	26.5	26.5	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
33.1	33.0	31.2	30.1	29.6	29.4	...	...	...	...	...	...	...	...	...	...	...	...	S32750	

New Lines Added (highlighted) in both A789 and A790 for UNS S32003. Placed in order of strength in Ferritic/Austenitic Category.

Added values at 650 F as listed in CC

Table A-3 Stainless Steels (Cont'd)

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Welded Pipe and Tube — Without Filler Metal (Cont'd)									
Austenitic (Cont'd)									
A312	TP348	. . .	S34800	18Cr–10Ni–Cb	8	(1)(10)	75	30	0.85
	TP348	. . .	S34800	18Cr–10Ni–Cb	8	(1)(9)(10)	75	30	0.85
	TP348H	. . .	S34809	18Cr–10Ni–Cb	8	(1)	75	30	0.85
	TP348H	. . .	S34809	18Cr–10Ni–Cb	8	(1)(9)	75	30	0.85
A312	TPXM-15	. . .	S38100	18Cr–18Ni–2Si	8	(1)	75	30	0.85
	TPXM-15	. . .	S38100	18Cr–18Ni–2Si	8	(1)(9)	75	30	0.85
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)	95	45	0.85
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)(9)	95	45	0.85
A409	. . .	. . .	S30815	21Cr–11Ni–N	8	(1)	87	45	0.85
	. . .	. . .	S30815	21Cr–11Ni–N	8	(1)(9)	87	45	0.85
A789	. . .	. . .	S32550	25.5Cr–5.5Ni–3.5Mo–2Cu	10H	(1)(25)(26)	110	80	0.85
A790	. . .	. . .	S32550	25.5Cr–5.5Ni–3.5Mo–2Cu	10H	(1)(25)(26)	110	80	0.85
Ferritic/Martensitic									
A268	TP405	. . .	S40500	12Cr–Al	7	. . .	60	30	0.85
	TP410	. . .	S41000	13Cr	6	. . .	60	30	0.85
	TP429	. . .	S42900	15Cr	6	. . .	60	35	0.85
	TP430	. . .	S43000	17Cr	7	. . .	60	35	0.85
	TP446-1	. . .	S44600	27Cr	10I	(1)	70	40	0.85
	TPXM-27	. . .	S44627	26Cr–1Mo	10I	(1)(2)	65	40	0.85
	TPXM-33	. .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

New Lines Added (highlighted) in both A789 and A790 for UNS S32003.
Placed in order of strength in Ferritic/Austenitic Category.

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Ferritic/Austenitic									
A789	S31803	. . .	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	0.85
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	94	65	0.85
	2205	. . .	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	70	0.85
	~~S32003~~	. . .	S32003	21Cr-3.5Ni-1.75Mo-N	10H	(1)(23)(24)	100	70	0.85
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	101	77	0.85
	S32750	. . .	S32750	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	116	80	0.85
A790	S31803	. . .	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	0.85
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	94	65	0.85
	~~S32003~~	. . .	S32003	21Cr-3.5Ni-1.75Mo-N	10H	(1)(23)(24)	95	65	0.85
	2205	. . .	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	65	0.85
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	101	77	0.85
	S32750		S32750	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	116	80	0.85

S32003

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Welded Pipe — Filler Metal Added									
Austenitic									
A358	304	1 & 3	S30400	18Cr–8Ni	8	(1)(10)(11)	75	30	1.00
	304	2	S30400	18Cr–8Ni	8	(1)(10)(11)	75	30	0.90
	304	1 & 3	S30400	18Cr–8Ni	8	(1)(9)(10)(11)	75	30	1.00
	304	2	S30400	18Cr–8Ni	8	(1)(9)(10)(11)	75	30	0.90
A358	304L	1 & 3	S30403	18Cr–8Ni	8	(1)	70	25	1.00
	304L	2	S30403	18Cr–8Ni	8	(1)	70	25	0.90
	304L	1 & 3	S30403	18Cr–8Ni	8	(1)(9)	70	25	1.00
	304L	2	S30403	18Cr–8Ni	8	(1)(9)	70	25	0.90
A358	304N	1 & 3	S30451	18Cr–8Ni–N	8	(1)(10)	80	35	1.00
	304N	2	S30451	18Cr–8Ni–N	8	(1)(10)	80	35	0.90
	304N	1 & 3	S30451	18Cr–8Ni–N	8	(1)(9)(10)	80	35	1.00
	304N	2	S30451	18Cr–8Ni–N	8	(1)(9)(10)	80	35	0.90

Table A-3 Stainless Steels (Cont'd) (16)

100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type or Grade	Spec. No.
Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
Welded Pipe and Tube – Without Filler Metal (Cont'd) Austenitic (Cont'd)																			
17.0	15.6	14.6	13.6	12.8	12.2	11.9	11.8	11.6	11.5	11.5	11.4	11.4	11.4	*10.3*	*7.8*	*5.2*	*3.8*	TP348	A312
17.0	17.0	16.0	15.1	14.6	14.3	14.3	14.3	14.3	14.3	14.3	14.2	14.1	*13.6*	*10.3*	*7.8*	*5.2*	*3.8*	TP348	
17.0	15.6	14.6	13.6	12.8	12.2	11.9	11.8	11.6	11.5	11.5	11.4	11.4	11.4	11.4	11.3	*8.9*	*6.7*	TP348H	
17.0	17.0	16.0	15.1	14.6	14.3	14.3	14.3	14.3	14.3	14.3	14.2	14.1	14.0	13.7	*12.0*	*8.9*	*6.7*	TP348H	
17.0	14.2	12.7	11.7	11.0	10.4	10.2	10.0	9.8	9.6	9.4	9.2	9.0	8.8	...	...	...	...	TPXM-15	A312
17.0	17.0	16.1	15.5	14.8	14.1	13.8	13.5	13.2	12.9	12.6	12.4	12.1	11.9	...	...	...	...	TPXM-15	
23.0	20.8	18.6	17.2	16.2	15.6	15.3	15.1	15.0	...	...	...	...	...	...	...	...	...	...	
23.0	23.0	21.9	20.9	20.1	19.7	19.6	19.6	19.5	...	...	...	...	...	...	...	...	...	...	
21.2	21.0	18.7	16.9	15.7	15.0	14.8	14.6	14.5	14.3	14.1	13.9	13.8	12.7	9.9	7.7	5.9	4.4	...	A409
21.2	21.0	19.8	19.0	18.5	18.2	18.0	17.9	17.7	17.5	17.3	17.0	16.2	12.7	9.9	7.7	5.9	4.4	...	
26.7	26.6	25.1	24.3	24.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
26.7	26.6	25.1	24.3	24.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
Ferritic/Martensitic																			
14.6	14.6	14.3	14.0	13.8	13.5	13.2	12.9	...	...	...	...	...	...	...	...	...	...	TP405	A268
14.6	14.6	14.3	14.0	13.8	13.5	13.2	12.9	...	...	...	...	...	...	...	...	...	...	TP410	
14.6	14.6	14.3	14.0	13.8	13.5	13.2	12.9	...	...	...	...	...	...	...	...	...	...	TP429	
14.6	14.6	14.3	14.0	13.8	13.5	13.2	12.9	...	...	...	...	...	...	...	...	...	...	TP430	
17.0	17.0	16.4	16.0	15.6	15.2	15.0	14.7	...	...	...	...	...	...	...	...	...	...	TP446-1	
15.8	15.8	15.5	15.4	15.4	15.4	15.4	...	...	...	...	...	...	...	...	...	...	...	TPXM-27	
																	...	TPXM-33	
Ferritic/Austenitic																			
21.9	21.9	21.1	20.3	19.8	19.6	...	...	...	...	...	...	...	...	...	...	...	...	S31803	A789
22.8	22.8	21.7	21.0	21.0	21.0	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
23.1	23.1	22.3	21.4	20.9	20.7	...	...	...	...	...	...	...	...	...	...	...	...	2205	
24.3	23.6	22.1	21.9	21.9	21.9	21.9	...	...	...	...	...	...	...	...	...	...	...	S32003	
24.5	24.5	23.4	22.6	22.6	22.6	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
28.2	28.0	26.5	25.6	25.2	25.0	...	...	...	...	...	...	...	...	...	...	...	...	S32750	
21.9	21.9	21.1	20.3	19.8	19.6	...	...	...	...	...	...	...	...	...	...	...	...	S31803	A790
22.8	22.8	21.7	21.0	21.0	21.0	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
23.1	22.4	21.0	20.8	20.8	20.8	20.8	...	...	...	...	...	...	...	...	...	...	...	S32003	
23.1	23.1	22.3	21.4	20.9	20.7	...	...	...	...	...	...	...	...	...	...	...	...	2205	
24.5	24.5	23.4	22.6	22.6	22.6	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
28.2	28.0	26.5	25.6	25.2	25.0	...	...	...	...	...	...	...	...	...	...	...	...	S32750	
Welded Pipe – Filler Metal Added Austenitic																			
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	304	A358
18.0	15.0	13.5	12.4	11.6	11.1	10.8	10.6	10.3	10.1	9.9	9.7	9.5	9.3	9.1	*8.8*	*7.0*	*5.5*	304	
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	304	
16.2	16.2	15.3	14.8	14.1	13.4	13.1	12.8	12.6	12.3	12.0	11.8	11.6	11.3	*10.0*	*7.9*	*6.3*	*4.9*	304	
16.7	14.3	12.8	11.7	10.9	10.4	10.2	10.0	9.8	9.7	...	...	...	...	...	...	...	...	304L	A358
15.0	12.8	11.5	10.5	9.8	9.3	9.1	9.0	8.8	8.7	...	...	...	...	...	...	...	...	304L	
16.7	16.7	16.7	15.8	14.7	14.0	13.7	13.5	13.3	13.0	...	...	...	...	...	...	...	...	304L	
15.0	15.0	15.0	14.2	13.3	12.6	12.3	12.1	11.9	11.7	...	...	...	...	...	...	...	...	304L	
22.9	19.1	16.7	15.1	14.0	13.3	13.0	12.8	12.5	12.3	12.1	11.8	11.6	11.3	11.0	*9.8*	*7.7*	*6.1*	304N	A358
20.6	17.2	15.0	13.5	12.6	11.9	11.7	11.5	11.3	11.1	10.9	10.6	10.4	10.2	9.9	*8.8*	*7.0*	*5.5*	304N	
22.9	22.9	21.7	20.3	18.9	17.9	17.5	17.2	16.9	16.6	16.3	16.0	15.6	15.2	*12.4*	*9.8*	*7.7*	*6.1*	304N	
20.6	20.6	19.6	18.3	17.0	16.1	15.8	15.5	15.2	14.9	14.7	14.4	14.0	13.7	*11.2*	*8.8*	*7.0*	*5.5*	304N	

New Lines Added (highlighted) in both A789 and A790 for UNS S32003. Placed in order of strength in Ferritic/Austenitic Category.

Added values at 650 F as listed in CC

(16)

Table A-3 Stainless Steels (Cont'd)

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Welded Pipe — Filler Metal Added (Cont'd)									
Austenitic (Cont'd)									
A409	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(19)(29)	70	25	1.00
	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(20)(29)	70	25	0.90
	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(21)(29)	70	25	0.80
	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(9)(19)(29)	70	25	1.00
	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(9)(20)(29)	70	25	0.90
	TP316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(9)(21)(29)	70	25	0.80
Ferritic/Austenitic									
A928	S31803	1 & 3	~~S32205~~ S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	~~95~~ 90	65	1.00
	S31803	2	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	0.90
	2205	1 & 3	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	65	1.00
	2205	2	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	65	0.90
Plate, Sheet, and Strip									
Austenitic									
A240	. . .	. . .	N08904	44Fe–25Ni–21Cr–Mo	45	(1)	71	31	1.00
	201LN	. . .	S20153	16Cr–4Ni–6Mn	8	(1)	95	45	1.00
	201LN	. . .	S20153	16Cr–4Ni–6Mn	8	(1)(9)	95	45	1.00
A240	304	. . .	S30400	18Cr–8Ni	8	(10)(11)	75	30	1.00
	304	. . .	S30400	18Cr–8Ni	8	(9)(10)(11)	75	30	1.00
	304L	. . .	S30403	18Cr–8Ni	8	(1)	70	25	1.00
	304L	. . .	S30403	18Cr–8Ni	8	(1)(9)	70	25	1.00
	304N	. . .	S30451	18Cr–8Ni–N	8	(1)(10)	80	35	1.00
	304N	. . .	S30451	18Cr–8Ni–N	8	(1)(9)(10)	80	35	1.00
A240	. . .	. . .	S30815	21Cr–11Ni–N	8	(1)	87	45	1.00
	. . .	. . .	S30815	21Cr–11Ni–N	8	(1)(9)	87	45	1.00
A240	309H	. . .	S30909	23Cr–12Ni	8	(9)(11)(18)	75	30	1.00
	309H	. . .	S30909	23Cr–12Ni	8	(11)(18)	75	30	1.00
	309S	. . .	S30908	23Cr–12Ni	8	(1)(10)	75	30	1.00
	309S	. . .	S30908	23Cr–12Ni	8	(1)(9)(10)	75	30	1.00
A240	310H	. . .	S31009	25Cr–20Ni	8	(9)	75	30	1.00
	310H	. . .	S31009	25Cr–20Ni	8	. . .	75	30	1.00
	310S	. . .	S31008	25Cr–20Ni	8	(10)(11)(14)	75	30	1.00
	310S	. . .	S31008	25Cr–20Ni	8	(9)(10)(11)(14)	75	30	1.00
	310S	. . .	S31008	25Cr–20Ni	8	(10)(11)(15)	75	30	1.00
	310S	. . .	S31008	25Cr–20Ni	8	(9)(10)(11)(15)	75	30	1.00
A240	316	. . .	S31600	16Cr–12Ni–2Mo	8	(10)(11)	75	30	1.00
	316	. . .	S31600	16Cr–12Ni–2Mo	8	(9)(10)(11)	75	30	1.00
	316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(29)	70	25	1.00
	316L	. . .	S31603	16Cr–12Ni–2Mo	8	(1)(9)(29)	70	25	1.00
	316N	. . .	S31651	16Cr–12Ni–2Mo–N	8	(10)	80	35	1.00
	316N	. . .	S31651	16Cr–12Ni–2Mo–N	8	(9)(10)	80	35	1.00

Table A-3 Stainless Steels (Cont'd)

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Plate, Sheet, and Strip (Cont'd)									
Austenitic (Cont'd)									
A240	317	. . .	S31700	18Cr–13Ni–3Mo	8	(1)(10)(11)	75	30	1.00
	317	. . .	S31700	18Cr–13Ni–3Mo	8	(1)(9)(10)(11)	75	30	1.00
	317L	. . .	S31703	18Cr–13Ni–3Mo	8	(1)	75	30	1.00
	317L	. . .	S31703	18Cr–13Ni–3Mo	8	(1)(9)	75	30	1.00
	321	. . .	S32100	18Cr–10Ni–Ti	8	(10)(11)	75	30	1.00
	321	. . .	S32100	18Cr–10Ni–Ti	8	(9)(10)(11)	75	30	1.00
A240	347	. . .	S34700	18Cr–10Ni–Cb	8	(10)(11)	75	30	1.00
	347	. . .	S34700	18Cr–10Ni–Cb	8	(9)(10)(11)	75	30	1.00
	348	. . .	S34800	18Cr–10Ni–Cb	8	(1)(10)(11)	75	30	1.00
	348	. . .	S34800	18Cr–10Ni–Cb	8	(1)(9)(10)(11)	75	30	1.00
A240	XM-15	. . .	S38100	18Cr–8Ni–2Si	8	(1)	75	30	1.00
	XM-15	. . .	S38100	18Cr–8Ni–2Si	8	(1)(9)	75	30	1.00
	317LMN	. . .	S31726	19Cr–15.5Ni–4Mo	8	(1)	80	35	1.00
	317LMN	. . .	S31726	19Cr–15.5Ni–4Mo	8	(1)(9)	80	35	1.00
A240	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)	95	45	1.00
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)(9)	95	45	1.00
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)	100	45	1.00
	. . .	. . .	S31254	20Cr–18Ni–6Mo	8	(1)(9)	100	45	1.00
	. . .	. . .	S32550	25.5Cr–5.5Ni–3.5Mo–2Cu	10H	(1)(25)(26)	110	80	1.00
Ferritic/Martensitic									
A240	405	. . .	S40500	12Cr–1Al	7	(3)	60	25	1.00
	410	. . .	S41000	13Cr	6	(1)	65	30	1.00
	410S	. . .	S41008	13Cr	7	(1)	60	30	1.00
	429	. . .	S42900	15Cr	6	(1)(3)	65	30	1.00
A240	430	. . .	S43000	17Cr	7	(1)(3)	65	30	1.00
	XM-27	. . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	1.00
	XM-33	. . .	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	1.00
Ferritic/Austenitic									
A240	S31803	. . .	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	1.00
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	94	65	1.00
	S32003	. . .	S32003	21Cr-3.5Ni-1.75Mo-N	10H	(1)(23)(24)	95	65	1.00
	2205	. . .	S32205	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	95	65	1.00
	S32003	. . .	S32003	21Cr-3.5Ni-1.75Mo-N	10H	(1)(23)(24)	100	70	1.00
	S32101	. . .	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	101	77	1.00
	S32750	. . .	S32750	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	116	80	1.00
Forgings									
Austenitic									
A182	F904L	. . .	N08904	44Fe–25Ni–21Cr–Mo	45	(1)	71	31	1.00
	F44	. . .	S31254	20Cr–18Ni–6Mo	8	(1)	94	44	1.00
	F44	. . .	S31254	20Cr–18Ni–6Mo	8	(1)(9)	94	44	1.00
A182	F304	. . .	S30400	18Cr–8Ni	8	(10)(12)	70	30	1.00
	F304	. . .	S30400	18Cr–8Ni	8	(9)(10)(12)	70	30	1.00
	F304	. . .	S30400	18Cr–8Ni	8	(10)	75	30	1.00
	F304	. . .	S30400	18Cr–8Ni	8	(9)(10)	75	30	1.00
A182	F304H	. . .	S30409	18Cr–8Ni	8	(12)	70	30	1.00
	F304H	. . .	S30409	18Cr–8Ni	8	(9)(12)	70	30	1.00
	F304H	. . .	S30409	18Cr–8Ni	8	. . .	75	30	1.00
	F304H	. . .	S30409	18Cr–8Ni	8	(9)	75	30	1.00

New Lines Added (highlighted) in A240 for UNS S32003.
Placed in order of strength in Ferritic/Austenitic Category.

Table A-3 Stainless Steels (Cont'd)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding

100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type or Grade	Spec. No.
																		Plate, Sheet, and Strip (Cont'd)	
																		Austenitic (Cont'd)	
20.0	17.3	15.6	14.3	13.3	12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	*9.8*	*7.4*	317	A240
20.0	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	*12.4*	*9.8*	*7.4*	317	
20.0	17.0	15.2	14.0	13.1	12.5	12.2	12.0	11.7	11.5	11.3	...	...	...	...	...	...	...	317L	
20.0	20.0	19.6	18.9	17.7	16.9	16.5	16.2	15.8	15.5	15.2	...	...	...	...	...	...	...	317L	
20.0	18.0	16.5	15.3	14.3	13.5	13.2	13.0	12.7	12.6	12.4	12.3	12.1	12.0	*9.6*	*6.9*	*5.0*	*3.6*	321	
20.0	20.0	19.1	18.7	18.7	18.3	17.9	17.5	17.2	16.9	16.7	16.5	16.4	*16.2*	*9.6*	*6.9*	*5.0*	*3.6*	321	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	*12.1*	*9.1*	*6.1*	*4.4*	347	A240
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	*16.0*	*12.1*	*9.1*	*6.1*	*4.4*	347	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	*12.1*	*9.1*	*6.1*	*4.4*	348	
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	*16.0*	*12.1*	*9.1*	*6.1*	*4.4*	348	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	...	...	...	...	XM-15	A240
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	...	...	...	...	XM-15	
22.9	20.0	17.9	16.3	15.3	14.6	...	...	...	...	...	...	...	...	...	...	...	...	317LMN	
22.9	21.8	20.9	20.5	20.3	19.7	...	...	...	...	...	...	...	...	...	...	...	...	317LMN	
27.1	24.5	21.9	20.2	19.1	18.3	18.0	17.8	17.7	...	...	...	...	...	...	...	...	...	...	A240
27.1	27.1	25.8	24.6	23.7	23.2	23.1	23.0	22.9	...	...	...	...	...	...	...	...	...	...	
28.6	24.5	21.9	20.2	19.1	18.3	18.0	17.8	17.7	...	...	...	...	...	...	...	...	...	...	
28.6	28.6	27.2	25.9	25.0	24.4	24.3	24.1	23.9	...	...	...	...	...	...	...	...	...	...	
31.4	31.3	29.5	28.6	28.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
																		Ferritic/Martensitic	
16.7	15.3	14.8	14.5	14.3	14.0	13.8	13.5	...	...	...	...	...	...	...	...	...	...	405	A240
18.6	18.4	17.8	17.4	17.2	16.8	16.6	16.2	15.7	15.1	14.4	*12.3*	*8.8*	*6.4*	*4.4*	*2.9*	*1.8*	*1.0*	410	
17.1	17.1	16.8	16.5	16.3	15.9	15.6	15.2	14.7	14.1	13.4	*12.3*	*8.8*	*6.4*	*4.4*	*2.9*	*1.8*	*1.0*	410S	
18.6	18.4	17.8	17.4	17.2	16.8	16.6	16.2	15.7	15.1	14.4	*12.0*	*9.2*	*6.5*	*4.5*	*3.2*	*2.4*	*1.8*	429	
18.6	18.4	17.8	17.4	17.2	16.8	16.6	16.2	15.7	15.1	14.4	*12.0*	*9.2*	*6.5*	*4.5*	*3.2*	*2.4*	*1.8*	430	A240
18.6	18.6	18.3	18.1	18.1	18.1	18.1	...	...	...	...	...	...	...	...	...	...	...	XM-27	
19.4	19.4	19.3															...	XM-33	
																		Ferritic/Austenitic	
25.7	25.7	24.8	23.9	23.3	23.1	...	...	...	...	...	...	...	...	...	...	...	...	S31803	A240
26.9	26.9	25.6	24.7	24.7	24.7		...	...	...	...	...	...	...	...	...	...	...	S32101	
27.1	26.3	24.8	24.5	24.5	24.5	24.5	...	...	...	...	...	...	...	...	...	...	...	S32003	
27.1	27.1	26.2	25.2	24.6	24.3	...	...	...	...	...	...	...	...	...	...	...	...	2205	
28.6	27.7	26.1	25.8	25.8	25.8	25.8	...	...	...	...	...	...	...	...	...	...	...	S32003	
28.9	28.9	27.5	26.5	26.5	26.5	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
33.1	33.0	31.2	30.1	29.6	29.4	...	...								...	...	...	S32750	
																		Forgings	
																		Austenitic	
20.3	16.7	15.1	13.8	12.7	11.9	11.6	11.4	...	...	...	...	...	...	...	...	...	...	F904L	A182
26.9	23.9	21.4	19.8	18.6	17.9	17.6	17.4	17.3	...	...	...	...	...	...	...	...	...	F44	
26.9	26.9	25.5	24.3	23.5	23.0	22.8	22.7	22.6	...	...	...	...	...	...	...	...	...	F44	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	F304	A182
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	F304	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	F304	
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	F304	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	F304H	A182
20.0	18.9	17.7	17.1	16.9	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	F304H	
20.0	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	*9.8*	*7.7*	*6.1*	F304H	
20.0	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	*9.8*	*7.7*	*6.1*	F304H	

New Lines Added (highlighted) in A240 for UNS S32003. Placed in order of strength in Ferritic/Austenitic Category.

Added values at 650 F as listed in CC

(16)

Table A-3 Stainless Steels (Cont'd)

Spec. No.	Type or Grade	Class	UNS Alloy No.	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Bar (Cont'd)									
Austenitic (Cont'd)									
A479	348	...	S34800	18Cr–10Ni–Cb	8	(10)	75	30	1.00
	348	...	S34800	18Cr–10Ni–Cb	8	(9)(10)	75	30	1.00
	348H	...	S34809	18Cr–10Ni–Cb	8	...	75	30	1.00
	348H	...	S34809	18Cr–10Ni–Cb	8	(9)	75	30	1.00
Ferritic/Martensitic									
A479	XM-27	...	S44627	27Cr–1Mo	10I	(2)	65	40	1.00
Ferritic/Austenitic									
A479	S31803	...	S31803	22Cr–5.5Ni–3Mo–N	10H	(1)(23)(24)	90	65	1.00
	S32101	...	S32101	21Cr–5Mn–1.5Ni–Cu–N	10H	(1)(23)(24)	94	65	1.00
	2205	...	S32205	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	95	65	1.00
	S32750	...	S32750	25Cr–7Ni–4Mo–N	10H	(1)(22)(23)	116	80	1.00

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers indicated in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given herein or in Table A-8.

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.

(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.

(i) See para. 124.1.2 for lower temperature limits.

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) Use of this material at temperatures above 650°F is not approved because of the possibility of temper embrittlement.

(3) This steel may be expected to develop embrittlement at room temperature after service at temperatures above 700°F. Consequently, its use at higher temperatures is not recommended unless due caution is observed.

(4) For fittings made from A182 forgings over 5 in. in thickness, the allowable stress values tabulated shall be reduced by the ratio of 70 divided by 75.

(5) The material quality factors and allowable stress values for these materials may be increased in accordance with para. 102.4.6.

(6) Tensile strengths in parentheses are expected minimum values.

(7) See MSS SP-43 for requirements for lightweight stainless steel fittings. MSS SP-43 Schedule 5S fittings shall not be used for design temperatures above 400°F. MSS SP-43 Schedule 10S fittings shall not be used for design temperatures above 750°F.

(8) The material quality factor for centrifugally cast pipe (0.85) is based on all surfaces being machined after heat treatment. The surface finish, after machining, shall be 250 μin. arithmetic average deviation or smoother.

(9) Due to relatively low yield strength of these materials, these higher allowable stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These values should not be used for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(10) The allowable stress values tabulated for temperatures over 1,000°F apply only if the carbon content of the material is 0.04% or higher.

(30) These allowable stress values apply to seamless pipe ≤ 3/8" in wall thickness.
(31) These allowable stress values apply to seamless pipe > 3/8" in wall thickness.

Table A-3 Stainless Steels (Cont'd) (16)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type or Grade	Spec. No.
																		Bar (Cont'd)	
																		Austenitic (Cont'd)	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	*12.1*	*9.1*	*6.1*	*4.4*	348	A479
20.0	20.0	18.8	17.8	17.2	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	*16.0*	*12.1*	*9.1*	*6.1*	*4.4*	348	
20.0	18.4	17.1	16.0	15.0	14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	13.4	13.3	*10.5*	*7.9*	348H	
20.0	20.0	18.8	17.8	17.1	16.9	16.8	16.8	16.8	16.8	16.8	16.7	16.6	16.4	16.2	*14.1*	*10.5*	*7.9*	348H	
																		Ferritic/Martensitic	
18.6	18.6	18.3	18.1	18.1	18.1	18.1	...	...	...	...	...	...	...	...	...	...	...	XM-27	A479
																		Ferritic/Austenitic	
25.7	25.7	24.8	23.9	23.3	23.1	...	...	...	...	...	...	...	...	...	...	...	...	S31803	A479
26.9	26.9	25.6	24.7	24.7	24.7	...	...	...	...	...	...	...	...	...	...	...	...	S32101	
27.1	27.1	26.2	25.2	24.6	24.3	...	...	...	...	...	...	...	...	...	...	...	...	2205	
33.1	33.0	31.2	30.1	29.6	29.4	...	...	...	...	...	...	...	...	...	...	...	...	S32750	

NOTES (Cont'd):

(11) The allowable stress values tabulated for temperatures over 1,000°F apply only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapidly cooling by other means.

(12) These allowable stress values apply to forgings over 5 in. in thickness.

(13) The allowable stress values tabulated for temperatures over 800°F apply only if the carbon content of the material is 0.04% or higher.

(14) These allowable stress values shall be used only when the grain size of the material is ASTM No. 6 or coarser.

(15) These allowable stress values shall be used when the grain size of the material is finer than ASTM No. 6 or when the grain size has not been determined.

(16) Use of external pressure charts for material in the form of barstock is permitted for stiffening rings only.

(17) At the ferrite levels tabulated below, these materials will have significant reductions in Charpy V-notch toughness values at room temperature and below following service exposure at the indicated temperatures. This reduction indicates the potential for brittle fracture with high rate loading in the presence of sharp notches or cracks.

Ferrite Content	Service Temperature
5% and less	1,100°F and above
10%	900°F and above
15%	800°F and above
20%	700°F and above
25%—30%	600°F and above
35%—40%	500°F and above

(18) The stress values at 1,050°F and above shall be used only when the grain size is ASTM No. 6 or coarser.

(19) These allowable stress values apply for single or double butt welded pipe with radiography per para. 136.4.5.

(20) These allowable stress values apply for double butt welded pipe, without radiography.

(21) These allowable stress values apply for single butt welded pipe, without radiography.

(22) Any heat treatment applied to this material shall be performed at 1,880°F to 2,060°F, followed by a rapid cool.

(16) (23) The use of this material is limited to 600°F (315°C). This material may exhibit embrittlement at room temperature after moderately elevated temperature service. Cold work (strain hardening) such as that introduced during tube bending and certain manufacturing and assembly processes can make UNS S32750 more susceptible to embrittlement when exposed to temperatures in excess of 480°F (250°C).

~~(24) Any heat treatment applied to this material shall be performed at 1,870°F to 2,010°F, followed by a rapid cool. For A182, A240, and A479 material, this is more restrictive than the material specification and shall be met.~~

(25) Openings ≥ 4 in. shall conform to para. 127.4.8, except that full-penetration welds shall be used and separate reinforcing pads shall not be used.

(26) This steel may be expected to develop embrittlement after exposure to temperatures above 500°F for prolonged times. See ASME Boiler and Pressure Vessel Code, Section II, Part D, Appendix A, ~~A-340 and A-360.~~ A-207 and A-208.

(27) These allowable stress values apply only to forgings 5 in. in thickness and under.

(28) The stress values at temperatures above 1,000°F apply only if Supplementary Requirement S1 has been specified.

(29) The material shall have an ASTM grain size of 7 or coarser for use at 1,000°F (550°C) and above.

(24) Except for UNS No. S32003 material, any heat treatment applied shall be performed at 1,870°F to 2,010°F, followed by a rapid cool. For A182, A240 and A479 material, this is more restrictive than the material specification and shall be met. For UNS No. S32003 material, any heat treatment applied shall be performed at 1,850°F to 2,050°F, followed by rapid cooling in air or water.

(16)

Table A-4 Nickel and High Nickel Alloys

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube								
B161	N02200	Annealed	Ni	41	(1)(5)	55	15	1.00
	N02200	Annealed	Ni	41	(1)(6)	55	12	1.00
	N02200	Str. rel.	Ni	41	(1)	65	40	1.00
B161	N02201	Annealed	Ni–Low C	41	(1)(5)	50	12	1.00
	N02201	Annealed	Ni–Low C	41	(1)(6)	50	10	1.00
	N02201	Str. rel.	Ni–Low C	41	(1)	60	30	1.00
B163	N08800	Annealed	Ni–Cr–Fe	45	~~(1)~~(7)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	~~(1)~~(2)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	~~(1)~~	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	~~(1)~~(2)	65	25	1.00
B165	N04400	Annealed	Ni–Cu	42	(1)(5)	70	28	1.00
	N04400	Annealed	Ni–Cu	42	(1)(6)	70	25	1.00
	N04400	Str. rel.	Ni–Cu	42	(1)(2)(3)	85	35	1.00
B167	N06600	H.F./ann.	Ni–Cr–Fe	43	~~(1)~~(5)	80	30	1.00
	N06600	H.F./ann.	Ni–Cr–Fe	43	~~(1)~~(2)(5)	75	30	1.00
	N06600	H.F./ann.	Ni–Cr–Fe	43	~~(1)~~(6)	75	25	1.00
	N06600	H.F./ann.	Ni–Cr–Fe	43	~~(1)~~(2)(6)	80	25	1.00
B167	N06600	C.D./ann.	Ni–Cr–Fe	43	~~(1)~~(5)	80	35	1.00
	N06600	C.D./ann.	Ni–Cr–Fe	43	~~(1)~~(2)(5)	80	35	1.00
	N06600	C.D./ann.	Ni–Cr–Fe	43	~~(1)~~(6)	80	30	1.00
	N06600	C.D./ann.	Ni–Cr–Fe	43	~~(1)~~(2)(6)	80	30	1.00
B167	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(7)	95	35	1.00
	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(2)(7)	95	35	1.00
	N06690	C.W./ann.	58Ni–29Cr–9Fe	43	(7)(23)	85	35	1.00
	N06690	C.W./ann.	58Ni–29Cr–9Fe	43	(2)(7)(23)	85	35	1.00
B407	N08800	C.D./ann.	Ni–Cr–Fe	45	(7)	75	30	1.00
	N08800	C.D./ann.	Ni–Cr–Fe	45	(2)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(7)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(2)(7)	65	25	1.00
B423	N08825	C.W./ann.	Ni–Fe–Cr–Mo–Cu	45	~~(1)~~(7)	85	35	1.00
	N08825	C.W./ann.	Ni–Fe–Cr–Mo–Cu	45	~~(1)~~(2)(7)	85	35	1.00
B444	N06625	Sol. ann.	Ni–Cr–Mo–Cb	43	(14)(18)	100	40	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(2)(14)	120	60	1.00
B622	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(12)	100	45	1.00
	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(2)(12)	100	45	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	1.00
B677	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)	87	43	1.00
	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)(2)	87	43	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(19)(20)	94	43	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(2)(19)(20)	94	43	1.00

Table A-4 Nickel and High Nickel Alloys (Cont'd)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube (Cont'd)								
B690	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	~~(1)~~(8)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	~~(1)~~(2)(8)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	~~(1)~~(21)	100	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	~~(1)~~(2)(21)	100	45	1.00
B729	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
Welded Pipe and Tube								
B464	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	0.85
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	0.85
B468	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	0.85
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	0.85
B546	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	(1)(7)	95	35	0.85
	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	(1)(2)(7)	95	35	0.85
B619	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(12)	100	45	0.85
	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(2)(12)	100	45	0.85
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	0.85
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	0.85
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	0.85
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	0.85
B626	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(12)	100	45	0.85
	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(2)(12)	100	45	0.85
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	0.85
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	0.85
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	0.85
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	0.85
B673	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)	87	43	0.85
	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)(2)	87	43	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(19)(20)	94	43	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(2)(19)(20)	94	43	0.85
B674	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)	87	43	0.85
	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)(2)	87	43	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(19)(20)	94	43	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(2)(19)(20)	94	43	0.85
B675	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(22)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(22)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(21)	100	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(21)	100	45	0.85
B676	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(22)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(22)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(21)	100	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(21)	100	45	0.85

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Table A-4 Nickel and High Nickel Alloys (Cont'd)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Welded Pipe and Tube (Cont'd)								
B704	N06625	Annealed	Ni–Cr–Mo–Cb	43	(14)	120	60	0.85
B705	N06625	Annealed	Ni–Cr–Mo–Cb	43	(14)	120	60	0.85
B804	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(21)	100	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(21)	100	45	0.85
Plate, Sheet, and Strip								
B168	N06600	Annealed	Ni–Cr–Fe	43	~~(1)~~	80	35	1.00
	N06600	Annealed	Ni–Cr–Fe	43	~~(1)~~(2)	80	35	1.00
	N06600	Hot rolled	Ni–Cr–Fe	43	~~(1)~~(4)	85	35	1.00
	N06600	Hot rolled	Ni–Cr–Fe	43	~~(1)~~(2)(4)	85	35	1.00
B168	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(7)	95	35	1.00
	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(2)(7)	95	35	1.00
	N06690	Annealed	58Ni–29Cr–9Fe	43	(7)	85	35	1.00
	N06690	Annealed	58Ni–29Cr–9Fe	43	(2)(7)	85	35	1.00
B409	N08800	Annealed	Ni–Cr–Fe	45	(4)(7)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(2)(4)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(4)(7)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(2)(4)(7)	65	25	1.00
B424	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	~~(1)~~(7)	85	35	1.00
	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	~~(1)~~(2)(7)	85	35	1.00
B435	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	1.00
B443	N06625	Sol. ann.	Ni–Cr–Mo–Cb	43	(14)(18)	100	40	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(14)	110	55	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(14)(15)	120	60	1.00
B463	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(12)	80	35	1.00
B575	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(12)	100	45	1.00
	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(2)(12)	100	45	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	1.00
B625	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)	87	43	1.00
	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)(2)	87	43	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(19)(20)	94	43	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	45	(1)(2)(19)(20)	94	43	1.00
B688	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(7)(11)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(7)(11)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(7)(10)(21)	100	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(7)(10)(21)	100	45	1.00

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Table A-4 Nickel and High Nickel Alloys (Cont'd)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Bars, Rods, Shapes, and Forgings								
B166	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(7)	95	35	1.00
	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(2)(7)	95	35	1.00
	N06690	Annealed	58Ni–29Cr–9Fe	43	(7)	85	35	1.00
	N06690	Annealed	58Ni–29Cr–9Fe	43	(2)(7)	85	35	1.00
B408	N08800	Annealed	Ni–Cr–Fe	45	(7)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(2)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(7)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(2)(7)	65	25	1.00
B425	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	~~(1)~~(7)	85	35	1.00
	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	~~(1)~~(2)(7)	85	35	1.00
B446	N06625	Sol. ann.	Ni–Cr–Mo–Cb	43	(14)(18)	100	40	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(2)(14)(16)	110	50	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(2)(14)(15)(17)	120	60	1.00
B462	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
B473	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
B564	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(7)	95	35	1.00
	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	~~(1)~~(2)(7)	95	35	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(2)(14)(16)	110	50	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(2)(14)(15)(17)	120	60	1.00
B564	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(22)	95	45	1.00
	N08800	Annealed	Ni–Cr–Fe	45	~~(1)~~	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	~~(1)~~(2)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	~~(1)~~	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	~~(1)~~(2)	65	25	1.00
B572	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	1.00
B574	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(12)	100	45	1.00
	N06022	Sol. ann.	Ni–Mo–Cr–Low C	44	~~(1)~~(2)(12)	100	45	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	1.00
B649	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)	87	43	1.00
	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–Low C	45	(1)(2)	87	43	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	. . .	(1)	94	43	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–Low C	. . .	(1)(2)	94	43	1.00
B691	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(8)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–Cu–N	45	(1)(2)(8)(22)	95	45	1.00

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Table A-4 Nickel and High Nickel Alloys (Cont'd)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Fittings								
B366	N06022	Sol. ann.	Low C–Ni–Mo–Cr	44	~~(1)~~(12)	100	45	1.00
	N06022	Sol. ann.	Low C–Ni–Mo–Cr	44	~~(1)~~(2)(12)	100	45	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	~~(1)~~(14)	110	50	1.00
B366	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
	N08367	Annealed	Fe–Ni–Cr–Mo–N	45	(1)(8)(22)	95	45	1.00
	N08367	Annealed	Fe–Ni–Cr–Mo–N	45	(1)(2)(8)(22)	95	45	1.00
B366	N08925	Annealed	Low C–Ni–Fe–Cr–Mo–Cu	45	(1)	87	43	1.00
	N08925	Annealed	Low C–Ni–Fe–Cr–Mo–Cu	45	(1)(2)	87	43	1.00
	N08926	Annealed	Low C–Ni–Fe–Cr–Mo–Cu–N	45	(1)	94	43	1.00
	N08926	Annealed	Low C–Ni–Fe–Cr–Mo–Cu–N	45	(1)(2)	94	43	1.00
B366	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	1.00
B462	N08367	Sol. ann.	Fe–Ni–Cr–Mo–N	45	(1)(8)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–N	45	(1)(2)(8)(22)	95	45	1.00
Welded Fittings								
B366	N06022	Sol. ann.	Low C–Ni–Mo–Cr	44	~~(1)~~(12)	100	45	0.85
	N06022	Sol. ann.	Low C–Ni–Mo–Cr	44	~~(1)~~(12)(13)	100	45	1.00
	N06022	Sol. ann.	Low C–Ni–Mo–Cr	44	~~(1)~~(2)(12)	100	45	0.85
	N06022	Sol. ann.	Low C–Ni–Mo–Cr	44	~~(1)~~(2)(12)(13)	100	45	1.00
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(14)	110	50	0.85
	N06625	Annealed	Ni–Cr–Mo–Cb	43	(13)(14)	110	50	1.00
B366	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)	80	35	0.85
	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)(13)	80	35	1.00
	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)(2)	80	35	0.85
	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)(2)(13)	80	35	1.00
B366	N08367	Sol. ann.	Fe–Ni–Cr–Mo–N	45	(1)(8)(22)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–N	45	(1)(8)(13)(22)	95	45	1.00
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–N	45	(1)(2)(8)(22)	95	45	0.85
	N08367	Sol. ann.	Fe–Ni–Cr–Mo–N	45	(1)(2)(8)(13)(22)	95	45	1.00
B366	N08925	Annealed	Low C–Ni–Fe–Cr–Mo–Cu	45	(1)	87	43	0.85
	N08925	Annealed	Low C–Ni–Fe–Cr–Mo–Cu	45	(1)(13)	87	43	1.00
	N08925	Annealed	Low C–Ni–Fe–Cr–Mo–Cu	45	(1)(2)	87	43	0.85
	N08925	Annealed	Low C–Ni–Fe–Cr–Mo–Cu	45	(1)(2)(13)	87	43	1.00
B366	N08926	Annealed	Low C–Ni–Fe–Cr–Mo–Cu–N	45	(1)(19)(20)	94	43	0.85
	N08926	Annealed	Low C–Ni–Fe–Cr–Mo–Cu–N	45	(1)(13)	94	43	1.00
	N08926	Annealed	Low C–Ni–Fe–Cr–Mo–Cu–N	45	(1)(2)(19)(20)	94	43	0.85
	N08926	Annealed	Low C–Ni–Fe–Cr–Mo–Cu–N	45	(1)(2)(13)	94	43	1.00
B366	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)	100	41	0.85
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(12)(13)	100	41	1.00
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)	100	41	0.85
	N10276	Sol. ann.	Low C–Ni–Mo–Cr	43	~~(1)~~(2)(12)(13)	100	41	1.00

Table A-4 Nickel and High Nickel Alloys (Cont'd)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Welded Fittings (Cont'd)								
B366	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45	0.85
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(13)	100	45	1.00
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)	100	45	0.85
	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)(2)(13)	100	45	1.00

GENERAL NOTES:
(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.
(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.
(c) The P-Numbers indicated in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.
(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."
(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given herein or in Table A-8.
(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.
(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components that are not manufactured in accordance with referenced standards.
(h) The y coefficient $= 0.4$ except where Note (7) applies [see Table 104.1.2(A)].
(i) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.
(j) See para. 124.1.2 for lower temperature limits.

NOTES:
(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).
(2) Due to the relatively low yield strengths of these materials, these higher allowable stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these values may result in dimensional changes due to permanent strain. These values should not be used for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.
(3) The maximum temperature is limited to 500°F because harder temper adversely affects design stress in the creep rupture temperature range.

Table A-5 Cast Iron (16)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding						
400	450	500	600	650	Class	Spec. No.
						Gray Cast Iron
2.0	...	...	...	...	20	A48
2.5	...	...	...	...	25	
3.0	...	...	...	...	30	
3.5	...	...	...	...	35	
4.0	...	...	...	...	40	
4.5	...	...	...	...	45	
5.0	...	...	...	...	50	
5.5	...	...	...	...	55	
6.0	...	...	...	...	60	
2.1	...	...	...	...	A	A126
3.1	...	...	...	...	B	
4.1	...	...	...	...	C	
2.0	2.0	...	...	...	20	A278
2.5	2.5	...	...	...	25	
3.0	3.0	...	...	...	30	
3.5	3.5	...	...	...	35	
4.0	4.0	...	...	...	40	
4.5	4.5	...	...	...	45	
5.0	5.0	...	...	...	50	
5.5	5.5	...	...	...	55	
6.0	6.0	...	...	...	60	
						Ductile Cast Iron
9.6	9.6	9.6	~~9.6~~ 9.0	8.5	60-40-18	A395
10.4	10.4	...	...	...	65-45-15	
9.6	9.6	9.6	9.0	8.5	60-42-10	A536
11.2	11.2	11.2	10.5	10.0	70-50-05	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG.100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) Material quality factors are not applicable to these materials.

(3) For saturated steam at 250 psi (406°F), the stress values given at 400°F may be used.

(4) For limitations on the use of this material, see para. 124.4.

(5) This material shall not be used where the design pressure exceeds 250 psig [1 725 kPa (gage)] or where the design temperature exceeds 450°F (230°C).

(6) This material shall not be used for boiler external piping where the design pressure exceeds 350 psig [2 415 kPa (gage)] or where the design temperature exceeds 450°F (230°C).

(7) Piping components conforming to either ASME B16.1 or ASME B16.4 may be used for boiler external piping, subject to all the requirements of the particular standard.

(8) For limitations on the use of this material, see para. 124.6.

Table A-6 Copper and Copper Alloys (Cont'd)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																
100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	UNS Alloy No.	Spec. No.
																Rod
13.3	12.6	12.0	11.5	11.1	10.7	5.3	2.0	...	...	...	...	...	...	...	C36000	B16
12.0	11.3	10.8	10.4	10.0	9.7	5.3	2.0	...	...	...	...	...	...	...	C36000	
10.0	9.4	9.0	8.7	8.3	8.1	5.3	2.0	...	...	...	...	...	...	...	C36000	
12.0	11.6	11.3	11.0	10.8	10.5	10.3	10.1	9.9	9.8	9.6	9.5	9.4	...	...	C71500	B151
10.7	10.1	9.6	9.2	8.9	8.6	5.3	2.0	...	...	...	...	...	...	...	C35300	B453
10.0	9.4	9.0	8.7	8.3	8.1	5.3	2.0	...	...	...	...	...	...	...	C35300	
10.0	9.4	9.0	8.7	8.3	8.1	5.3	2.0	...	...	...	...	...	...	...	C35300	
																Bar
12.0	11.3	10.8	10.4	10.0	9.7	5.3	2.0	...	...	...	...	...	...	...	C36000	B16
10.0	9.4	9.0	8.7	8.3	8.1	5.3	2.0	...	...	...	...	...	...	...	C36000	
																Die Forgings (Hot Pressed)
12.0	11.3	10.8	...	...	...	...	...	...	...	...	...	...	...	...	C37700	B283
10.0	9.4	9.0	...	...	...	...	...	...	...	...	...	...	...	...	C37700	
																Castings
7.8	7.8	7.8	7.8	7.8	7.8	6.6	6.2	5.8	*4.0*	...	...	...	...	...	C92200	B61
6.9	6.9	6.9	6.9	6.6	6.5	5.5	5.4	...	...	...	...	...	...	...	C83600	B62
13.4	12.6	12.2	11.8	11.6	*11.4*	*11.4*	*11.4*	*11.4*	*9.4*	*5.9*	...	...	...	...	C95200	B148
16.0	15.2	15.0	14.8	*14.8*	*14.8*	*14.8*	*12.8*	*11.1*	*8.8*	*6.8*	...	...	...	...	C95400	
7.8	7.8	7.8	7.8	7.8	7.8	6.6	6.2	5.8	*4.0*	...	...	...	...	...	C92200	B584
6.4	5.9	5.5	5.3	5.3	5.2	5.1	...	...	...	...	...	...	...	...	C93700	
6.0	5.8	5.6	5.5	5.4	...	...	...	...	...	...	...	...	...	...	C97600	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) This material may be used for Boiler External Piping provided that the nominal size does not exceed 3 in. and the design temperature does not exceed 406°F. This material shall not be used for blowoff or blowdown piping except as permitted in para. 122.1.4. Where threaded brass or copper pipe is used for feedwater piping, it shall have a wall thickness not less than that required for schedule 80 steel pipe of the same nominal size.

(3) Welding or brazing of this material is not permitted.

(4) When this material is used for welded or brazed construction, the allowable stress values used shall not exceed those given for the same material in the annealed condition.

(5) Castings that are welded or repair welded shall be heat treated at 1,150°F–1,200°F, followed by moving-air cooling. The required time at temperature is based on the cross-section thicknesses as follows:

  (a) $1\frac{1}{2}$ hr for the first inch or fraction thereof

  (b) $\frac{1}{2}$ hr for each additional inch or fraction thereof

(6) Welds must be made by an electric fusion welding process involving the addition of filler metal.

(7) Material conforming to ASTM B16 alloy C36000 shall not be used in primary pressure relief valve applications.

(8) Materials shall be tested to determine the presence of residual stresses that might result in failure of individual parts due to stress corrosion cracking. Tests shall be conducted in accordance with ASTM B154 or ASTM B858. The test frequency shall be as specified in ASTM B249.

Table A-7 Aluminum and Aluminum Alloys (Cont'd)

Spec. No.	UNS Alloy No.	Temper	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Rods, Bars, and Shapes (Cont'd)								
B221	A96063	T1	Up thru 0.500	23	(1)(2)(21)(22)	17	9	1.00
	A96063	T1	0.501–1.000	23	(1)(2)(21)(22)	16	8	1.00
	A96063	T5	Up thru 0.500	23	(1)(2)(21)(22)	22	16	1.00
	A96063	T5	0.501–1.000	23	(1)(2)(21)(22)	21	15	1.00
	A96063	T6	Up thru 1.000	23	(1)(2)(21)(22)	30	25	1.00
	A96063	T5, T6 welded	Up thru 1.000	23	(1)(7)(21)(22)	17	10	1.00
Castings								
B26	A24430	F	. . .	. . .	(1)(2)	17	6	0.80
	A03560	T6	. . .	. . .	(1)(2)	30	20	0.80
	A03560	T71	. . .	. . .	(1)(2)	25	18	0.80

GENERAL NOTES:
(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.
(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.
(c) The P-Numbers listed in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.
(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."
(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given.
(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.
(g) Pressure–temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components that are not manufactured in accordance with referenced standards.
(h) Aluminum and aluminum alloys shall not be used for flammable fluids within the boiler plant structure (see para. 122.7).
(i) The *y* coefficient equals 0.4 [see Table 104.1.2(A)].
(j) The tabulated stress values that are shown in italics are at temperatures in the range where creep and stress rupture strength govern the selection of stresses.
(k) See para. 124.1.2 for lower temperature limits.

NOTES:
(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).
(2) These allowable stress values are not applicable when either welding or thermal cutting is employed.
(3) These allowable stress values are not applicable when either welding or thermal cutting is employed. In such cases, the corresponding stress values for the O temper shall be used.
(4) These allowable stress values are 90% of those for the corresponding core material.
(5) These allowable stress values apply only to seamless pipe smaller than NPS 1 that is extruded and then drawn.
(6) These allowable stress values are not applicable when either welding or thermal cutting is employed. In such cases, the corresponding stress values for the welded condition shall be used.

TP321H	S32109	. . .	18Cr-10Ni-Ti	8	(9)	70	25

Table A-8 Temperatures 1,200°F and Above

Spec. No.	Type or Grade	UNS Alloy No.	Temper	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi
Seamless Pipe and Tube								
A213	TP304H	S30409	. . .	18Cr–8Ni	8	. . .	75	30
	. . .	S30815	. . .	21Cr–11Ni–N	8	(1)	87	45
	TP310H	S31009	. . .	25Cr–20Ni	8	(2)(4)	75	30
	TP316H	S31609	. . .	16Cr–12Ni–2Mo	8	. . .	75	30
	TP316L	S31603	. . .	16Cr–12Ni–2Mo	8	(1)	70	25
A213	TP321H	S32109	. . .	18Cr–10Ni–Ti	8	. . .	75	30
	TP347H	S34709	. . .	18Cr–10Ni–Cb	8	. . .	75	30
	TP348H	S34809	. . .	18Cr–10Ni–Cb	8	. . .	75	30
A312	TP304H	S30409	. . .	18Cr–8Ni	8	. . .	75	30
	. . .	S30815	. . .	21Cr–11Ni–N	8	(1)	87	45
	TP310H	S31009	. . .	25Cr–20Ni	8	(2)(4)	75	30
	TP316H	S31609	. . .	16Cr–12Ni–2Mo	8	. . .	75	30
A312	TP321H	S32109	. . .	18Cr–10Ni–Ti	8	~~. . .~~ (8)	75	30
	TP347H	S34709	. . .	18Cr–10Ni–Cb	8	. . .	75	30
	TP348H	S34809	. . .	18Cr–10Ni–Cb	8	. . .	75	30
A376	TP304H	S30409	. . .	18Cr–8Ni	8	. . .	75	30
	TP316H	S31609	. . .	16Cr–12Ni–2Mo	8	. . .	75	30
	TP321H	S32109	. . .	18Cr–10Ni–Ti	8	. . .	75	30
	TP347H	S34709	. . .	18Cr–10Ni–Cb	8	. . .	75	30
B163	. . .	N08800	Annealed	Ni–Cr–Fe	45	(1)	75	30
	. . .	N08810	Annealed	Ni–Cr–Fe	45	(1)	65	25
B167	. . .	N06617	Annealed	52Ni–22Cr–13Co–9Mo	43	. . .	95	35
B407	. . .	N08800	C.D./ann.	Ni–Cr–Fe	45	. . .	75	30
	. . .	N08810	Annealed	Ni–Cr–Fe	45	. . .	65	25
B622	. . .	R30556	Annealed	Ni–Fe–Cr–Co–Mo–W	45	(1)	100	45
Welded Pipe and Tube — Without Filler Metal								
A249	TP304H	S30409	. . .	18Cr–8Ni	8	. . .	75	35
	. . .	S30815	. . .	21Cr–11Ni–N	8	(1)	87	45
	TP310H	S31009	. . .	25Cr–20Ni	8	(1)(2)(4)	75	35
	TP316H	S31609	. . .	16Cr–12Ni–2Mo	8	. . .	75	35
A249	TP321H	S32109	. . .	18Cr–10Ni–Ti	8	. . .	75	35
	TP347H	S34709	. . .	18Cr–10Ni–Cb	8	. . .	75	35
	TP348H	S34809	. . .	18Cr–10Ni–Cb	8	. . .	75	35
A312	TP304H	S30409	. . .	18Cr–8Ni	8	. . .	75	30
	. . .	S30815	. . .	21Cr–11Ni–N	8	(1)	87	45
	TP310H	S31009	. . .	25Cr–20Ni	8	(2)(4)	75	30
	TP316H	S31609	. . .	16Cr–12Ni–2Mo	8	. . .	75	30

1.00 4.6 3.5 2.7 2.1 1.6 1.3 0.9 TP321H

Table A-8 Temperatures 1,200°F and Above

E or *F*	Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding							Type or Grade	Spec. No.
	1,200	1,250	1,300	1,350	1,400	1,450	1,500		
								Seamless Pipe and Tube	
1.00	*6.1*	*4.7*	*3.7*	*2.9*	*2.3*	*1.8*	*1.4*	TP304H	A213
1.00	*5.2*	*4.0*	*3.1*	*2.4*	*1.9*	*1.6*	*1.3*	. . .	
1.00	*4.0*	*3.0*	*2.2*	*1.7*	*1.3*	*0.97*	*0.75*	TP310H	
1.00	*7.4*	*5.5*	*4.1*	*3.1*	*2.3*	*1.7*	*1.3*	TP316H	
1.00	*6.4*	*4.7*	*3.5*	*2.5*	*1.8*	*1.3*	*1.0*	TP316L	
1.00	*5.4*	*4.1*	*3.2*	*2.5*	*1.9*	*1.5*	*1.1*	TP321H	A213
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	TP347H	
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	TP348H	
1.00	*6.1*	*4.7*	*3.7*	*2.9*	*2.3*	*1.8*	*1.4*	TP304H	A312
1.00	*5.2*	*4.0*	*3.1*	*2.4*	*1.9*	*1.6*	*1.3*	. . .	
1.00	*4.0*	*3.0*	*2.2*	*1.7*	*1.3*	*0.97*	*0.75*	TP310H	
1.00	*7.4*	*5.5*	*4.1*	*3.1*	*2.3*	*1.7*	*1.3*	TP316H	
1.00	*5.4*	*4.1*	*3.2*	*2.5*	*1.9*	*1.5*	*1.1*	TP321H	A312
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	TP347H	
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	TP348H	
1.00	*6.1*	*4.7*	*3.7*	*2.9*	*2.3*	*1.8*	*1.4*	TP304H	A376
1.00	*7.4*	*5.5*	*4.1*	*3.1*	*2.3*	*1.7*	*1.3*	TP316H	
1.00	*5.4*	*4.1*	*3.2*	*2.5*	*1.9*	*1.5*	*1.1*	TP321H	
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	TP347H	
1.00	*6.6*	*4.2*	*2.0*	*1.6*	*1.1*	*1.0*	*0.80*	. . .	B163
1.00	*7.4*	*5.9*	*4.7*	*3.8*	*3.0*	*2.4*	*1.9*	. . .	
1.00	15.3	*14.5*	*11.2*	*8.7*	*6.6*	*5.1*	*3.9*	. . .	B167
1.00	*6.6*	*4.2*	*2.0*	*1.6*	*1.1*	*1.0*	*0.80*	. . .	B407
1.00	*7.4*	*5.9*	*4.7*	*3.8*	*3.0*	*2.4*	*1.9*	. . .	
1.00	*13.6*	*10.9*	*8.8*	*7.0*	*5.6*	*4.5*	*3.6*	. . .	B622
								Welded Pipe and Tube — Without Filler Metal	
0.85	*5.2*	*4.0*	*3.2*	*2.5*	*2.0*	*1.6*	*1.2*	TP304H	A249
0.85	*4.4*	*3.4*	*2.6*	*2.0*	*1.6*	*1.4*	*1.1*	. . .	
0.85	*3.4*	*2.6*	*1.9*	*1.4*	*1.1*	*0.82*	*0.64*	TP310H	
0.85	*6.3*	*4.7*	*3.5*	*2.6*	*1.9*	*1.5*	*1.1*	TP316H	
0.85	*4.6*	*3.5*	*2.7*	*2.1*	*1.6*	*1.3*	*1.0*	TP321H	A249
0.85	*6.7*	*5.0*	*3.7*	*2.7*	*2.1*	*1.6*	*1.1*	TP347H	
0.85	*6.7*	*5.0*	*3.7*	*2.7*	*2.1*	*1.6*	*1.1*	TP348H	
0.85	*5.2*	*4.0*	*3.2*	*2.5*	*2.0*	*1.6*	*1.2*	TP304H	A312
0.85	*4.4*	*3.4*	*2.6*	*2.0*	*1.6*	*1.4*	*1.1*	. . .	
0.85	*3.4*	*2.6*	*1.9*	*1.4*	*1.1*	*0.82*	*0.64*	TP310H	
0.85	*6.3*	*4.7*	*3.5*	*2.6*	*1.9*	*1.5*	*1.1*	TP316H	

Table A-8 Temperatures 1,200°F and Above (Cont'd)

E or *F*	Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding							Type or Grade	Spec. No.
	1,200	1,250	1,300	1,350	1,400	1,450	1,500		
									Forgings (Cont'd)
1.00	*5.4*	*4.1*	*3.2*	*2.5*	*1.9*	*1.5*	*1.1*	F321H	A182
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	F347H	
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	F348H	
1.00	15.3	*14.5*	*11.2*	*8.7*	*6.6*	*5.1*	*3.9*	. . .	B564
1.00	*6.6*	*4.2*	*2.0*	*1.6*	*1.1*	*1.0*	*0.80*	. . .	
1.00	*7.4*	*5.9*	*4.7*	*3.8*	*3.0*	*2.4*	*1.9*	. . .	
									Fittings (Seamless and Welded)
1.00	*6.1*	*4.7*	*3.7*	*2.9*	*2.3*	*1.8*	*1.4*	WP304H	A403
1.00	*7.4*	*5.5*	*4.1*	*3.1*	*2.3*	*1.7*	*1.3*	WP316H	
1.00	*6.4*	*4.7*	*3.5*	*2.5*	*1.8*	*1.3*	*1.0*	WP316L	
1.00	*5.4*	*4.1*	*3.2*	*2.5*	*1.9*	*1.5*	*1.1*	WP321H	
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	WP347H	
1.00	*7.9*	*5.9*	*4.4*	*3.2*	*2.5*	*1.8*	*1.3*	WP348H	
1.00	*13.6*	*10.9*	*8.8*	*7.0*	*5.6*	*4.5*	*3.6*	. . .	B366
0.85	*11.6*	*9.3*	*7.5*	*6.0*	*4.8*	*3.8*	*3.1*	. . .	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) These allowable stress values shall be used only if the carbon content of the material is 0.04% or higher.

(3) These allowable stress values tabulated shall be used only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapidly cooling by other means.

(4) These allowable stress values shall be used only when the grain size of the material is ASTM No. 6 or coarser.

(5) These allowable stress values shall be used only when Supplementary Requirement S1 per ASTM A479 has been specified.

(6) Seamless.

(7) Welded—all filler metal, including consumable insert material, shall comply with the requirements of Section IX of the ASME Boiler and Pressure Vessel Code.

(8) These allowable stress values apply to seamless pipe ≤3/8 in wall thickness

(9) These allowable stress values apply to seamless pipe >3/8 in wall thickness

Table A-9 Titanium and Titanium Alloys (Cont'd)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding												
100	150	200	250	300	350	400	450	500	550	600	Grade	Spec. No.
												Bars and Billets
10.0	9.3	8.3	7.4	6.6	6.0	5.5	5.1	4.7	4.2	3.6	1	B348
14.3	13.7	12.4	11.3	10.3	9.5	8.8	8.2	7.6	7.0	6.5	2	
18.6	17.5	15.8	14.2	12.8	11.5	10.3	9.3	8.5	7.9	7.4	3	
14.3	13.7	12.4	11.3	10.3	9.5	8.8	8.2	7.6	7.0	6.5	7	
20.0	20.0	18.7	17.4	16.2	15.2	14.3	13.6	13.1	12.7	12.3	12	
												Castings
11.4	10.5	10.0	9.0	8.3	7.6	. . .	. . .	. . .	. . .	. . .	C-2	B367

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), ~~AND~~ FIG. 100.1.2(B.3)~~.~~ ,100.1.2(C.1), AND 100.1.2(C.2).

(2) Filler metal shall not be used in the manufacture of welded pipe or tubing.

(3) Welding of this material is not permitted.

Table A-10 Bolts, Nuts, and Studs (Cont'd)

GENERAL NOTE: See para. 124.1.2 for lower temperature limits.

NOTES:

(1) This is a product specification. Allowable stresses are not necessary. Limitations on metal temperature for materials covered by this specification for use under B31.1 are as follows:

(a) Grades 1 and 2, −20°F to 600°F
(b) Grade 2H, −20°F to 800°F
(c) Grades 3 and 7, −20°F to 1,100°F
(d) Grade 4, −20°F to 900°F
(e) Grades 6 and 8F, −20°F to 800°F
(f) Grades 8, 8C, 8M, and 8T, −20°F to 1,200°F

(2) THIS MATERIAL IS NOT ACCEPTABLE FOR CONSTRUCTION OF PRESSURE-RETAINING PARTS OF BOILER EXTERNAL PIPING — SEE FIG. 100.1.2(A.1), FIG. 100.1.2(A.2), FIG. 100.1.2(B.1), FIG. 100.1.2(B.2), AND FIG. 100.1.2(B.3). ,100.1.2(C.1), AND 100.1.2(C.2).

(3) This material shall not be used above 400°F. The allowable stress value is 7,000 psi.

(4) The allowable stress values listed in MSS SP-58 for this material may be used for pipe supporting elements designed in accordance with MSS SP-58.

(5) These allowable stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints, where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the relative flexibility of the flange, bolt, and corresponding relaxation properties.

(6) These allowable stress values apply to bolting materials less than or equal to 1 in. in diameter.

(7) These allowable stress values apply to bolting materials greater than or equal to 1 in. in diameter and less than or equal to $1\frac{1}{2}$ in. in diameter.

(8) These allowable stress values apply to bolting materials greater than or equal to $1\frac{1}{2}$ in. in diameter and less than or equal to 3 in. in diameter.

(9) Between temperatures of −20°F and 400°F, allowable stress values equal to the lower of the following may be used: 20% of the specified tensile strength or 25% of the specified yield strength.

(10) These allowable stress values apply to bolting materials 4 in. in diameter and smaller.

(11) These allowable stress values apply to bolting materials $2\frac{1}{2}$ in. in diameter and smaller.

(12) These allowable stress values apply to bolting materials larger than $2\frac{1}{2}$ in. in diameter but not larger than 4 in. in diameter.

(13) These allowable stress values apply to bolting materials larger than 4 in. in diameter but not larger than 7 in. in diameter.

(14) Upon prolonged exposures to temperatures above 875°F, the carbide phase of carbon–molybdenum steel may be converted to graphite.

(15) Minimum tempering temperature shall be 800°F.

(16) The allowable stress values tabulated for temperatures over 1,000°F apply only if the carbon content of the material is 0.04% or higher.

(17) The allowable stress values tabulated for temperatures over 1,000°F apply only if the material is heat treated by heating to a minimum temperature of 1,900°F and quenching in water or rapidly cooling by other means.

(18) The hardness of this material, under the thread roots, shall not exceed Rockwell C35. The hardness shall be measured on a flat area, at least $\frac{1}{8}$ in. across, prepared by removing thread. No more material than necessary shall be removed to prepare the flat area. Hardness measurements shall be made at the same frequency as the tensile test.

(19) These allowable stress values apply to bolting materials $\frac{3}{4}$ in. in diameter and smaller.

(20) These allowable stress values apply to bolting materials larger than $\frac{3}{4}$ in. but not larger than 1 in. in diameter.

(21) These allowable stress values apply to bolting materials larger than 1 in. but not larger than $1\frac{1}{4}$ in. in diameter.

(22) These allowable stress values apply to bolting materials larger than $1\frac{1}{4}$ in. but not larger than $1\frac{1}{2}$ in. in diameter.

(23) These allowable stress values apply to bolting material that has been carbide solution treated.

(24) Due to relatively low yield strength of these materials, these higher allowable stress values were established at temperatures where the short-time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These values should not be used for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(25) These allowable stress values apply to bolting materials 8 in. in diameter and smaller. 800°F (427°C)

(26) Welding or brazing of this material is not permitted.

(27) These allowable stress values apply to bolting materials $\frac{1}{2}$ in. in diameter and smaller.

(28) Tempered to HR50.

(29) These allowable stress values apply to bolting materials greater than $\frac{1}{2}$ in. but not larger than 1 in. in diameter.

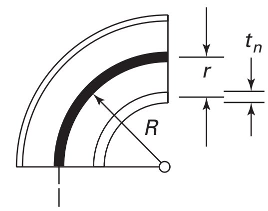
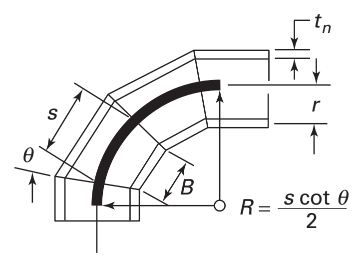
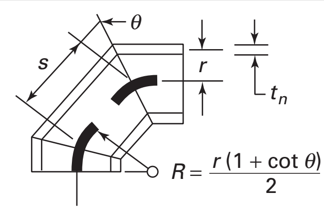
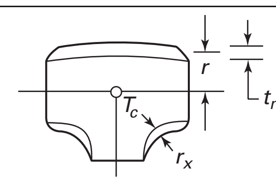
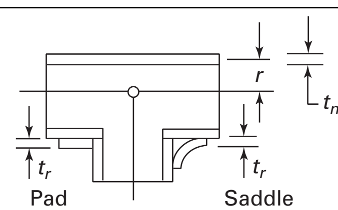
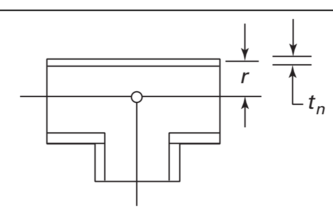
(30) These allowable stress values apply to bolting materials greater than 1 in. but not larger than 2 in. in diameter.

(31) These allowable stress values apply to bolting materials greater than 2 in. but not larger than 3 in. in diameter.

MANDATORY APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

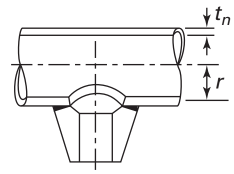
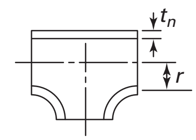
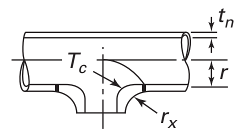
Insert in subscript: "[Note (15)]"

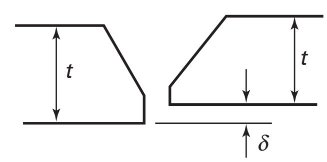
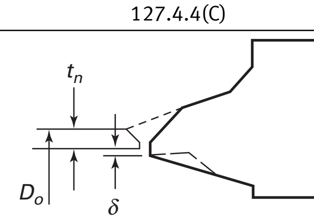
Table D-1 Flexibility and Stress Intensification Factors

Description	Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r(1 + \tan\theta)$ $B \geq 6\ t_n$ $\theta \leq 22\tfrac{1}{2}$ deg	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (5), (6)] $s \geq r(1 + \tan\theta)$ $\theta \leq 22\tfrac{1}{2}$ deg	$\frac{t_n (1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Notes (1), (2), (7)]	$\frac{3.1 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (8), (9)]	$\frac{\left(t_n + \frac{t_r}{2}\right)^{5/2}}{r\,(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Insert in subscript:
"[Note (15)]"

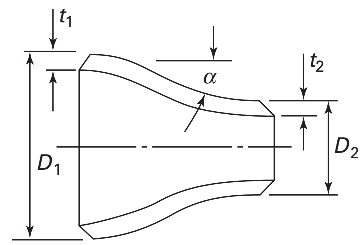
Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]	$\frac{3.3t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Extruded outlet meeting the requirements of para. 104.3.1(G) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert [Notes (1), (2), (7)]	$3.1\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/8$ in., and δ_{avg}/t = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/t)]$, but not less than 1.0 [Note (11)]	
Butt weld [Note (1)] $t < 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.33$	1		
Fillet welds	1	1.3 [Note (12)]	See Figs. 127.4.4(A), 127.4.4(B), and 127.4.4(C)
Tapered transition per para. 127.4.2(B) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$	

Insert in subscript: "[Note (15)]"

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Concentric reducer per ASME B16.9 [Notes (1), (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (14)]	5	2.5	. . .

GENERAL NOTE: The validity of the stress intensification and flexibility factor data in Table D-1 has been demonstrated for $D_o/t_n \leq 100$.

NOTES:

(1) The following nomenclature applies to Table D-1:

B = length of miter segment at crotch, in. (mm)
D_o = outside diameter, in. (mm)
D_{ob} = outside diameter of branch, in. (mm)
D_1 = outside diameter of reducer on large end, in. (mm)
D_2 = outside diameter of reducer on small end, in. (mm)
R = bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees)
r_x = external crotch radius of welded-in contour inserts and welding tees, in. (mm)
s = miter spacing at centerline, in. (mm)
T_c = crotch thickness of welded-in contour inserts and welding tees, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
t_r = reinforcement pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factors k and stress intensification factors i in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Chart D-1 by entering with the characteristic h computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor c given below, which can be read directly from Chart D-2, entering with the computed h: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i. Values from the Table may be corrected by dividing k by

$$\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}\right]$$

and dividing i by

$$\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}\right]$$

(6) Also includes single miter joints.

(7) If $r_x \geq D_{ob}/8$ and $T_c \geq 1.5t_n$, a flexibility characteristic, h, of $4.4t_n/r$ may be used.

(8) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

(9) The stress intensification factors in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

(10) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of para. 104.3 are met.

(b) The axis of the branch pipe is normal to the surface of run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.

(d) The inside corner radius r_1 (see Fig. D-1) is between 10% and 50% of t_{nh}.

(e) The outer radius r_2 (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b + y)/2$ [shown in Fig. D-1 sketch (c)], or $t_{nh}/2$.

(f) The outer radius r_3 (see Fig. D-1) is not less than the larger of:

(1) $0.002\theta d_o$;

(2) $2(\sin\theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).

(g) $R_m/t_{nh} \leq 50$ and $r'_m/R_m \leq 0.5$.

(11) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875t$ and $1.10t$ for an axial distance of $\sqrt{D_o t}$. D_o and t are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a full weld is made between the pipe and fitting as shown in Fig. 127.4.4(C). For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Fig. 127.4.4(B) and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 127.4.4(A) sketches (b) and (d), has been shown to improve the fatigue performance of the weld.

(13) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(14) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

(15) The designer may use the stress intensification and flexibility factors from ASME B31J instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of in-plane (i_i), out-plane (i_o), and torsional (i_t) stress intensification factor shall be used in calculating stresses in accordance with para. 104.8. Alternatively, stress intensification factors may be developed using ASME B31J, Appendix A.

MANDATORY APPENDIX F
REFERENCED STANDARDS

(16)

Specific editions of standards incorporated in this Code by reference are shown in this issue of Mandatory Appendix F. It is not practical to refer to a specific edition of each standard throughout the Code text, but instead, the specific edition reference dates are shown here. Mandatory Appendix F will be revised at intervals as needed and issued. The names and addresses of the sponsoring organizations are also shown in this issue.

American National Standard

Z223.1-2012

ASCE/SEI Standard

7-05, 7-10, 7-16

ASTM Specifications [Note (1)]

A36/A36M-05
A47/A47M-99 (R04)
A48/A48M-03
A53/A53M-07

A105/A105M-05
A106/A106M-10
A125-96 (R07)
A126-04
A134-96 (R05)
A135/A135M-06
A139/A139M-04
A178/A178M-02
A179/A179M-90a (R05)
A181/A181M-06
A182/A182M-07a
A192/A192M-02
A193/A193M-07
A194/A194M-07a
A197/A197M-00 (R06)

A210/A210M-02
A213/A213M-07a
A214/A214M-96 (R05)
A216/A216M-07
A217/A217M-07
A229/A229M-99
A234/A234M-07
A240/A240M-~~11b~~ 16
A242/A242M-04$^{\epsilon 1}$
A249/A249M-07
A254-97 (R02)
A268/A268M-05a
A276-06
A278/A278M-01 (R06)
A283/A283M-00
A285/A285M-03
A299/A299M-04

ASTM Specifications [Note (1)] (Cont'd)

A307-07b
A312/A312M-13b
A320/A320M-07a
A322-07
A333/A333M-05
A335/A335M-06
A336/A336M-07
A350/A350M-04a
A351/A351M-06
A354-07
A358/A358M-05
A369/A369M-06
A376/A376M-06
A377-03
A387/A387M-06a
A389/A389M-03
A395/A395M-99 (R04)

A403/A403M-13a
A409/A409M-01 (R05)
A420/A420M-07
A426/A426M-07
A437/A437M-06
A449-07b
A450/A450M-04a
A451/A451M-06
A453/A453M-04
A479/A479M-11

A515/A515M-03
A516/A516M-06
A530/A530M-04a
A564/A564M-04
A575-96 (R02)
A576-90b (R06)
A587-96 (R05)

A671-06
A672-06
A691-98 (R02)

A714-99 (R03)
A789/A789M-~~11~~ 17
A790/A790M-~~11~~ 16

ASTM Specifications [Note (1)] (Cont'd)

A815/A815M-07a

A928/A928M-11
A965/A965M-12
A992/A992M-06a
A1091/A1091M-16e1

B26/B26M-05
B32-04
B42-02
B43-98 (R04)
B61-02
B62-02
B68-02
B68M-99 (R05)
B75-02
B88-03
B88M-05

B108-06
B111/B111M-04
B148-97
B150/B150M-03
B151/B151M-05
B161-05
B163-04
B165-05
B166-08
B167-11
B168-08
B171-04

B209/B209M-06
B210-04
B210M-05
B221-06
B234-04
B234M-04
B241/B241M-02
B247-02a
B247M-02a
B251-02$^{\epsilon 1}$
B251M-97 (R03)
B265-07
B280-03
B283-06

Referenced Standards (Cont'd)

ASTM Specifications [Note (1)] (Cont'd)

B302-07
B315-06
B338-06a
B348-06a
B361-02
B366-04b$^{\epsilon 1}$
B367-06
B381-06a

B407-04
B408-06
B409-06$^{\epsilon 1}$
B423-05
B424-05
B425-99 (R05)
B435-06
B443-00 (R05)
B444-06
B446-03 (R08)
B462-06
B463-04
B464-05
B466/B466M-07
B467-88 (R03)
B468-04
B473-07

B546-04
B547/B547M-02
B564-06a
B572-06
B574-06$^{\epsilon 1}$
B575-06
B584-06a

B608-07
B619-06
B622-06
B625-05
B626-06
B649-06
B673-05$^{\epsilon 1}$
B674-05
B675-02
B676-03
B677-05
B688-96 (R04)
B690-02 (R07)
B691-95

B704-03
B705-05
B729-05

ASTM Specifications [Note (1)] (Cont'd)

B804-02
B828-02
B861-06a
B862-06b$^{\epsilon 1}$

ASTM Standard Test Methods

D323-06
E94-04
E125-85 (R04)
E186-04
E280-04
E446-04

MSS Standard Practices

SP-6-12
SP-9-13
SP-25-13
SP-42-13
SP-43-13
SP-45-03 (R08)
SP-51-12
SP-53-99 (R07)
SP-54-99 (R07)
SP-55-06
SP-58-09
SP-61-13
SP-67-11
SP-68-11
SP-75-14
SP-79-11
SP-80-13
SP-83-14
SP-88-10
SP-93-99 (R04)
SP-94-92
SP-95-14
SP-97-12
SP-105-10
SP-106-12

AWS Specifications

A3.0-01
D10.10-99
QC1-07

API Specifications

5L, 38th Edition, 1990
570, 3rd Edition, 2009

ASME Codes & Standards

Boiler and Pressure Vessel Code,
~~2001 Edition, including Addenda~~ Latest Edition

B1.1-1989
B1.13M-2001
B1.20.1-1983 (R2001)
(ANSI/ASME B1.20.1)
B1.20.3-1976 (R1998)
(ANSI B1.20.3)
B16.1-2005
B16.3-1998
B16.4-2005
B16.5-2003
B16.9-2001
B16.10-2000
B16.11-2005
B16.14-1991
B16.15-1985 (R1994)
(ANSI/ASME B16.15)
B16.18-1984 (R1994)
(ANSI B16.18)
B16.20-1998
B16.21-2005
B16.22-2001 (R2005)
B16.24-2001
B16.25-2003
B16.26-2011
B16.34-2004
B16.42-1998
B16.47-1996 (1998a)
B16.48-2005
B16.50-2001

B18.2.1-1996 (1999a)
B18.2.2-1987 (R1999)
(ASME/ANSI B18.2.2)
B18.2.3.5M-1979 (R2001)
B18.2.3.6M-1979 (R2001)
B18.2.4.6M-1979 (R1998)
B18.21.1-1999
B18.22M-1981
B18.22.1-1965 (R1998)

B31.3-2002
B31.4-2002
B31.8-1999
B31Ea-2010
B31J~~-2008 (R2013)~~ 2017
B31T-2010
B36.10M-2004
B36.19M-2004

CA-1, Latest Edition
QAI-1, Latest Edition

TDP-1-1998

EJMA Standards
Standards of the EJMA, Inc.
10th Edition 2015

and Standards

Referenced Standards (Cont'd)

AWWA and ANSI/AWWA Standards

C110/A21.10-~~98~~ 08
C111/A21.11-~~95~~ 07
C115/A21.15-~~99~~ 05
C150/A21.50-~~96~~ 08
C151/A21.51-~~96~~ 02
C153/A21.53-~~94~~ 06

C200-~~97~~ 05
C207-~~94~~ 07
C208-~~96~~ 07

AWWA and ANSI/AWWA Standards (Cont'd)

C300-~~97~~ 04
C301-~~99~~ 07
C302-~~95~~ 04
C304-~~99~~ 07

C500-~~93(95a)~~ 02
C504-~~94~~ 06
C509-~~94~~ 01

C600-~~99~~ 05
C606-~~97~~ 06

NFPA 56-14

National Fire Codes

NFPA 85-~~11~~ 15
NFPA 1963-~~09~~ 14

’FI Standards

ES-16-08
ES-24-08

FCI Standard

79-1-~~03~~ 09

GENERAL NOTE: The issue date shown immediately following the hyphen after the number of the standard (e.g., B1.1-1989, A36/A36M-05, SP-6-12) is the effective date of issue (edition) of the standard. B18.2.2-1987 (R1999) designates specification reaffirmed without change in 1999.

NOTE:
(1) For boiler external piping material application, see para. 123.2.2.

Specifications and standards of the following organizations appear in this Appendix:

AISC American Institute of Steel Construction
1 East Wacker Drive, Suite 700
Chicago, IL 60601-1802
Phone: 312 670-2400
Fax: 312 670-5403
www.aisc.org

ANSI American National Standards Institute
25 West 43rd Street
New York, NY 10036
Phone: 212 642-4900
Fax: 212 398-0023
www.ansi.org

API American Petroleum Institute
1220 L Street, NW
Washington, DC 20005-4070
Phone: 202 682-8000
www.api.org

ASCE American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, VA 20191-4400
Phone: 800 548-2723
703 295-6300 (International)
Fax: 703 295-6222
www.asce.org

ASME The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
Phone: 800-843-2763
Fax: 973 882-1717, 5155
www.asme.org

ASTM American Society for Testing and Materials
(ASTM International)
100 Barr Harbor Drive
P.O. Box C700
West Conshohocken, PA 19428-2959
Phone: 610 832-9585
Fax: 610 832-9555
www.astm.org

AWS American Welding Society
8669 NW 36 Street, No. 130
Miami, FL 33166
Phone: 305 443-9353 or 800 443-9353
www.aws.org

AWWA American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235
Phone: 303 794-7711 or 800 926-7337
www.awwa.org

FCI Fluid Controls Institute, Inc.
1300 Sumner Avenue
Cleveland, OH 44115-2851
Phone: 216 241-7333
Fax: 216 241-0105
www.fluidcontrolsinstitute.org

MSS Manufacturers Standardization Society of
the Valve and Fittings Industry, Inc.
127 Park Street, NE
Vienna, VA 22180-4602
Phone: 703 281-6613
www.msshq.org

EJMA Expansion Joint
Manufacturers Association, Inc.
25 North Broadway
Tarrytown, NY 10591
Phone: 914-332-0040
www.ejma.org

h	Thru wall dimension (height) of a flaw drawn normal to the inside pressure surface of the component	mm	in.	App. R, R-107*(a)(2)* App. R, R-107*(a)(4)*	App. R, Table R-108.1 App. R Table R-108.2 App. R Table R-108.3 App. R Figure R-108

Symbol	Definition	Units		References	
		SI	U.S.	Paragraph	Table/Fig./App.
D_o	Outside diameter of pipe	mm	in.	102.3.2(A) 104.1.2(A)[eqs. (7), (9)] 104.8.1[eq. (15)] 104.8.2[eq. (16)]	App. D, Table D-1 104.1.2(A)
D_{ob}	Outside diameter of branch	mm	in.	104.3.1(D.2) 104.3.1(D.2.3) 104.3.1(E) 104.3.1(G.4) 104.3.1(G.5)	App. D, Fig. D-1 104.3.1(G)
D_{oh}	Outside diameter of header or run pipe	mm	in.	104.3.1(D.2) 104.3.1(E) 104.3.1(G.4) 104.3.1(G.5)	104.3.1(G)
d	Inside diameter of pipe	mm	in.	104.1.2(A)[eqs. (8), (10)]	104.1.2(A)
d_1	Inside centerline longitudinal direction of the finished branch opening in the run of the pipe	mm	in.	104.3.1(D) 104.3.1(E)	104.3.1(D)
d_2	Half-width of reinforcement zone	mm	in.	104.3.1(D.2)	104.3.1(D)
d_5	Diameter of finished opening	mm	in.	104.4.2	. . .
d_6	Inside or pitch diameter of gasket	mm	in.	104.5.3(A)[eq. (14)]	104.5.3
d_b	Corroded internal diameter of branch pipe	mm	in.	104.3.1(G.4)	104.3.1(G)
d_c	Corroded internal diameter of extruded outlet	mm	in.	104.3.1(G.4) 104.3.1(G.5) 104.3.1(G.6)	104.3.1(G)
d_i	Inside diameter of Y-globe valve	mm	in.	. . .	122.1.7(C)
d_n	Nominal inside diameter of pipe	mm	in.	102.3.2(A)	. . .
d_r	Corroded internal diameter of run	mm	in.	104.3.1(G.4)	104.3.1(G)
E	Weld joint efficiency factor	. . .	. . .	104.1.2(A.5)	102.4.3 App. A Notes and Tables
E	Young's modulus of elasticity (used with subscripts)	MPa	psi	119.6.2 119.6.4 119.10.1[eqs. (18), (19)]	App. C, Tables C-1 and C-2 App. D, Table D-1
F	Casting quality factor	. . .	. . .	104.1.2(A.5)	App. A Notes and Tables
f	Stress range reduction factor	. . .	. . .	102.3.2(B)[eq. (1)]	. . .
h	Subscript referring to run or header	. . .	. . .	104.3.1(D.2)	104.3.1(D) 104.3.1(G)
h	Thread depth (ref. ASME B1.20.1)	mm	in.	102.4.2	. . .
h	Flexibility characteristic, to compute i, k	. . .	. . .	. . .	App. D, Table D-1

ℓ	Length of flaw, drawn parallel to the inside pressure retaining surface of the component	mm	in.	App. R, R-107*(a)(1)*	App. R Table R-108.1 App. R Table R-108.2 App. R Table R-108.3 App. R Figure R-108

Symbol	Definition	Units		References	
		SI	U.S.	Paragraph	Table/Fig./App.
h_o	Height of extruded lip	mm	in.	104.3.1(G.2) 104.3.1(G.4)	104.3.1(G)
I	Lorenz equation compensation factor	. . .	. . .	102.4.5[eqs. (3), (4), (5), (6)]	. . .
i	Stress intensification factor	. . .	. . .	104.8.1[eq. (15)] 104.8.2[eq. (16)] 104.8.3[eq. (17)] 104.8.4(C)	App. D, Table D-1
j	Subscript for resultant moment	. . .	. . .	104.8.4(A)	. . .
K	Factor for reinforcing area	. . .	. . .	104.3.1(G.5)	104.3.1(G)
k	Factor for occasional loads	. . .	. . .	104.8.2[eq. (16)]	. . .
k	Flexibility factor	. . .	. . .	. . .	App. D, Table D-1
L	Developed length of line axis	m	ft	119.7.1(A.3)	. . .
L_1	Height of nozzle	mm	in.	104.8.4(C)	App. D, Fig. D-1
L_4	Altitude of reinforcing zone outside run pipe	mm	in.	104.3.1(D.2)	104.3.1(D)
L_8	Altitude of reinforcing zone for extruded outlet	mm	in.	104.3.1(G.4) 104.3.1(G.6)	104.3.1(G)
M	Moment of bending or torsional force (used with subscripts to define applications as shown in referenced paragraphs)	mm·N	in.-lb	104.8.1[eq. (15)] 104.8.2[eq. (16)] 104.8.3[eq. (17)] 104.8.4(A) 104.8.4(C)	104.8.4
MAWP	Maximum allowable working pressure	kPa	psi	100.2	. . .
MSOP	Maximum sustained operating pressure	kPa	psi	101.2.2	. . .
N	Total number of equivalent reference displacement stress range cycles	. . .	. . .	102.3.2(B)[eq. (2)]	. . .
N_E	Number of cycles of reference displacement stress range	. . .	. . .	102.3.2(B)[eq. (2)]	. . .
N_i	Number of cycles associated with displacement stress range	. . .	. . .	102.3.2(B)[eq. (2)]	. . .
NPS	Nominal pipe size	. . .	in.	General	. . .

P_o = Pressure coincident with the occasional load being evaluated kPa psi 104.8.2[eq. (16)]

Symbol	Definition	Units		References	
		SI	U.S.	Paragraph	Table/Fig./App.
P	Internal design gage pressure of pipe, component	kPa	psi	102.3.2(A) 104.1.2(A)[eqs. (7), (8), (9), (10)] 104.5.1(A) 104.5.2(B) 104.5.3(A)[eq. (14)] 104.5.3(B) 104.8.1[eq. (15)] ~~104.8.2[eq. (16)]~~ 122.1.2(A) 122.1.3(A) 122.1.4(A) 122.1.4(B) 122.1.6(B) 122.1.7(C) 122.4(B)	App. D, Table D-1
q_i	Ratio of computed stress range other than reference range (S_i) to computed reference stress range (S_E)	. . .	. . .	102.3.2(B)[eq. (2)]	. . .
R	Reaction moment in flexibility analysis (used with subscripts)	mm-N	in.-lb	119.10.1[eqs. (18), (19)]	. . .
R	Centerline radius of elbow or bend, and effective "radius" of miter bends	mm	in.	102.4.5(B) 104.3.3(C.3.1) 129.3.4.1	App. D, Table D-1 102.4.5
R_f	Mean radius after forming	mm	in.	129.3.4.1	. . .
R_g	Original mean radius	mm	in.	129.3.4.1	. . .
R_m	Mean radius of run pipe	mm	in.	. . .	App. D, Fig. D-1 App. D, Table D-1
r	Mean radius of pipe using nominal wall t_n	mm	in.	104.3.3	App. D, Table D-1
r_1	Half width of reinforcement zone	mm	in.	104.3.1(G.4)	104.3.1(G)
r_1, r_2, r_3	Transition radii of branch reinforcement	mm	in.	. . .	App. D, Fig. D-1
r_b	Branch mean cross-sectional radius	mm	in.	104.8.4	. . .
r_i	Inside radius of branch	mm	in.	104.8.4(C)	App. D, Fig. D-1
r'_m	Mean radius of branch	mm	in.	104.8.4(C)	App. D, Fig. D-1 App. D, Table D-1
r_o	Radius of curvature of external curved portion	mm	in.	104.3.1(G.2) 104.3.1(G.4) 104.3.1(G.6)	104.3.1(G)
r_{od}	Normal outside radius of pipe or tube	mm	in.	129.3.4.1	. . .
r_p	Outside radius of branch reinforcement	mm	in.	. . .	App. D, Fig. D-1 App. D, Table D-1
r_x	External crotch radius of welded-in contour inserts	mm	in.	. . .	App. D

S	Seperation distance between the outer extent of a flaw and the nearest surface.	mm	in.	App. R, R-107*(a)(4)*	App. R Figure R-108

Symbol	Definition	Units		References	
		SI	U.S.	Paragraph	Table/Fig./App.
S	Basic material allowable stress	MPa	psi	122.1.2(A) 122.1.3(B) 122.4(B.3)	. . .
S	Basic material allowable stress	MPa	ksi	102.3.1(A)	App. A Tables and Notes
S_a	Bolt design stress at atmospheric temperature	kPa	psi	104.5.1(A)	. . .
S_b	Bolt design stress at design temperature	kPa	psi	104.5.1(A)	. . .
S_c	Basic material allowable stress at minimum (cold) temperature	MPa	psi	102.3.2(B)[eq. (1)]	. . .
S_f	Allowable stress for flange material or pipe	kPa	psi	104.5.1(A)	. . .
S_h	Basic material allowable stress at maximum (hot) temperature	MPa	psi	102.3.2(B)[eq. (1)] 104.8.1[eq. (15)] 104.8.2[eq. (16)] 104.8.3[eq. (17)] 119.10.1 [eq. (19)]	. . .
S_{lp}	Longitudinal pressure stress	kPa	psi	102.3.2(A) 104.8	. . .
S_A	Allowable stress range for expansion stress	MPa	psi	102.3.2(B)[eq. (1)] 104.8.3[eq. (17)]	. . .
S_E	Computed thermal expansion stress range	MPa	psi	104.8.3[eq. (17)] 119.6.4 119.10.1[eq. (19)]	. . .
S_L	Longitudinal stress due to pressure, weight, and other sustained loads	MPa	psi	102.3.2(D) 104.8.1[eq. (15)]	. . .
SE	Allowable stress (including weld joint efficiency factor)	MPa	psi	102.3.2(B) 104.1.2(A)[eqs. (7), (8), (9), (10)] 104.5.2(B) 104.5.3(A)[eq. (14)] 104.5.3(B)	. . .
SE	Allowable stress (including weld joint efficiency factor)	MPa	ksi	102.3.1(A)	App. A Tables and Notes
SF	Allowable stress (including casting quality factor)	MPa	psi	104.1.2(A)	. . .
SF	Allowable stress (including casting quality factor)	MPa	ksi	102.3.1(A)	App. A Tables and Notes
s	Miter spacing pipe centerline	mm	in.	. . .	App. D, Table D-1
T	Actual pipe wall thickness (by measurement) or the minimum wall thickness permissible under the purchase specification, used with or without subscripts, namely T_b = thickness of branch T_h = thickness of header, etc.	mm	in.	104.3.1(D.2) 104.3.1(G.4) 104.3.1(G.6) 104.8.4(C)	104.3.1(D) 104.3.1(G) App. D, Fig. D-1
T_c	Crotch thickness of welded-in contour inserts	mm	in.	. . .	App. D, Table D-1

Symbol	Definition	Units		References	
		SI	U.S.	Paragraph	Table/Fig./App.
T_o	Corroded finished thickness extruded outlet	mm	in.	104.3.1(G.4) 104.3.1(G.6)	104.3.1(G)
t	Pressure design thickness pipe, components (used with subscripts)	mm	in.	104.1.2(A)[eqs. (7), (8), (9), (10)] 104.3.1(D.2) 104.3.1(G.4) 104.3.3(C.3.1) 104.3.3(C.3.2) 104.4.1(B) 104.4.2 104.5.2(B)[eq. (13)] 104.5.3(A)[eq. (14)] 104.5.3(B) 104.8.1 104.8.4(C) 127.4.8(B) 132.4.2(E)	104.3.1(G) 104.5.3 127.4.8(D)
$t_{1,2}$	Nominal wall thickness of reducer	mm	in.	. . .	App. D, Table D-1
t_c	Throat thickness of cover fillet weld, branch connection	mm	in.	127.4.8(B) 132.4.2(E)	127.4.8(D) 127.4.8(E)
t_e	Effective branch wall thickness	mm	in.	104.8.4(C)	. . .
t_m	Minimum required thickness of component, including allowances (c) for mechanical joining, corrosion, etc. (used with subscripts), namely t_{mb} = minimum thickness of branch t_{mh} = minimum thickness of header	mm	in.	104.1.2(A)[eqs. (7), (8), (9), (10)] 104.3.1(D.2) 104.3.1(E) 104.3.1(G) 104.3.3(C.3.1) 104.3.3(C.3.2) 104.4.1(B) 104.5.2(B)[eq. (13)] 104.5.3(A)	102.4.5 104.1.2(A) 104.3.1(D) 104.3.1(G) 127.4.2
t_n	Nominal wall thickness of component (used with subscripts), namely t_{nb} = nominal wall thickness of branch t_{nh} = nominal wall thickness of header t_{nr} = nominal thickness of reinforcement	mm	in.	102.3.2(A.3) 104.3.3 104.8.1[eq. (15)] 104.8.2[eq. (16)] 104.8.4(C) 127.4.8(B) 129.3.4.1 132.4.2(E)	127.4.4(B) 127.4.4(C) 127.4.8(D) 127.4.8(E) App. D, Fig. D-1 App. D, Table D-1
t_r	Thickness of reinforcing pad or saddle	mm	in.	104.3.1(D.2) 104.3.1(E)	104.3.1(D) App. D, Table D-1
t_s	Wall thickness of segment or miter	mm	in.	104.3.3(C.3)	. . .
t_w	Weld thickness	mm	in.	104.3.1(C.2)	127.4.8(G)
U	Anchor distance (length of straight line joining anchors)	m	ft	119.7.1(A.3)	. . .
W	Weld strength reduction factor	. . .	. . .	102.4.7 ← 102.4.5(B) 104.1.4 ← 104.1.2	102.4.7
x_{min}	Size of fillet weld for slip-on and socket welding flanges or socket wall for socket welds	mm	in.	. . .	127.4.4(B)
Y	Resultant of movement to be absorbed by pipelines	. . .	. . .	119.7.1(A.3)	. . .

MANDATORY APPENDIX J
QUALITY CONTROL REQUIREMENTS FOR BOILER EXTERNAL PIPING (BEP)

FOREWORD

This Mandatory Appendix contains the quality control requirements for boiler external piping. The following is that portion of Nonmandatory Appendix A, A-301 and A-302, of the ASME Boiler and Pressure Vessel Code, Section I, which is applicable to BEP.

J-1 QUALITY CONTROL SYSTEM

J-1.1 General

J-1.1.1 Quality Control System. The Manufacturer or assembler shall have and maintain a quality control system which will establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), and inspection of boilers and boiler parts (by the Authorized Inspector), will be met. Provided that Code requirements are suitably identified, the system may include provisions for satisfying any requirements by the Manufacturer or user that exceed minimum Code requirements and may include provisions for quality control of non-Code work. In such systems, the Manufacturer may make changes in parts of the system that do not affect the Code requirements without securing acceptance by the Authorized Inspector. Before implementation, revisions to quality control systems of Manufacturers and assemblers of safety and safety relief valves shall have been found acceptable to an ASME designee if such revisions affect Code requirements.

The system that the Manufacturer or assembler uses to meet the requirements of this Section must be one suitable for his/her own circumstances. The necessary scope and detail of the system shall depend on the complexity of the work performed and on the size and complexity of the Manufacturer's (or assembler's) organization. A written description of the system the Manufacturer or assembler will use to produce a Code item shall be available for review. Depending upon the circumstances, the description may be brief or voluminous.

The written description may contain information of proprietary nature relating to the Manufacturer's (or assembler's) processes. Therefore, the Code does not require any distribution of this information, except for the Authorized Inspector or ASME designee.

It is intended that information learned about the system in connection with evaluation will be treated as confidential and that all loaned descriptions will be returned to the Manufacturer upon completion of the evaluation.

J-1.2 Outline of Features to Be Included in the Written Description of the Quality Control System

The following is a guide to some of the features that should be covered in the written description of the quality control system and that is equally applicable to both shop and field work.

J-1.2.1 Authority and Responsibility. The authority and responsibility of those in charge of the quality control system shall be clearly established. Persons performing quality control functions shall have sufficient and well-defined responsibility, the authority, and the organizational freedom to identify quality control problems and to initiate, recommend, and provide solutions.

J-1.2.2 Organization. An organization chart showing the relationship between management and engineering, purchasing, manufacturing, field assembling, inspection, and quality control is required to reflect the actual organization. The purpose of this chart is to identify and associate the various organizational groups with the particular function for which they are responsible. The Code does not intend to encroach on the Manufacturer's right to establish, and from time to time to alter, whatever form of organization the Manufacturer considers appropriate for its Code work.

J-1.2.3 Drawings, Design Calculations, and Specification Control. The Manufacturer's or assembler's quality control system shall provide procedures that will ensure that the latest applicable drawings, design calculations, specifications, and instructions, required by the Code, as well as authorized changes, are used for manufacture, assembly, examination, inspection, and testing.

J-1.2.4 Material Control. The Manufacturer or assembler shall include a system of receiving control that will ensure that the material received is properly identified and has documentation, including required material certifications or material test reports, to satisfy

Code requirements as ordered. The material control system shall insure that only the intended material is used in Code construction.

J-1.2.5 Examination and Inspection Program. The Manufacturer's quality control system shall describe the fabrication operations, including examinations, sufficiently to permit the Authorized Inspector to determine at what stages specific inspections are to be performed.

J-1.2.6 Correction of Nonconformities. There shall be a system agreed upon with the Authorized Inspector for correction of nonconformities. A nonconformity is any condition that does not comply with the applicable rules of this Section. Nonconformities must be corrected or eliminated in some way before the completed component can be considered to comply with this Section.

J-1.2.7 Welding. The quality control system shall include provisions for indicating that welding conforms to requirements of Section IX as supplemented by this Section.

J-1.2.8 Nondestructive Examination. The quality control system shall include provisions for identifying nondestructive examination procedures the Manufacturer will apply to conform with requirements of this Section.

J-1.2.9 Heat Treatment. The quality control system shall provide controls to ensure that heat treatments as required by the rules of this Section are applied. Means shall be indicated by which the Authorized Inspector can satisfy him/herself that these Code heat treatment requirements are met. This may be by review of furnace time – temperature records or by other methods as appropriate.

J-1.2.10 Calibration of Measurement and Test Equipment. The Manufacturer or assembler shall have a system for the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Section.

J-1.2.11 Records Retention. The Manufacturer or assembler shall have a system for the maintenance of radiographs and Manufacturers' Data Reports as required by this Section.

J-1.2.12 Sample Forms. The forms used in the quality control system and any detailed procedures for their use shall be available for review. The written description shall make necessary references to these forms.

J-1.2.13 Inspection of Boilers and Boiler Parts

J-1.2.13.1 Inspection of boilers and boiler parts shall be by the Authorized Inspector described in PG-91.

J-1.2.13.2 The written description of the quality control system shall include reference to the Authorized Inspector.

J-1.2.13.2.1 The Manufacturer (or assembler) shall make available to the Authorized Inspector at the Manufacturer's plant (or construction site) a current copy of the written description or the applicable quality control system.

J-1.2.13.2.2 The Manufacturer's quality control system shall provide for the Authorized Inspector at the Manufacturer's plant to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the Inspector to perform his/her duties in accordance with this Section. The Manufacturer may provide such access either to his/her own files of such documents or by providing copies to the Inspector.

J-1.2.14 Inspection of Pressure-Relieving Valves

J-1.2.14.1 Inspection of safety, safety relief, and power-actuated pressure relieving valves shall be by designated representative of the ASME, as described in PG-73.3.

J-1.2.14.2 The written description of the quality control system shall include reference to the ASME designee.

J-1.2.14.2.1 The valve Manufacturer (or assembler) shall make available to the ASME designee at the Manufacturer's plant a current copy of the written description of the applicable quality control system.

J-1.2.14.2.2 The valve Manufacturer's (or assembler's) quality control system shall provide for the ASME designee to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the designee to perform his/her duties in accordance with this Section. The Manufacturer may provide such access either to his/her own files of such documents or by providing copies to the designee.

grout: a heavily filled paste material used to fill crevices and transitions between piping components.

heat fusion joint: a joint made by heating the surfaces to be joined and pressing them together so they fuse and become essentially one piece.

hot-gas welded joint: a joint made by simultaneously heating a filler material and the surfaces to be joined with a stream of hot air or hot inert gas until the materials soften, after which the surfaces to be joined are pressed together and welded with the molten filler material.

hydraulic design basis (HDB)

for reinforced thermosetting resins (filament wound or centrifugally cast): one of a series of established stress values specified in ASTM Test Method D2992 for an RTR component, obtained by categorizing the long-term hydrostatic strength determined in accordance with Test Method D2992.

for thermoplastics: one of a series of established stress values specified in ASTM Test Method D2837 for a plastic compound, obtained by categorizing the long-term hydrostatic strength determined in accordance with Test Method D2837. This method subjects the material to tensile stress for an extended period of time, and extrapolates the creep results to estimate the tensile strength for a 50-yr life.

hydrostatic design stress (HDS): the estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be applied continuously with a high degree of certainty that failure of the pipe will not occur. Estimated by applying a design factor, typically 0.5 for thermoplastics in water service, to the HDB.

liner: a coating or layer of material, constructed as, applied to, or inserted within the inside surface of a piping component, intended to protect the structure from chemical attack, to inhibit erosion, or to prevent leakage under strain.

seal weld: the addition of material external to a joint, by welding or bonding, for the purpose of enhancing leak tightness.

solvent cement joint: a joint using a solvent cement to soften the surfaces to be joined, after which the joining surfaces are pressed together and become essentially one piece as the solvent evaporates.

stiffness factor: the measurement of a pipe's ability to resist deflection, as determined in accordance with ASTM D2412.

thixotropic agent: a material added to resin to impart high static shear strength (viscosity) and low dynamic shear strength.

ultraviolet absorber: a material that, when combined in a resin mixture, will selectively absorb ultraviolet radiation.

woven roving: a heavy glass fiber fabric reinforcing material made by the weaving of glass fiber roving.

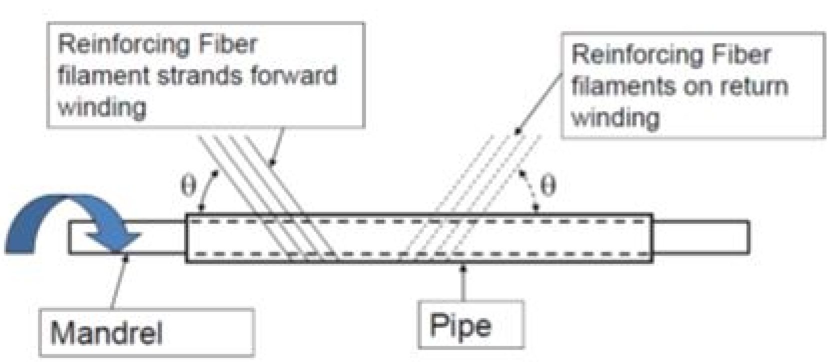
N-100.2.2 Abbreviations. Abbreviations used in this Appendix denote materials and terms as follows:

Abbreviation	Term
ABS[1]	Acrylonitrile-butadiene-styrene
AP	Polyacetal
CP	Chlorinated polyether
CPVC[1]	Chlorinated poly (vinyl chloride)
DS	Design stress
FEP[1]	Perfluoro (ethylene propylene)
HDB	Hydrostatic design basis
HDPE	High density polyethylene
HDS	Hydrostatic design stress
PA[1]	Polyamide (nylon)
PB	Polybutylene
PE[1]	Polyethylene
PFA	Poly (perfluoroalkoxy)
POP	Poly (phenylene oxide)
PP[1]	Polypropylene
PPS	Polyphenylene
PR	Pressure rated
PTFE[1]	Polytetrafluoroethylene
PVC[1]	Poly (vinyl chloride)
PVDC	Poly (vinylidene chloride)
PVDF	Poly (vinlyidene fluoride)
RTR	Reinforced thermosetting resin
SDR	Standard dimension ratio
SIDR	Standard inside diameter dimension ratio

NOTE:
(1) Abbreviation in accordance with ASTM D1600.

winding angle: the acute angle (θ in Fig N100.2.1) between the pipe longitudinal axis and the helical winding of the reinforcing filament being wound around a mandrel to produce a filament wound fiber-reinforced thermosetting resin pipe.

Fig N100.2.1



listed in Tables N-102.2.1(A)-1, N-102.2.1(A)-2, and N-102.2.1(A)-3.

(B) Pipe and other piping components that do not have allowable stresses or pressure–temperature ratings shall be qualified for pressure design as required in para. N-104.7.

N-102.2.3 Ratings: Normal Operating Condition. A nonmetallic piping system shall be considered safe for operation if the maximum anticipated coincident temperature and pressure that may act on any part or component of the system does not exceed the maximum pressure and temperature allowed by this Code for that particular part or component. The design pressure and temperature shall not exceed the pressure–temperature rating for the particular component and material as defined in the applicable specification or standard listed in Table N-126.1. For metallic piping with nonmetallic lining, the rules of para. 102.2.3 apply, provided that the suitability of the lining material for the maximum anticipated coincident temperature and pressure conditions has been established through prior successful extensive experience or tests.

N-102.2.4 Allowances for Pressure and Temperature Variations

(A) Nonmetallic Piping. Allowances for variations of pressure, temperature, or both above design conditions are not permitted. The most severe conditions of coincident pressure and temperature shall be used to determine the design conditions.

(B) Metallic Piping Lined With Nonmetals. Allowances for pressure and temperature variations provided in para. 102.2.4 are permitted only if the suitability of the lining material for the increased conditions is established through prior successful extensive experience or tests under comparable conditions.

N-102.2.5 Ratings at Transitions. Where two services that operate at different pressure–temperature conditions are connected, the valve segregating the two services shall be rated for the most severe service conditions. Other requirements of para. 102.2.5 must be considered where applicable.

N-102.3 Allowable Stresses and Other Limits

N-102.3.1 Allowable Stress Values

(A) General. Tables N-102.2.1(A)-1, N-102.2.1(A)-2, and N-102.2.1(A)-3 list recommended maximum allowable stresses in the form of hydrostatic design stresses (HDS), allowable design stresses (DS), and the hydrostatic design basis (HDB) that may be used in design calculations except where modified by other provisions of this Appendix. The use of hydrostatic design stresses for calculations other than pressure design has not been established. The basis for determining allowable stresses and pressures is outlined in (B) below. The allowable stresses are grouped by materials and listed for stated temperatures. Where sufficient data have been provided, straight-line interpolation between temperatures is permissible. The materials listed are available from one or more manufacturers, and some manufacturers may publish somewhat different HDS values for the materials than the values listed in Tables N-102.2.1(A)-1, N-102.2.1(A)-2, and N-102.2.1(A)-3. The manufacturer's published values for these materials are acceptable for use where they have been established in accordance with (B) below and verified in accordance with para. N-104.7.

(B) Basis for Allowable Stresses for Internal Pressure

(B.1) Thermoplastics. A method of determining hydrostatic design basis (HDB) and pressure rating (PR) is described in ASTM D2837, which also describes application of a design factor to the HDB to determine hydrostatic design stress (HDS) and pressure rating (PR). Hydrostatic design stresses are provided in Table N-102.2.1(A)-1, based on HDB values listed in PPI TR-4 and design factors for water from PPI TR-9. Design factors for other services are also given in PPI TR-9.

(B.2) Reinforced Thermosetting Resin (Laminated). For laminated piping components, the design stresses (DS) are listed in Table N-102.2.1(A)-2. These typically are based on one-tenth of the minimum tensile strengths specified in Table 1 of ASTM C582.

(B.3) Reinforced Thermosetting Resin (Filament Wound and Centrifugally Cast). For filament wound and centrifugally cast piping components, hydrostatic design basis (HDB) values are listed in Table N-102.2.1(A)-3. These values may be obtained by procedures in ASTM D2992. HDS may be obtained by multiplying the HDB by a service (design) factor[1] selected for the application, in accordance with procedures described in ASTM D2992, within the following limits:

(B.3.1) When using the cyclic HDB from Table N-102.2.1(A)-3, the service (design) factor shall not exceed 1.0.

(B.3.2) When using the static HDB from Table N-102.2.1(A)-3, the service (design) factor shall not exceed 0.5.

Add New Para. (see next page)

N-102.3.2 Limits of Calculated Stresses Due to Sustained Loads

(A) Internal Pressure Stresses. The limits for stress due to internal pressure are provided in para. N-104.1.2.

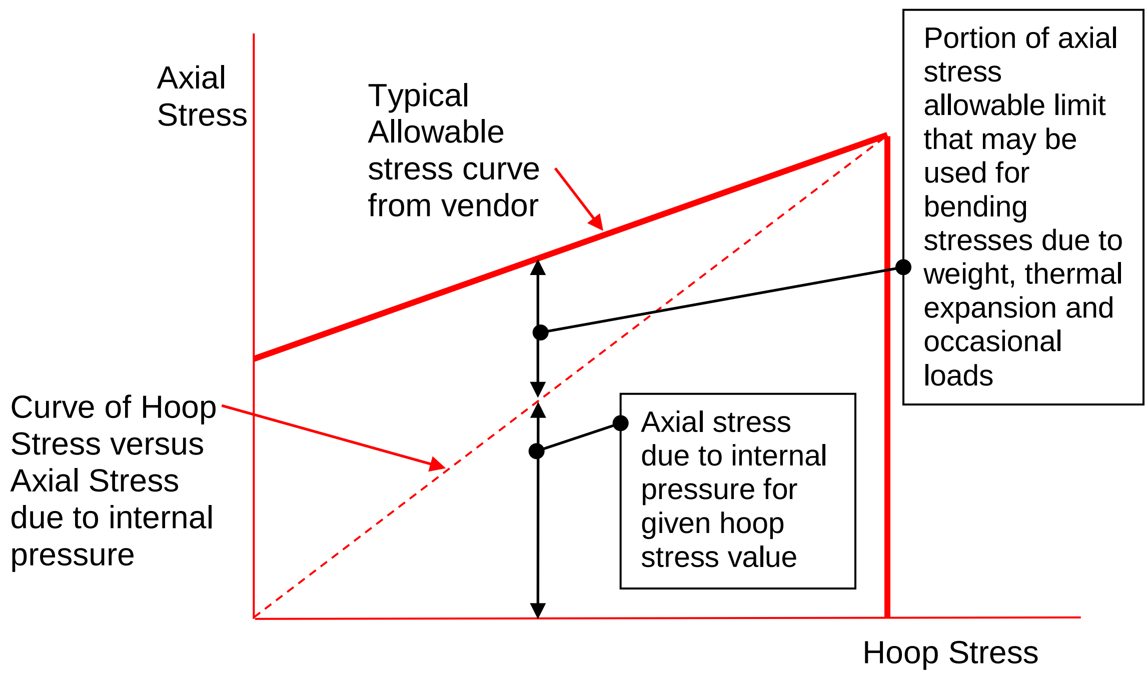
(B) External Pressure Stresses. Thermoplastic piping, reinforced thermosetting resin piping, and metallic piping lined with nonmetals, subject to external pressure, shall be considered safe when the wall thickness and/or means of stiffening meet the requirements of para. N-104.7.2.

[1] The service (design) factor, *F*, should be selected by the designer after evaluating fully the service conditions and the engineering properties of the specific material under consideration. Aside from the limits in paras. N-102.3.1(B.3.1) and (B.3.2), it is not the intent of this Code to specify service (design) factors.

(B.3.3) The evaluation of stresses in filament wound reinforced thermosetting resin pipe and fitting components must consider the different strengths in the hoop and axial directions of the material. For a 55 degree filament winding angle (which is typical for filament wound pipe), the axial strength is approximately ½ of the hoop strength of the material. For greater winding angles, the axial strength will be even lower. The figure N-102.1.3(B.3.3) shows a typical axial strength versus hoop strength diagram for a filament wound material. The data points for the axial strength at zero hoop stress and the axial strength at the maximum hoop stress will need to be provided by a vendor for his specific product, since no generic allowable stress diagrams currently exist. Note that for most filament wound fiberglass products, the portion of the allowable axial stress available for weight, thermal expansion and occasional loads will approach zero as the hoop stress approaches the maximum allowable limit for the material.

(B.3.4) The stress analysis of the filament wound pipe and fitting components must consider both the simultaneous axial and hoop stresses at each point in the piping system, and take into account any hoop stress, stress intensification factors (SIF's) as well as axial stress SIF's that may be applicable to a given component.

Figure N-2.3.1(B.3.3) - Typical Allowable Stress Curve for Filament Wound Reinforced Thermosetting Resin Pipe



(B.3.5) Note that for above ground pipe, due to the different axial and hoop strengths of filament wound reinforced thermosetting resin pipe and fitting components, the minimum wall thickness required for the pipe and fitting components may be governed by the axial strength requirements, rather than just hoop strength considerations.

joint and one pipe-to-fitting joint. The size of the pipe used for the test assembly shall be as follows:

(C.1.1) When the largest size to be joined (within the BPS) is NPS 4 or smaller, the test assembly shall be the same NPS as the largest size to be joined.

(C.1.2) When the largest size to be joined within the BPS is greater than NPS 4, the test assembly shall be made of piping components either NPS 4 or a minimum of 25% of the NPS of the largest piping component to be joined, whichever is larger.

(C.2) The test assembly shall be subjected to one of the following qualification test operations:

(C.2.1) When the test assembly has been cured, it shall be subjected to a hydrostatic pressure test of the maximum of either 150 psig or 1.5 times an equivalent allowable pressure, which shall be calculated using the least nominal wall thickness and outside diameter of the pipe in the test assembly. This pressure shall be determined using the equation in para. N-104.1.2(A) for the test material. The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions. Joints shall not leak or separate when tested.

(C.2.2) When a test assembly is joined by heat fusion, the fusion joints may be tested by cutting a minimum of three coupons containing the joint and bending the strips using a procedure that shall be defined in the BPS. As a minimum requirement, the test strips shall not break when bent a minimum of 90 deg, at ambient temperature, over an inside bend radius of 1.5 times the nominal diameter of the tested pipe.

(D) Performance Requalification

(D.1) Renewal of a bonding performance qualification is required when

(D.1.1) a bonder or bonding operator has not used the specific bonding process for a period of time greater than 6 months, or a specific maximum period of time otherwise permitted in the BPS for the work

(D.1.2) there is a specific reason to question a bonder or bonding operator's ability to make bonds that meet the BPS

(D.2) Renewal of a bonding performance qualification for a specific bonding process may be made in only a single test assembly.

N-127.6 Qualification Records

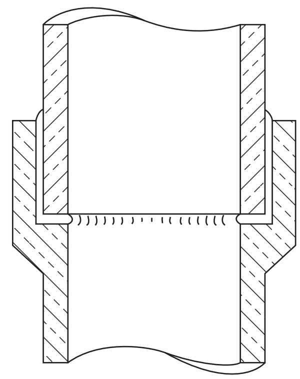
An erector using bonders or bonding operators shall maintain a record of the procedures used and of operators employed by him/her who are qualified in these procedures.

N-127.7 Thermoplastic Pipe Joints

N-127.7.1 Solvent-Cemented Joints

(A) Preparation. PVC and CPVC surfaces to be cemented shall be cleaned by wiping with a clean cloth moistened with acetone or methylethyl ketone. Cleaning for ABS shall conform to ASTM D2235. Cuts shall be free of burrs and circumferential cuts shall be as square as those obtained by the use of a saw with a miter box or a square-end sawing vise. A slight interference fit between the pipe and a fitting socket is preferred, and the diametral clearance between a pipe and the entrance of a mating socket shall not exceed 0.04 in. This fit shall be checked before solvent cementing.

Fig. N-127.7.1(B) Solvent-Cemented Joint



(B) Procedure. Joints shall be made in accordance with a qualified BPS. ASTM D2855 provides a suitable basis for such a procedure. Solvent cements for PVC, CPVC, and ABS shall conform to ASTM D2564, D2846, and D2235, respectively. Cement shall be sufficient to produce a small continuous fillet of cement at the outer limits of the joints. See Fig. N-127.7.1(B).

(C) Branch Connections. For branch connections not using a tee, a manufactured full reinforcement saddle with an integral branch socket shall be solvent cemented to the run pipe over its entire contract surface.

(D) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. N-127.7.3:

(D.1) protrusion of dried cement exceeding 50% of pipe wall thickness into the bore of the pipe

(D.2) unfilled or unbonded areas in a joint, as indicated by the lack of interruption of the continuous fillet noted in (B) above

N-127.7.2 Heat and Fusion Joints

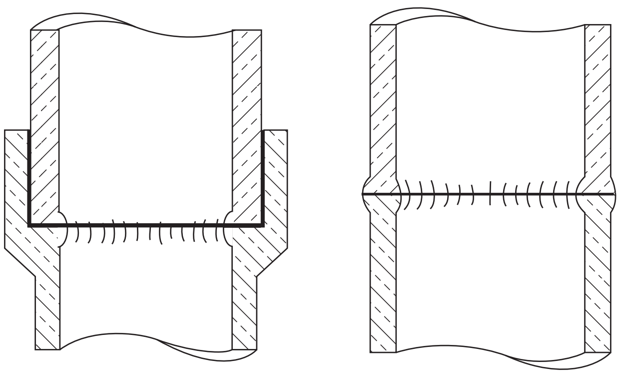
(A) Preparation. Surfaces to be heat fused together shall be cleaned of any foreign material. Cuts shall be free of burrs, and circumferential cuts shall be as square as those obtained by the use of a saw with a miter box or a square-end sawing vise.

(B) Procedure. Joints shall be made in accordance with a qualified ~~BPS. The general procedures in ASTM D2657, Technique I — Socket Fusion, Technique II — Butt Fusion, and Technique III — Saddle Fusion, provide a suitable basis for such a procedure~~. Both surfaces to be joined shall be uniformly heated to produce a continuous

FPS (Fusion Procedure Specification) that meets the applicable requirements of ASME BPVC Section IX Part QF. For socket fusion and saddle fusion joints not addressed in Part QF, ASTM D2657 provides a basis for FPS development.

a qualified FPS that meets the requirements of ASME BPVC Section IX Part QF. See Fig. N-127.7.3(B).

Fig. N-127.7.2(B) Heat Fusion Joints



(a) Socket Joint

(b) Butt Joint

homogeneous bond between them. This will produce a small continuous fillet of fused material at the outer limits of the joints. See Fig. N-127.7.2(B).

(C) Branch Connections. Branch connections shall be made only with the use of molded fittings in sizes that are commercially available.

(D) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. N-127.7.3:

(D.1) protrusion of fused material exceeding 25% of the pipe wall thickness into the bore of the pipe

(D.2) unfilled or unbonded areas in a joint as indicated by the lack or interruption of the continuous fillet noted in (B) above

N-127.7.3 Electrofusion Joints

(A) Preparation. Surfaces to be heat fused together shall be cleaned of all foreign material.

(B) Procedure. Joints shall be made in accordance with ~~the qualified BPS. The general procedures in ASTM F1290, Technique 1 — Coupling Procedure and Technique 2 — Saddle Procedure, provide a suitable basis for the development of such a procedure. See Fig. N-127.7.3(B).~~

N-127.7.4 Repair of Defects. Defective material, joints, and other workmanship in piping that fail to meet the requirements of Chapters N-III and N-V, and of the engineering design, shall be repaired or replaced. Limitations on imperfections, and the method and extent of the required examination of repairs and replacements, shall be the same as for the original work.

N-127.8 FRP Pipe Joints

N-127.8.1 Thermosetting Resin Joints

(A) Preparation. Cutting of pipe and preparation of bonding surfaces shall be done as recommended by the manufacturer, without chipping or cracking of the cut ends; particularly, the inner surface of centrifugally cast pipe. Pipe may be preheated, if necessary, to comply with the above requirements. Cuts shall be free of burrs, and circumferential cuts shall be as square as required by the purchaser's specifications or the recommendations of the manufacturer, whichever requires the closer squareness. For branch connections, holes in the run pipe may be made with a hole saw. Mold-release agent, and any other material that may interfere with adhesion, shall be removed from surfaces to be bonded.

(B) Joining Procedures

(B.1) Socket and Spigot Joints. Joints shall be made in accordance with a qualified BPS based on the manufacturer's recommended procedure. Application of adhesive to the surfaces to be joined and assembly of those surfaces shall produce a continuous bond between them. Cut ends of the pipe and edges of the laminate fabric shall be sealed to prevent fluid penetration of the pipe wall or the laminate material. See Fig. N-127.8.1(B).

(B.2) Butt-and-Wrap Joints. Joints shall be made in accordance with a qualified BPS. The general procedures in ASTM C582, Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminated for Corrosion Resistant Equipment, provide a suitable basis for the development of such a procedure. Application of plies of reinforcement, saturated with catalyzed resin, to the surfaces to be joined shall produce a continuous structure with the surfaces. Cut ends shall be sealed as required in (B.1) above. See Fig. N-127.8.1(B).

(C) Branch Connections. Branch connections shall be made using a manufactured tee fitting or a full reinforcement saddle having suitable provisions for joining as in (B) above. The cut edges of any hole in the run pipe shall be sealed with adhesive at the time the saddle is bonded to the run pipe.

(D) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. N-127.7.3:

(D.1) protrusion of adhesive exceeding 25% of pipe wall thickness into the bore at the bottom of a socket, or inside a branch connection

(D.2) unfilled or unbonded areas in the joint

N-127.8.2 Repair of Defects. Defective material, joints, and other workmanship in piping that fail to meet the requirements of Chapters N-III and N-V, and of the engineering design, shall be repaired or replaced. Limitations on imperfections, and the method and extent of the required examination of repairs and replacements, shall be the same as for the original work.

N-127.9 Welding of Metallic Piping Lined With Nonmetals

Welding is not permitted on lined components in the field. Welding performed by the manufacturer to produce pipe, fittings, and flanges to be used in an elastomeric lined piping system shall conform to the

MANDATORY APPENDIX P
METALLIC BELLOWS EXPANSION JOINTS

Design requirements of Appendix P are dependent on and compatible with Standards of the Expansion Joint Manufacturers Association, Inc. (EJMA Standards)

P-1 GENERAL

The intent of this Appendix is to set forth design, manufacturing, and installation requirements and considerations for bellows type expansion joints, supplemented by the EJMA Standards. It is intended that applicable provisions and requirements of Chapters I through VI of this Code shall be met, except as modified herein. This Appendix does not specify design details. The detailed design of all elements of the expansion joint is the responsibility of the manufacturer.

P-2 PIPING DESIGNER RESPONSIBILITIES

The piping designer shall specify the design conditions and requirements necessary for the detailed design and manufacture of the expansion joint in accordance with para. P-2.1 and the piping layout, anchors, restraints, guides, and supports required by para. P-2.2.

P-2.1 Expansion Joint Design Conditions

The piping designer shall specify all necessary design conditions including the following.

P-2.1.1 Static Design Conditions. The design conditions shall include any possible variations of pressure or temperature, or both, above operating levels. Use of a design metal temperature other than the fluid temperature for any component of the expansion joint shall be verified by computation, using accepted heat transfer procedures, or by test or measurement on similarly designed equipment in service under equivalent operating conditions.

P-2.1.2 Cyclic Design Conditions. These conditions shall include coincident pressure, temperature, imposed end displacements and thermal expansion of the expansion joint itself, for cycles during operation. Cycles due to transient conditions (startup, shutdown, and abnormal operation) shall be stated separately. (See EJMA Standards, 4.12.1.5 on fatigue life expectancy, for guidance in defining cycles.)

P-2.1.3 Other Loads. Other loads, including dynamic effects (such as wind, thermal shock, vibration, seismic forces, and hydraulic surge); and static loads, such as weight (insulation, snow, ice, etc.), shall be stated.

P-2.1.4 Fluid Properties. Properties of the flowing medium pertinent to design requirements, flow velocity and direction, for internal liners, etc., shall be specified.

P-2.1.5 Other Design Conditions. Other conditions that may affect the design of the expansion joint, such as use of shrouds, external or internal insulation, limit stops, other constraints, and connections in the body (e.g., drains or bleeds) shall be stated.

P-2.2 Piping Design Requirements

P-2.2.1 General. Piping layout, anchorage, restraints, guiding, and support shall be designed to avoid imposing motions and forces on the expansion joint other than those for which it is intended. For example, a bellows expansion joint is not normally designed to absorb torsion. Pipe guides, restraints, and anchorage shall conform to the EJMA Standards. Anchors and guides shall be provided to withstand expansion joint thrust forces when not self-restrained by tie rods, hinge bars, pins, etc. (See para. P-3.1.) Column buckling of the piping (e.g., due to internal fluid pressure) shall also be considered.

P-2.2.2 Design of Anchors

(a) Main Anchors. Main anchors shall be designed to withstand the forces and moments listed in P-2.2.2(b), and pressure thrust, defined as the product of the effective thrust area of the bellows and the maximum pressure to which the joint will be subjected in operation. Consideration shall be given to the increase of pressure thrust loads on anchors due to unrestrained expansion joints during leak testing if supplemental restraints are not used during the test (see para. 137.2.3). For convoluted, omega, or disk type joints, the effective thrust area recommended by the manufacturer shall be used. If this information is unavailable, the area shall be based on the mean diameter of the bellows.

(b) Intermediate Anchors. Anchors shall be capable of withstanding the following forces and moments:

(1) those required to compress, extend, offset, or rotate the joint by an amount equal to the calculated linear or angular displacement

(2) static friction of the pipe in moving on its supports between extreme extended and contracted positions (with calculated movement based on the length

of pipe between anchor and expansion joint)

(3) operating and transient dynamic forces caused by the flowing medium

(4) other piping forces and moments

P-3 EXPANSION JOINT MANUFACTURER RESPONSIBILITIES

The expansion joint manufacturer shall provide the detailed design and fabrication of all elements of the expansion joint in accordance with the requirements of the Code and the engineering design. This includes

(a) all piping within the end connections of the assembly supplied by the manufacturer, including pipe, flanges, fittings, connections, bellows, and supports or restraints of piping

(b) specifying the need for supports or restraints external to the assembly as required, and of the data for their design

(c) determining design conditions for all components supplied with the expansion joint that are not in contact with the flowing medium

P-3.1 Expansion Joint Design

The design of bellows-type expansion joints shall be based on recognized and accepted analysis methods and design conditions stated in para. P-2.1. These joints shall be designed so that permanent deformation of the expansion joint and pressure-restraint hardware will not occur during leak testing. Convoluted-type bellows shall be designed in accordance with the EJMA Standards, except as otherwise required or permitted herein. Design of other types of bellows shall be qualified as required by para. 104.7.2.

P-3.1.1 Factors of Safety. The factor of safety on squirm pressure shall be not less than 2.25. (See EJMA Standards, 4.12.1.6 on bellows stability and squirm.) The factor of safety on ultimate rupture pressure shall be not less than 3.0.

P-3.1.2 Design Stress Limits. For convoluted type bellows, stresses shall be calculated either by the formulas shown in the EJMA Standards or by other methods acceptable to the owner.

(a) Stresses shall be calculated in restraints (tie rods, hinge bars, pins, etc.) in self-restrained expansion joints and in the attachments of the restraining devices to the pipe or flanges. Direct tension, compression, bearing, and shear stresses shall not exceed the allowable stress limits stated in para. 102.3.1. The summation of general bending stress plus tension or compression stress shall not exceed the stress values listed in Appendix A, times the shape factor of the cross section. The shape factor is the ratio of the plastic moment to the yield moment (e.g., 1.5 for a rectangular section). For attachment of restraints to piping, see para. 121.8. Local stresses may be evaluated using the criteria of ASME Section VIII, Division 2, Part 5. Compression members shall be evaluated for buckling in accordance with the AISC Manual of Steel Construction, Allowable Stress Design. For self-restrained expansion joints, the restraints shall be designed to withstand the full design pressure thrust. Additional considerations may be required where time-dependent stresses prevail.

(b) Pressure design of pipe sections, fittings, and flanges shall meet the requirements of paras. 103 and 104.

(c) When the operating metal temperature of the bellows element is in the creep range,[1] the design shall be given special consideration and, in addition to meeting the requirements of this Appendix, shall be qualified as required by para. 104.7.2.

P-3.1.3 Fatigue Analysis

(a) A fatigue analysis[1] that takes into account all design cyclic conditions shall be performed and the calculated design cycle life shall be reported. The method of analysis for convoluted U-shaped bellows shall be in accordance with EJMA Standards.

(b) Material design fatigue curves for bellows with seams welded using an autogenous method are provided in the EJMA Standards. The curves are for use only in conjunction with the EJMA stress equations.

(c) Fatigue testing in accordance with Appendix F of the EJMA standards is required to develop fatigue curves for bellows of materials other than those provided for use in conjunction with the EJMA stress equations.

(d) When applying the fatigue curves from the EJMA Standards, a fatigue correction factor, f_c=0.75, shall be used.

(e) An alternate fatigue correction factor, f_c, may be used with the permission of the owner.

P-3.1.4 Limitations

(a) Expansion joint bellows shall not be constructed from lap welded pipe or lap welded tubing.

(b) All pressure containing or pressure thrust restraining materials shall conform to the requirements of Chapter III and Appendix A.

P-3.2 Expansion Joint Manufacture

Expansion joints shall be produced in accordance with the manufacturer’s specification, which shall include at least the following requirements.

P-3.2.1 Fabrication

(a) All welds shall be made by qualified welders or welding operators using welding procedures qualified as required by para. 127.5.

(b) The longitudinal seam weld in the bellows element shall be a full penetration butt weld. Prior to forming, the thickness of the weld shall be not less than 1.00 nor more than 1.10 times the thickness of the bellows material.

(c) A full fillet weld may be used as a primary weld to attach a bellows element to an adjoining piping component.

(d) When bellows are attached directly to an adjoining piping component by welding and the piping component is P-Nos. 4, 5A, or 5B base metal, the attachment weld shall be heat treated in accordance with para. 132, except that the exemptions from heat treatment given in para. 132.3 shall not be permitted. The holding time shall be based on the thickness of the piping component at the bellows attachment weld location. Examination of the attachment welds shall be performed after heat treatment. This heat treatment may affect bellows pressure capacity, mechanical properties, and corrosion resistance. If the required heat treatment is determined to be detrimental to the bellows' performance, the bellows shall not be attached directly to the piping component. In that case, the piping component side of the weld joint shall be buttered in accordance with ASME Section IX, para. QW-283 with appropriate filler metal, heat treated in accordance with Table 132, and then welded to the bellows.

P-3.2.2 Examination. The following are minimum quality control requirements:

(a) Required examinations shall be in accordance with para. 136.

(b) The bellows tube longitudinal seam weld shall be 100% visually examined (VT) on both the inside and outside surfaces prior to forming. Also, the longitudinal seam weld shall be 100% examined prior to forming either by radiography (RT) or, for material thickness ≤ $^3/_{32}$ in.(2.4 mm) welded in a single pass, by liquid penetrant (PT) of both inside and outside surfaces. For the purposes of this Appendix, either RT or PT is acceptable for design with a weld joint efficiency factor E of 1.00 when used within the stated thickness limits.

(c) After forming, a liquid penetrant examination shall be conducted on all accessible surfaces of the longitudinal seam weld, inside and outside. Welds attaching the bellows to the piping, etc., shall be 100% liquid penetrant examined.

(d) Acceptance criteria for RT shall be in accordance with para. 136.4.5. Acceptance criteria for PT shall be in accordance with para. 136.4.4. Acceptance criteria for VT shall be that cracks, undercutting, and incomplete penetration are not permitted.

P-3.2.3 Leak Test

(a) Each expansion joint shall receive a hydrostatic or pneumatic shop pressure test by the manufacturer in accordance with para. 137, except that the test pressure shall be the lesser of that calculated by eq. (P1) or eq. (P2), but not less than 1.5 times the design pressure. R_r in eq. (P2) shall be based on the bellows material. When the bellows design temperature is equal to or greater than T_{cr},[2] R_r in eq. (P2) shall be replaced by S_{yT}/S_{yt}, where S_{yT} is the yield strength at the test temperature and S_{yt} is the yield strength at the bellows design temperature. The test pressure shall be maintained for not less than 10 min.

$$P_T = 1.5\ P_S\ E_t/E \qquad \text{(P1)}$$

where

E = Young's modulus of elasticity at design temperature

E_t = Young's modulus of elasticity at test temperature

P_S = limiting design pressure based on column instability (for convoluted U-shaped bellows, see 4.13.1 and 4.13.2 of the EJMA Standards)

P_T = minimum test gage pressure

$$P_T = 1.5\ P\ R_r \qquad \text{(P2)}$$

where

P = internal design gage pressure

R_r = S_T/S, but shall not exceed 6.5

S_T = allowable stress at test temperature

S = allowable stress at design temperature

(b) Expansion joints designed to resist the pressure thrust shall not be provided with any additional axial restraint during the leak test. Moment restraint simulating piping rigidity may be applied if necessary.

(c) In addition to examination for leaks and general structural integrity during the pressure test, the expansion joint shall be examined before, during, and after the test to confirm that no unacceptable squirm has occurred. Squirm shall be considered to have occurred if under the internal test pressure an initially symmetrical bellows deforms, resulting in lack of parallelism or uneven spacing of convolutions. Such deformation shall be considered unacceptable when the maximum ratio of bellows pitch under pressure to the

pitch before applying pressure exceeds 1.15 for unreinforced bellows or 1.20 for reinforced bellows. Examination for leakage and deformation shall be performed at a pressure not less than two-thirds of the test pressure, after full test pressure has been applied.

(d) Examination for squirm shall be performed at full test pressure. For safety purposes, this may be accomplished by remote viewing (e.g., by optical magnification or video recording) of the changes in convolution spacing with respect to a temporarily mounted dimensional reference. Examination for leakage shall be performed at a pressure not less than two-thirds of test pressure, after application of full test pressure. For a pneumatic test, the precautions of para. 137.5 shall be observed.

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[1] Consideration shall be given to the detrimental effects of creep-fatigue interaction when the operating metal temperature of the bellows element will be in the creep range. Creep-fatigue interaction may become significant at temperatures above 800°F (425°C) for austenitic stainless steels.

[2] T_{cr} = temperature 50°F (25°C) below the temperature identifying the start of time-dependent properties listed under "NOTES – TIME-DEPENDENT PROPERTIES" (Txx) in the Notes to Table 1A of ASME Section II, Part D for the base materials joined by welding.

Mandatory Appendix R

Use of Alternative Ultrasonic Acceptance criteria

R-100 General

This Appendix provides an alternative ultrasonic fracture mechanics based acceptance criteria that may be used for Code piping welds in lieu of those described in para. 136.4.6 *(B).*

R-101 Scope

a) The examination shall be conducted using automated or semi-automated techniques utilizing computer based data acquisition.
b) The examination shall be performed in accordance with a written procedure approved by a UT (Ultrasonic Testing) Level III and conforming to the requirements of ASME Section V, Article 4 Mandatory Appendix VIII and:
   1) For Phased Array – ASME Section V, Article 4, Mandatory Appendix V.
   2) For Time of Flight Diffraction (TOFD) - ASME Section V, Article 4, Mandatory Appendix III.
c) Procedure qualification shall meet the requirements of ASME Section V, Article 4, Mandatory Appendix IX.

R-102 Equipment

A mechanical guided scanner capable of maintaining a fixed and consistent search unit position relative to the weld centerline shall be used.

R-103 Personnel

a) Personnel performing nondestructive examination to the requirements of this Appendix shall be qualified and certified in the Ultrasonic method in accordance with a procedure or program as described in BPV Code, Section V, Article 1, T-120 (e),or (f), and (g).
b) Set-up and scanning of welds shall be performed by personnel certified as UT Level II or III (or by Level I personnel under the direct supervision of Level II or Level III personnel).
c) Interpretation and evaluation of data shall be performed by NDE Level II or III personnel.
d) Personnel demonstration requirements shall be as stated in ASME Section V, Article 4 Mandatory Appendix VIII.

R-104 Examination

a) The initial straight beam scan for reflectors that could interfere with the angle beam examination shall be performed (a) manually, (b) as part of a previous manufacturing process, or (c) during the weld examination, provided detection of these reflectors is included in the demonstration as required in R-101(c).
b) The examination area shall include the volume of the weld, plus the lesser of 1.0 in.(25mm) or *t* of adjacent base metal. Alternatively, the examination volume may be reduced to include the actual heat affected zone (HAZ) plus 0.25 in. (6mm) of base material beyond the heat affected zone on each side of the weld, provided the extent of the weld HAZ is measured and documented.

R-105 Data Recording

Data shall be recorded in the unprocessed form as specified in Section V, Article 4, V-471.6. The data record shall include the complete examination area as specified in R-104 (b).

R-106 Data Analysis

a) Reflectors exceeding the limits below shall be investigated to determine whether the indication originates from a discontinuity or is a geometric indication in accordance with (b) below.
   1) For amplitude based techniques,

the location, amplitude, and extent of all reflectors that produce a response greater than 20% of the reference level shall be evaluated.

2) For non-amplitude based techniques, the location and extent of all images that have an indicated length greater than 0.16 in (4.0mm) shall be investigated.

b) Ultrasonic indications of geometric and/or metallurgical origin shall be classified as specified in ASME Section V, Article 4 Paragraph T-481.

1) Alternatively, other techniques or NDE methods may be used to classify an indication as geometric (e.g., alternative beam angles, radiography). The method employed is for information only to classify the indication as geometric, and ASME B31.1 requirements for examination techniques are only required to the extent they are applicable.

R-107 Discontinuity Evaluation

a) The dimension of the discontinuity(s) shall be determined by the rectangle that fully contains the area of the discontinuity(s). (Refer to Figure R-108)

1) The length, ℓ, of the discontinuity shall be drawn parallel to the inside pressure retaining surface of the component.

2) The height, *h*, of the discontinuity shall be drawn normal to the inside pressure retaining surface of the component.

3) The discontinuity shall be characterized as a surface or subsurface discontinuity, as shown in Figure R-108.

4) A subsurface indication shall be considered as a surface discontinuity if the separation (*S* in Figure R-108) of the indication from the nearest surface of the component is equal to or less than half the through wall dimension (*h* in Figure R-108, sketch [b]) of the subsurface indication.

b) Multiple Discontinuities

1) Discontinuous indications that are oriented primarily in parallel planes shall be considered to lie in a single plane if the distance between the adjacent planes is equal to or less than 0.50 in.(13mm) or 0.5*t*, whichever is less.

2) If the space between two indications aligned along the axis of weld is less than the height of the indication of greater height, the two discontinuities shall be considered a single discontinuity.

3) If the space between two indication aligned in the through-thickness dimension is less than the height of the indication of greater height, the two indications shall be considered a single discontinuity.

R-108 Discontinuity Acceptance Criteria

Discontinuities shall be evaluated using the applicable criteria of Tables R-108.1 through R-108.3. Regardless of discontinuity height or aspect ratio, discontinuity length shall not exceed 4*t*

TABLE R-108.1

Discontinuity Acceptance Criteria for Weld Thickness
<25mm (1.0 in.)

	h/t	**ℓ**
Surface discontinuity	≤ 0.100	≤ 6.4 mm (0.25 in.)
Subsurface discontinuity	≤ 0.286	≤ 6.4 mm (0.25 in.)

GENERAL NOTES:

(a) *t* = thickness of the weld excluding any allowable reinforcement. For a butt joint joining two members having different thickness at the joint, *t* is the thinner of the two thicknesses joined. If a full penetration weld includes a fillet weld, the effective throat dimension of the fillet weld shall be included in *t*.

(b) A discontinuity is considered rejectable if its dimensions exceed the *h/t* value or the ℓ value in the Table above.

TABLE R-108.2

Surface Discontinuity Acceptance Criteria for Weld Thickness ≥ 25mm (1.0in.)

Aspect Ratio, h/ℓ	**Weld Thickness**		
	≥ 25mm to 64mm (1.0 in. to 2.5 in.)	*> 64mm to < 100mm (2.5 in. to 3.9 in.)*	*100mm to 300mm (3.9 in. to 11.8 in.)*
	h/t		***h/t***
0.00	≤ 0.031	***(See Note C)***	≤ 0.019
0.05	≤ 0.033		≤ 0.020
0.10	≤ 0.036		≤ 0.022
0.15	≤ 0.041		≤ 0.025
0.20	≤ 0.047		≤ 0.028
0.25	≤ 0.055		≤ 0.033
0.30	≤ 0.064		≤ 0.038
0.35	≤ 0.074		≤ 0.044
0.40	≤ 0.083		≤ 0.050
0.45	≤ 0.085		≤ 0.051
0.50	≤ 0.087		≤ 0.052

General Notes:

(a) *t* = thickness of the weld excluding any allowable reinforcement. For a butt joint joining two members having different thickness at the joint, *t* is the thinner of the two thicknesses joined. If a full penetration weld includes a fillet weld, the effective throat dimension of the fillet weld shall be included in *t*.

(b) Aspect Ratio (*h/ℓ*) used may be determined by rounding the calculated *h/ℓ* down to the nearest 0.05 increment value within the column, or by linear interpolation.

(c) Regardless of discontinuity height or aspect ratio, discontinuity length shall not exceed 4*t*.

(d) For intermediate thickness *t* (weld thicknesses between 64mm and 100mm [2.5 in. and 3.9 in.]) linear interpolation is required to obtain *h/t* values.

TABLE R-108.3

Subsurface Discontinuity Acceptance Criteria for Weld Thickness ≥25mm (1.0in.)

Aspect Ratio, h/ℓ	**Weld Thickness**		
	≥25mm to 64mm (1.0 in. to 2.5 in.)	*> 64mm to < 100mm (2.5 in. to 3.9 in.)*	*100mm to 300mm (3.9 in. to 11.8 in.)*
	h/t		***h/t***
0.00	≤0.068		≤0.040
0.10	≤0.076		≤0.044
0.20	≤0.086		≤0.050
0.30	≤0.098		≤0.058
0.40	≤0.114		≤0.066
0.50	≤0.132	***(See Note C)***	≤0.076
0.60	≤0.156		≤0.088
0.70	≤0.180		≤0.102
0.80	≤0.210		≤0.116
0.90	≤0.246		≤0.134
1.00	≤0.286		≤0.152

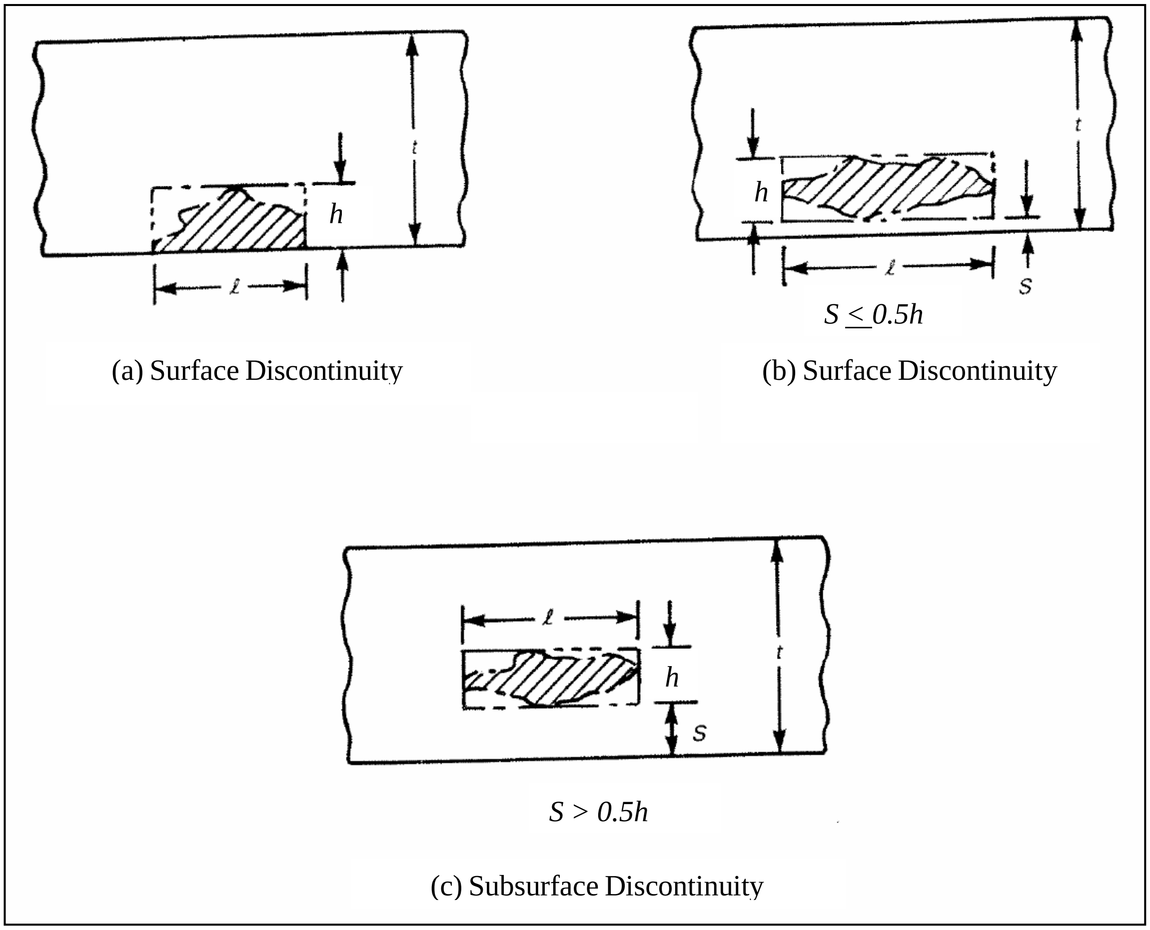
General Notes:

(a) *t* = thickness of the weld excluding any allowable reinforcement. For a butt joint joining two members having different thickness at the joint, *t* is the thinner of the two thicknesses joined. If a full penetration weld includes a fillet weld, the effective throat dimension of the fillet weld shall be included in *t*.

b) Aspect Ratio (*h/ℓ*) used may be determined by rounding the calculated *h/ℓ* down to the nearest 0.05 increment value within the column, or by linear interpolation.

c) Regardless of discontinuity height or aspect ratio, discontinuity length shall not exceed 4*t*.

d) For intermediate thickness *t* (weld thicknesses between 64mm and 100mm [2.5 in. and 3.9 in.]) linear interpolation is required to obtain *h/t* values.



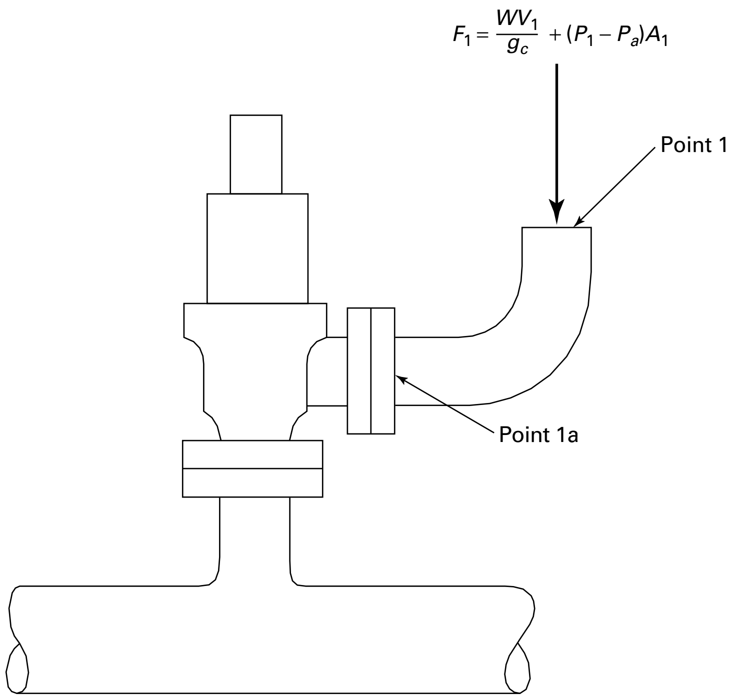
(a) Surface Discontinuity

(b) Surface Discontinuity

(c) Subsurface Discontinuity

Figure R-108:
Surface and Subsurface Indications

Fig. II-2-1 Discharge Elbow (Open Discharge Installation)



(A.2) Determine the velocity, V_1, that exists at the discharge elbow outlet (Fig. II-2-1).

$$V_1 = \sqrt{\frac{2g_c J(h_o - a)}{(2b - 1)}}$$

where

A_1 = discharge elbow area, in.^{2}
g_c = gravitational constant
= 32.2 lbm-ft/lbf-sec^2
h_o = stagnation enthalpy at the safety valve inlet, Btu/lbm
J = 778.16 ft-lbf/Btu
P_1 = pressure, psia (lbf/in.^{2}, absolute)
V_1 = velocity, ft/sec
W = actual mass flow rate, lbm/sec

Common values of a and b are listed in Table II-2.2.1.

(A.3) Determine the safety valve outlet pressure, P_{1a}, at the inlet to the discharge elbow (Fig. II-2-1).

~~*(A.3.1)* Determine the length to diameter ratio (dimensionless) for the pipe sections in the discharge elbow (L/D).~~

~~$$L/D = \frac{L_{max}}{D}$$~~ $\Sigma\left(\frac{L}{D}\right)$

(A.3.1) Determine the total equivalent length to diameter ratio (L/D) by adding the ratio of each component (pipe, elbow, fittings, etc.).

(A.3.2) Determine a Darcy-Weisbach friction factor, f, to be used. (For steam, a value of 0.013 can be used as a good estimate since f will vary slightly in turbulent pipe flow.)

Table II-2.2.1 Values of *a* and *b*

Steam Condition	*a*, Btu/lbm	*b*
Wet steam, < 90% quality	291	11
Saturated steam, ≥ 90% quality, 15 psia ≤ P_1 ≤ 1,000 psia	823	4.33
Superheated steam, ≥ 90% quality, 1,000 psia < P_1 ≤ 2,000 psia(1)	831	4.33

NOTE:
(1) This method may be used as an approximation for pressures over 2,000 psi, but an alternate method should be used for verification.

(A.3.3) Determine a specific heat ratio (for superheated steam, k = 1.3 can be used as an estimate — for saturated steam, k = 1.1).

(A.3.4) Calculate $f(L_{max}/D)$.

$\Sigma\left(\frac{L}{D}\right)$

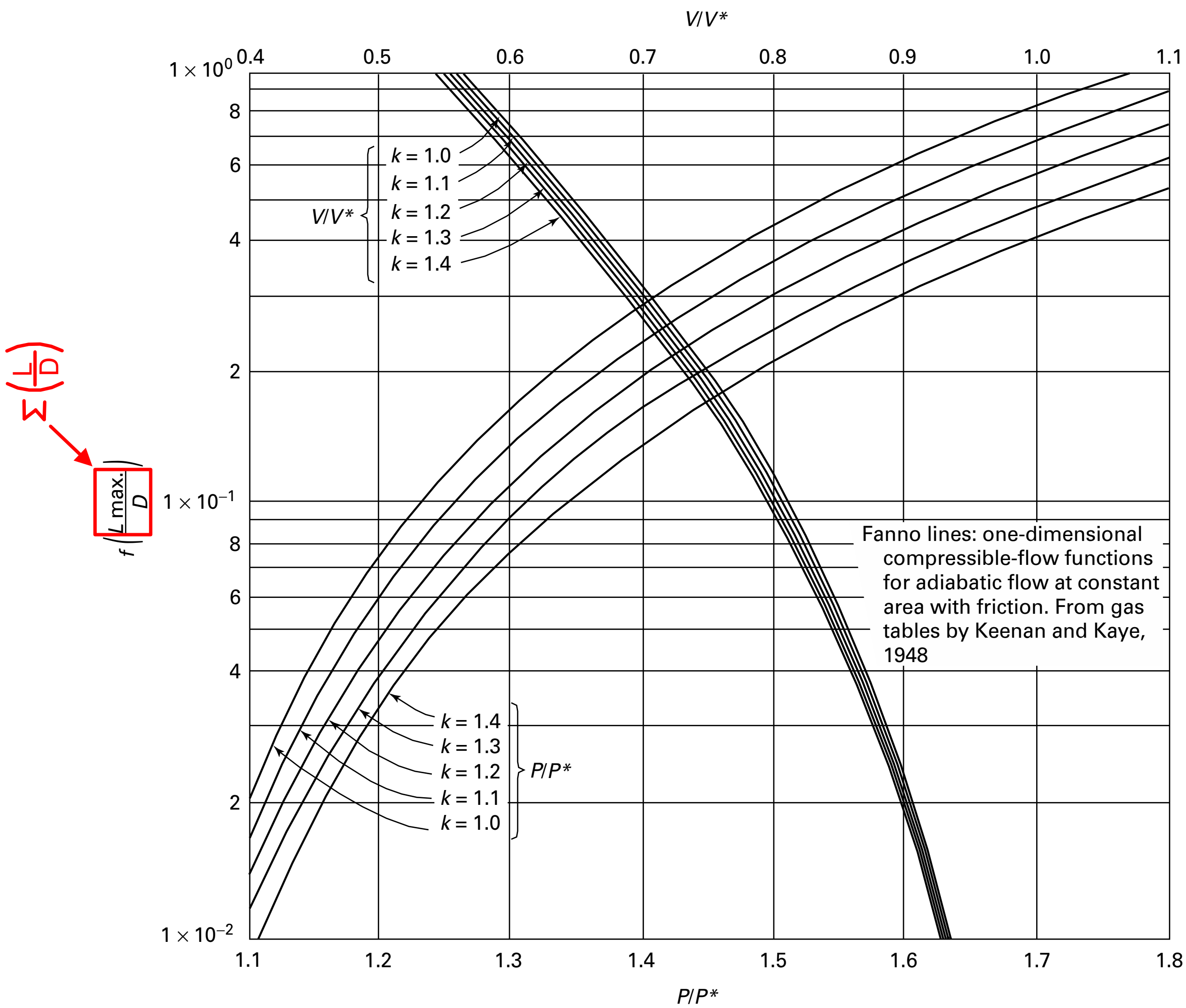
(A.3.5) Enter Chart II-1 with value of $f(L_{max}/D)$ and determine P/P^*.

(A.3.6) $P_{1a} = P_1\ (P/P^*)$.

(A.3.7) P_{1a} is the maximum operating pressure of the discharge elbow.

(B) Second, determine the design pressure and velocity for the vent pipe.

Chart II-1 Compressible Flow Analysis



(B.1) Determine the pressure, P_3, that exists at the vent pipe outlet (Fig. II-2-2).

$$P_3 = P_1 \left(\frac{A_1}{A_3}\right)$$

(B.2) Determine the velocity, V_3, that exists at the vent pipe outlet (Fig. II-2-2).

$$V_3 = V_1$$

(B.3) Repeat Steps (A.3.1) to (A.3.7) in the calculation of the discharge elbow maximum operating pressure to determine the maximum operating pressure of the vent pipe.

(B.4) Determine the velocity, V_2, and pressure, P_2, that exist at the inlet to the vent pipe (Fig. II-2-2).

(B.4.1) Enter Chart II-1[2] with value of $f(L_{max}/D)$ from Step (3.4) and determine values of V/V^* and P/P^*.

(B.4.2) Calculate V_2.

$$V_2 = V_3\,(V/V^*)$$

(B.4.3) $P_2 = P_3\,(P/P^*)$. This is the highest pressure the vent stack will see and should be used in calculating vent pipe blowback (see para. II-2.3.1.2).

II-2.2.2 Pressure for Closed Discharge Installations. The pressures in a closed discharge pipe during steady

Σ (L/D)

[2] Chart II-1 may be extended to other values of $f\,(L_{max}/D)$ by use of the Keenan and Kaye Gas Tables for Fanno lines. The Darcy–Weisbach friction factor is used in Chart II-1, whereas the Gas Tables use the Fanning factor, which is one-fourth the value of the Darcy–Weisbach factor.

II-3 BENDING MOMENT COMPUTATIONS

II-3.1 General

One of the most important considerations related to the mechanical design and analysis of safety valve installation is the identification and calculation of the moments at critical points in the installation. If the bending moments are not properly calculated, it will not be possible to meet the loading and stress criteria contained in ASME B31.1. As a minimum, the following loads, previously discussed in para. II-2 of this Appendix, should be considered in determining these moments:

(A) thermal expansion
(B) deadweight
(C) earthquake
(D) reaction force from valve discharge
(E) other mechanical loads

The analysis of the safety valve installation should include all critical sections, such as intersection points, elbows, transition sections, etc., and any related piping, vessels, and their supports that may interact with the safety valve installation. It is often most appropriate to model the safety valve installation and its related piping as a lumped mass system joined by straight or curved elements.

II-3.2 Thermal Expansion Analysis

There are many standard and acceptable methods for determination of moments due to thermal expansion of the piping installation. The thermal expansion analysis must comply with the requirements in para. 119. The safety valve installation often presents a special problem in that there may be a variety of operational modes to consider where each mode represents a different combination of temperatures in various sections of the piping system. The design condition shall be selected so that none of the operational modes represents a condition that gives thermal expansion bending moments greater than the design condition.

The design of the safety valve installation should consider the differential thermal growth and expansion loads, as well as the local effects of reinforcing and supports. The design should also consider the differential thermal growth and expansion loads existing after any combination of safety valves (one valve to all valves) operates, raising the temperature of the discharge piping.

II-3.3 Deadweight Analysis

The methods used for determination of bending moments due to deadweight in a safety valve installation are not different from the methods used in any other piping installation. If the support system meets the requirements in para. 121, the bending moments due to deadweight may be assumed to be 1,500Z (in.-lb) where Z is the section modulus (in.^{3}) of the pipe or fitting being considered. However, bending moments due to deadweight are easily determined and should always be calculated in systems where stresses exceed 90% of the allowable stress limits in meeting the requirements of eqs. (15) and (16) of para. 104.8.

II-3.4 Earthquake Analysis

Seismic loads must be known to calculate bending moments at critical points in the safety valve installation. If a design specification exists, it should stipulate if the piping system must be designed for earthquake. If so, it should specify the magnitude of the earthquake, the plant conditions under which the earthquake is assumed to occur, and the type earthquake analysis to be used (equivalent static or dynamic). If a design specification does not exist, it is the responsibility of the designer to determine what consideration must be given to earthquake analysis. It is beyond the scope of this Appendix to provide rules for calculating moments due to earthquake. The literature contains satisfactory references for determining moments by use of static seismic coefficients and how to perform more sophisticated dynamic analyses of the piping system using inputs in such form as time histories of displacement, velocity, and acceleration or response spectra where displacement, velocity, or acceleration is presented as a function of frequency.

~~Two types of seismic bending moments occur. One type is due to inertia effects and the other type is due to seismic motions of pipe anchors and other attachments. As will be shown later, the moments due to inertia effects must be considered in eq. (16), para. 104.8, in the kS_h category. Moments due to seismic motions of the attachments may be combined with thermal expansion stress and considered in eq. (17), para. 104.8 in the S_A category. For this reason, it may sometimes be justified for the designer to consider the moments separately; otherwise both sets of moments would have to be included in the kS_h category.~~

II-3.5 Analysis for Reaction Forces Due to Valve Discharge

II-3.5.1 Open Discharge Systems

II-3.5.1.1 The moments due to valve reaction forces may be calculated by simply multiplying the force, calculated as described in para. II-2.3.1.1, times the distance from the point in the piping system being analyzed, times a suitable dynamic load factor. In no case shall the reaction moment used in para. II-4.2 at the branch connection below the valve be taken at less than the product of

$$(DLF)\ (F_1)\ (D)$$

where

D = nominal O.D. of inlet pipe
DLF = dynamic load factor (see para. II-3.5.1.3)
F_1 = force calculated per para. II-2.3.1.1

such as the reaction force of a blowing valve or the pressure-momentum transient in a closed piping system. Since snubbers generally displace a small distance before becoming rigid, the displacement must be considered in the analysis. In addition, if the load is applied to the snubber for a relatively long time, the snubber performance characteristics shall be reviewed to ensure that the snubber will not permit motion during the time period of interest, or the additional displacement must be considered in the analysis. The snubber performance shall also be reviewed for response to repetitive load applications caused by the safety valve cycling open and closed several times during a pressure transient.

II-5.8 Silencer Installation

Silencers are occasionally installed on safety valve discharges to dissipate the noise generated by the sonic velocity attained by the fluid flowing through the valve.

Silencers must be properly sized to avoid excessive backpressure on the safety valve causing improper valve action or reducing relieving capacity.

Safety valve discharge piping, silencers, and vent stacks shall be properly supported to avoid excessive loading on the valve discharge flange.

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II-6 SAMPLE DESIGNS

Examples of various safety valve installations that a designer may encounter in practice are presented in Fig. II-1.2(A) and Fig. II-6-1.

II-7 SAMPLE PROBLEM (SEE FIG. II-7-1 AND FIG. II-7-2)

II-7.1 Procedure

(A) Determine pressure and velocity at discharge elbow exit.

(B) Calculate maximum operating pressure for discharge exit.

(C) Calculate reaction force at discharge elbow exit.

(D) Calculate bending moments of Points (1) and (2) from reaction force and seismic motion.

(E) Determine stress intensification factors at Points (1) and (2).

(F) Calculate predicted stresses at Points (1) and (2) and compare with allowable stress.

(G) Calculate maximum operating pressure for vent pipe.

(H) Check for blowback.

(I) Calculate forces and moments on vent pipe.

II-7.1.1 Pressure and Velocity at Discharge Elbow Exit (Para. II-2.2.1)

$$P_1 = \frac{W}{A_1}\frac{(b-1)}{b}\sqrt{\frac{2(h_o-a)J}{g_c(2b-1)}}$$

$$V_1 = \sqrt{\frac{2g_c\,J(h_o-a)}{(2b-1)}}$$

where

A_1 = 50.03 in.^{2}

a = 823 Btu/lbm for 15 ≤ P_1 ≤ 1,000 psia and h_o ≤ 1,600 Btu/lbm

b = 4.33 for 15 ≤ P_1 ≤ 1,000 psia and h_o ≤ 1,600 Btu/lbm

g_c = 32.2 lbm-ft/lbf-sec^2

h_o = stagnation enthalpy for steam at 925 psia, 1,000°F
= 1,507.3 Btu/lbm

J = 778 ft-lbf/Btu

P_1 = 118 psia

V_1 = 2,116 ft/sec

W = flow rate
= 116.38 lbm/sec

II-7.1.2 Discharge Elbow Maximum Operating Pressure. For 8 in. Class 150 ASME weld neck flange,

$$\frac{L}{D} = \frac{4\text{ in.}}{7.981\text{ in.}} = 0.5$$

For 8 in. SCH 40 short radius elbow,

$$\frac{L}{D} = 30$$

For 12 in. of 8 in. SCH 40 pipe,

$$\frac{L}{D} = \frac{12\text{ in.}}{7.981\text{ in.}} = 1.5$$

$$\Sigma\left(\frac{L}{D}\right) = \left(\frac{L_{max}}{D}\right) = 0.5 + 30 + 1.5 = 32.0$$

$\Sigma\left(\frac{L}{D}\right)$

$$f = 0.013$$

$$k = 1.3$$

$$f\left(\frac{L_{max}}{D}\right) = 0.416$$

From Chart II-1, P/P^* = 1.647.

$$P_{1a} = P_1\,(P/P^*) = 194\text{ psia}$$

II-7.1.3 Reaction Force at Discharge Elbow Exit. Reaction force,

$$F_1 = \frac{WV_1}{g_c} + (P_1 - P_a)\,A_1$$

where

W = 116.38 lbm/sec

V_1 = 2,116 ft/sec

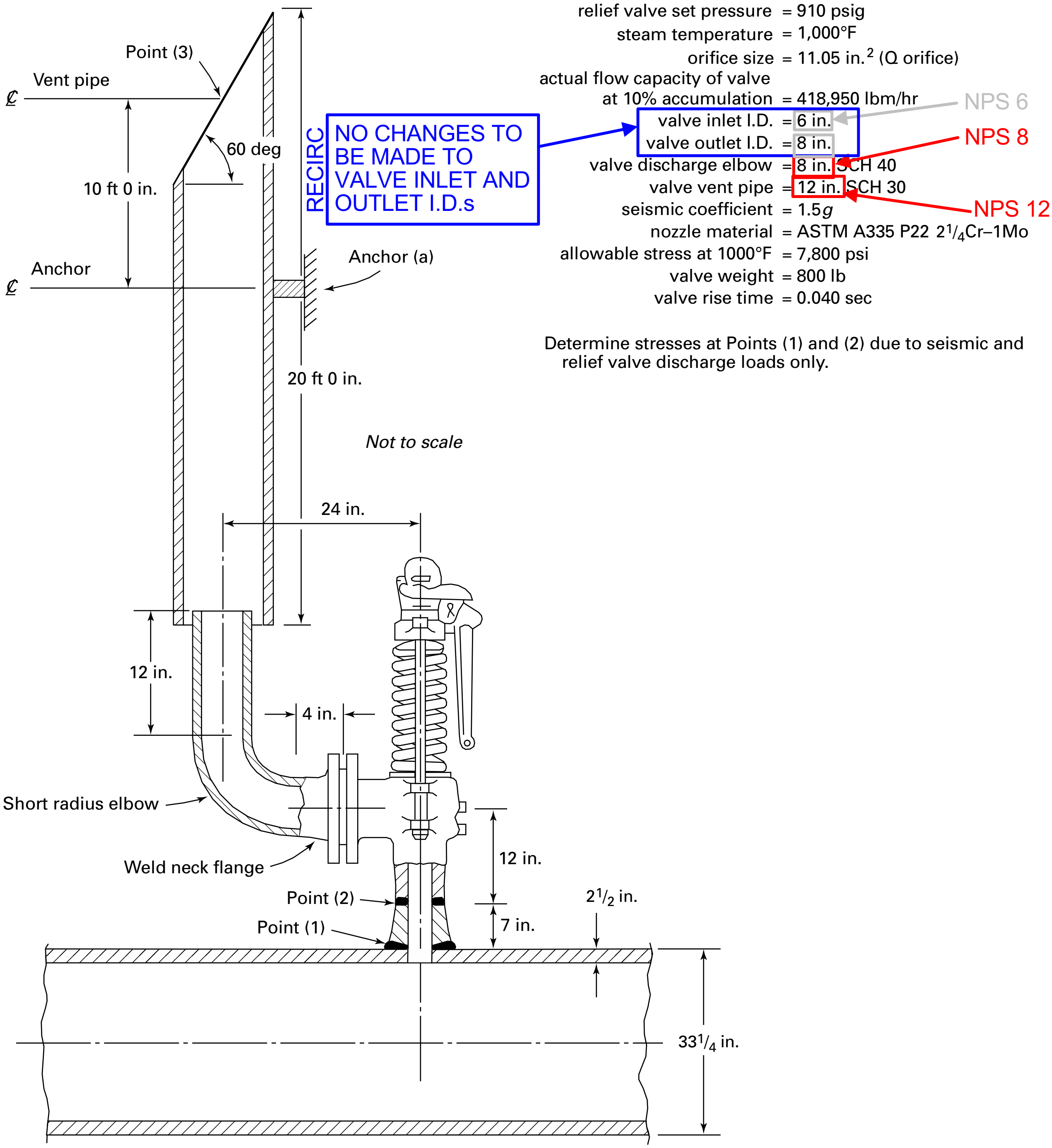
g_c = 32.2 lbm-ft/lbf-sec^2

P_1 = 118 psia

P_a = 15 psia

A_1 = 50.03 in.^{2}

Fig. II-7-1 Sample Problem Figure 1



relief valve set pressure = 910 psig
steam temperature = 1,000°F
orifice size = 11.05 in.^{2} (Q orifice)
actual flow capacity of valve at 10% accumulation = 418,950 lbm/hr
valve inlet I.D. = 6 in.
valve outlet I.D. = 8 in.
valve discharge elbow = 8 in. SCH 40
valve vent pipe = 12 in. SCH 30
seismic coefficient = 1.5*g*
nozzle material = ASTM A335 P22 2$^1/_4$Cr–1Mo
allowable stress at 1000°F = 7,800 psi
valve weight = 800 lb
valve rise time = 0.040 sec

Determine stresses at Points (1) and (2) due to seismic and relief valve discharge loads only.

$$D_o = 8.75 \text{ in.}$$

$$t_n = 1.218 \text{ in.}$$

$$\text{Pressure stress}_{(2)} = 1{,}635 \text{ psi}$$

$$\text{Flexure stress}_{(2)} = \frac{0.75\, i\, M_{(2)}}{Z_{(2)}}$$

$$Z_{(2)} = \frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$$

$$D_o = 8.75 \text{ in.}$$

$$D_i = 6 \text{ in.}$$

$$Z_{(2)} = 51.1 \text{ in.}^3$$

$$i_{(2)} = 1.0$$

$$M_{(2)} = 355{,}419 \text{ in.-lb}$$

$$\text{Flexure stress}_{(2)} = 6{,}955 \text{ psi}$$

(Note that $0.75i$ is set equal to 1.0 whenever $0.75i$ is less than 1.0, as in this case.)

$$\text{Combined stress}_{(2)} = \text{pressure stress}_{(2)} + \text{flexure stress}_{(2)} = 8{,}590 \text{ psi}$$

(C) *Comparison of Predicted Stress With Allowable Stress.* Allowable stress of nozzle material at 1,000°F is

$$S_h = 7{,}800 \text{ psi}$$

$$k = 1.2$$

$$kS_h = 9{,}360 \text{ psi}$$

$$\text{Combined stress}_{(1)} = 6{,}969 \text{ psi}$$

$$\text{Combined stress}_{(2)} = 8{,}590 \text{ psi}$$

II-7.1.7 Calculate the Maximum Operating Pressure for Vent Pipe

$$P_3 = P_1\left(\frac{A_1}{A_3}\right) = 118 \text{ psia}\left(\frac{50.03 \text{ in.}^2}{114.80 \text{ in.}^2}\right)$$

$$= 51.4 \text{ psia}$$

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L/D for 20 ft 0 in. of 12 in. SCH 30 pipe = 19.85.

$\Sigma\left(\frac{L}{D}\right)$ → ~~$\Sigma(L/D) = \left(\frac{L_{max}}{D}\right)$~~ = 19.85

$$f = 0.013$$

$$k = 1.3$$

$\Sigma\left(\frac{L}{D}\right)$

$$f\left(\frac{L_{max}}{D}\right) = 0.258$$

From Chart II-1, $P/P^* = 1.506$.

$$P_2 = P_3\,(P/P^*) = 77.4 \text{ psia}$$

II-7.1.8 Check for Blowback From Vent Pipe. Calculate the velocity V_2 that exists at the inlet to the vent pipe (para. II-2.2.1.4).

$$f\left(\frac{L_{max}}{D}\right) = 0.258 \text{ from Step (7)}$$

$\Sigma\left(\frac{L}{D}\right)$

$$V_3 = V_1 = 2{,}116 \text{ ft/sec}$$

From Chart II-1, $V/V^* = 0.7120$.

$$V_2 = V_3\,(V/V^*) = 1{,}507 \text{ ft/sec}$$

Check the inequality from para. II-2.3.1.2.

$$\frac{W\,(V_1 - V_2)}{g_c} > (P_2 - P_a)\,A_2 - (P_1 - P_a)\,A_1$$

$$\frac{116.38\,(2{,}116 - 1{,}507)}{32.2} > (77.4 - 14.7)(114.8) - (118 - 14.7)(50.03)$$

$$2{,}201 > 2{,}030$$

The inequality has been satisfied but the designer may require a design margin that would make 14 in. SCH 30 more acceptable. If a larger vent pipe is chosen, then the vent pipe analysis would have to be repeated for the 14 in. SCH 30 pipe. NPS 14

II-7.1.9 Calculate Forces and Moments on Vent Pipe Anchor

$$F_2 = \frac{WV_2}{g_c} + (P_2 - P_a)\,A_2$$

$$= \frac{(116.38)(1{,}507)}{32.2} + (77.4 - 14.7)\,(114.8)$$

$$= 5{,}447 + 7{,}198.0 = 12{,}645 \text{ lbf}$$

$$F_3 = \frac{(116.38)(2{,}116)}{32.2} + (51.4 - 14.7)(114.8)$$

$$= 7{,}648 + 4{,}213 = 11{,}861 \text{ lbf}$$

Assume a 30 deg jet deflection angle for vent pipe outlet. Vertical component of F_3

$$F_{3V} = F_3 \cos 30 \text{ deg} = 10{,}272 \text{ lbf}$$

Horizontal component of F_3

$$F_{3H} = F_3 \sin 30 \text{ deg} = 5{,}931 \text{ lbf}$$

Net imbalance on the vent pipe in the vertical direction is

$$F_2 - F_{3V} = 2{,}373 \text{ lbf}$$

Moment on vent pipe anchor

$$\Sigma M = (F_2 - F_{3V})\frac{D_o}{2} + F_{3H} \times [\text{distance from (a) to Point (3)}]$$

$$= (2{,}373)\left(\frac{1.06}{2}\right) + (5{,}931)(10.0)$$

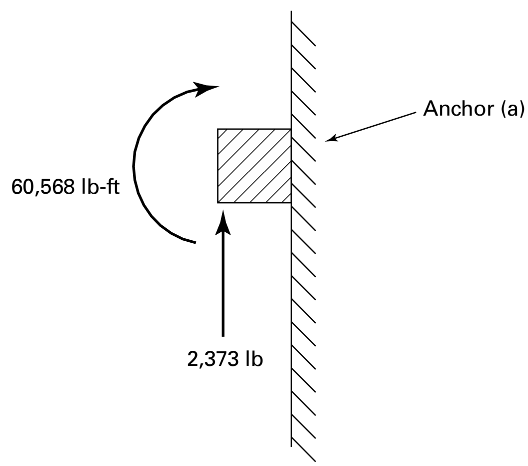
$$= 60{,}568 \text{ ft-lb}$$

The vent pipe anchor would then be designed for the loads shown in Fig. II-7-3 for safety valve operation.

II-7.1.10 Conclusion. Branch connection stresses at Points (1) and (2) due to seismic and relief valve discharge are within 1.2 S_h. Blowback will not occur with the 12 in. standard weight vent pipe. The vent pipe anchor loads have been identified.

NPS 12

Fig. II-7-3 Sample Problem Figure 3



ASME PCC-3 "Inspection Planning Using Risk-Based Methods" offers guidance for the development and implementation of a risk-based inspection program.

V-6.1.4 Welding procedures and preheat/postheat treatments of the weld joints shall meet the minimum requirements of Chapter V.

V-6.2 Inspection Program for Materials With Adverse History

V-6.2.1 Materials that have been reported to the industry to exhibit an adverse performance under certain conditions shall be given special attention by the Operating Company through a program of planned examination and testing. This program shall include the development of procedures for repair or replacement of the material when the Operating Company determines that such action is necessary.

V-6.2.2 Methods of surveillance and analysis shall be determined by the Operating Company.

V-6.2.3 The frequency of the material inspection shall also consider the expected service life of the component.

V-6.3 Nondestructive Examination

Nondestructive examinations used to investigate any suspect materials or problem areas shall be in accordance with Chapter VI.

Other techniques or acceptance criteria may be used when appropriate for the investigation being performed and when approved by the owner.

V-7 CPS POSITION HISTORY

V-7.1 General

V-7.1.1 The Operating Company shall develop and implement a program and procedures requiring recording and documentation of piping support observations and piping displacements. This program should include, at a minimum, CPS operating in the creep range. Records should be kept and maintained of position indicator readings, load adjustments, travel adjustments, repairs, and replacements.

V-7.1.2 Although the Code recognizes that CPS pipe supports seldom return to their exact original positions after each heat cycle, piping system displacements should be maintained within the bounds of engineering-evaluated limitations.

V-7.1.3 Documentation of the piping support observations and piping displacements should be performed on a periodic basis. Each set of hot and cold walkdowns should not exceed 5-yr intervals (typically associated with a scheduled major outage). Specific unit walkdown intervals are determined by the Operating Company. The intervals may be dependent on previous walkdown and NDE results, unit operating conditions, environment, and industry experience with specific piping or pipe supports. If a set of hot and cold walkdowns is not performed within 5 yr, the justification should be documented.

V-7.2 Visual Survey

The CPS should be observed visually, as frequently as deemed necessary. Any unusual conditions should be brought to the attention of plant management personnel as prescribed in the procedures of para. V-3.1. Observations should include determination of interferences with or from other piping or equipment, vibrations, and general condition of the piping system and supports, including but not limited to hangers, guides, restraints, anchors, supplementary steel, and attachments.

V-7.3 Piping Position Markers

V-7.3.1 Piping position and displacements may he monitored periodically at selected locations to document field conditions and to identify any migration beyond the bounds of engineering-evaluated limitations. For the purpose of easily making periodic position determinations at the selected locations, permanent markings or pointers may be attached to piping components. The positions of these markings or pointers should be noted and recorded with respect to stationary datum reference points.

V-7.3.2 Placement of pointers should be such that personnel safety hazards are not created.

V-7.4 Pipe Supports on CPS

V-7.4.1 Pipe support readings should be observed and recorded periodically. Piping system anomalies, such as interferences and lagging/insulation damage, should also be noted and recorded. Readings should be obtained while the piping is within the range of normal operating temperatures. The online pipe temperature range during the time of reading supports should be recorded. Walkdowns during unit shutdown should also be performed when the pipe is sufficiently cool [approximately 100°F (38°C) or below]. In addition to online and off-line walkdowns, a post-adjustment walkdown of the adjusted and adjacent supports should be performed. Walkdowns should be scheduled to evaluate the most critical operation scenarios; readings associated with each critical operation mode should be documented.

V-7.4.2 Variable and constant spring supports, dynamic restraints and snubbers, sliding supports, and rigid rod supports should be maintained so that they function as designed and within the limits specified by the manufacturers and designers. Maintenance of these items may include, but not necessarily be limited to, cleaning, lubrication, and corrosion protection. Snubbers should be examined and tested periodically in accordance with the manufacturer's recommendations to assure that they travel freely without binding and lock up within design parameters.

NONMANDATORY APPENDIX VI
APPROVAL OF NEW MATERIALS

The ASME B31.1 Committee considers requests for adoption of new materials desired by the owner/user or fabricator, manufacturer, installer, assembler of piping or piping components constructed to the Code. For the material to receive proper consideration, information and data are required to categorize the material properly. In general this information and data include, but are not necessarily limited to, the following:

(*A*) the chemical composition of the material including those elements that establish the characteristics and behavior of the material.

(*B*) the mechanical properties of the material, including tensile test data, ductility data, and other special [illegible]cal test data, which will assist the Committee [illegible]view of the material and its application.

To be Moved to 123.1.1 C in Chapter III

[illegible]) tensile test data (per ASTM E21), including [illegible]mate tensile strength and yield strength, at room [illegible]ture and at 100°F or 50°C intervals to a temperature at least 100°F higher than the intended use of the material.

(*B.2*) when creep properties are expected to limit the allowable stress, creep and creep rupture data at temperature intervals of 100°F or 50°C are also required. Such data should be [illegible] more time intervals, one of which should be longer than 2,000 hr but less than 6,000 hr, and one of which should be longer than 6,000 hr.

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(*C*) if the material is to be used in welded construction, data from actual welding tests made in accordance with Section IX of the ASME Boiler and Pressure Vessel Code (BPVC) should be submitted. Welding test data should include

(*C.1*) the welding processes and weld filler metal(s) intended for the fabrication of the material.

(*C.2*) all-weld-metal tensile test data for temperatures representative of intended service.

(*C.3*) any special restrictions on the welding of the material.

(*C.4*) the appropriate preheat and postweld heat treatment, if any, which will be given the material. If postweld heat treatment results in embrittlement of the material, the significance of such treatments with substantiating data should be forwarded. Toughness data on weld metal and heat affected zone in the as-welded and postweld heat treated conditions, when appropriate, should be submitted.

(*D*) where the mater[illegible]pplications, requires special h[illegible] procedures, or has known [illegible]ility to failure in certain services, precautionary requirements and information should also be submitted for review by the Committee.

To be Moved to 123.1.1 C.2 in Chapter III

(*E*) applicable product form(s) of the material, such as sheet, strip, plate, bars, shapes, seamless or welded pipe or tube forgings, castings, etc., for which application is to be considered must be identified.

The general data recommended should be submitted on a minimum of three heats, preferably commercial heats, of the material. Where the range of chemical composition affects the mechanical properties, the heats selected should cover both the high and low range of the effective chemical elements to show the effect on the mechanical properties. Any special heat treatment, whether applied by the material supplier or the fabricator, should be applied to the test pieces used to obtain the data.

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If the material is co[illegible]n ASTM specification, the specification number(s) and grade(s) involved must be identified in the application. If the material is not covered by an ASTM specification, application must be made to ASTM for specification coverage of this material.

Should there be a need for Code use prior to the inclusion of the material in ASTM specifications, the Committee will consider issuing a Code Case.

In addition to the information and data noted above, the Committee should be provided with an indication of user need, a copy of the letter to ASTM requesting specification coverage, and sufficient information for the Committee to modify an appropriate existing ASTM specification to establish the material specification requirements for the material product form.

When the new material is a minor modification of a material that is currently accepted by the Code, the data required may be reduced with the concurrence of the Committee.

If it is desired that the material be permitted for use in Boiler External Piping, this should be noted in the request. The request should indicate whether the material is currently permitted for use by ASME BPVC Section I or an ASME BPVC Section I Code Case and whether a request has been made or will be made to Section I to consider permitting the use of the material. The request shall indicate the intended application and range of service temperatures for the material. In determining whether a material should be permitted to be used in Boiler External Piping, the Committee will consider the following and other pertinent factors:

- whether the material is permitted to be used by ASME BPVC Section I
- whether the material is essentially the same as a material permitted to be used by ASME BPVC Section I
- the experience base for the use of the material
- whether the material is seam welded with filler metal added (seam-welded pipe with filler metal added is generally not permitted)
- whether the material is intended for use in water-wetted service and is austenitic stainless steel (austenitic stainless steels are generally not permitted in water-wetted service)

~~When the data supplied are insufficient for an adequate evaluation, the Committee will request additional data. Such requests [illegible]turned, indicating those areas in which additional information is required.~~

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